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The effect of brief mindfulness training on the micro-structure of human free-operant responding: Mindfulness affects stimulus-driven responding

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ABSTRACT

Background and objectives: The current study examines the extent to which mindfulness impacts on operant conditioning processes, and explores the suggestion that mindfulness training serves to make humans more sensitive to the current reinforcement contingencies with which they are presented. In particular, the effect of mindfulness on the micro-structure of human schedule performance was explored. It was expected that mindfulness might impact bout-initiation responding to a greater degree than within-bout responding, premised on the assumption that bout-initiation responses are habitual and not under conscious control, but within-bout responses are goal-directed and conscious.
Methods: Nonclinical participants experienced one of three brief (15min) interventions: focused attention breathing exercise (mindfulness), an unfocused attention breathing exercises, or no intervention. They then responded on a multiple random ratio (RR) random interval (RI) schedule.
Results: In the no intervention and unfocused attention groups, overall and within-bout response rates were higher on the RR than the RI schedule, but bout-initiation rates were the same on the two schedules. However, for the mindfulness groups all forms of responding were higher for the RR than the RI schedule. Previous work has noted that habitual, and/or unconscious or fringe-conscious events, are impacted by mindfulness training.
Limitations: A nonclinical sample may limit generality.
Conclusions: The current pattern of results suggests that this is also true in schedule-controlled performance, and offers an insight into the manner in which mindfulness alongside conditioning-based interventions, to bring all responses under conscious control.

Evidence for clinical efficacy of mindfulness techniques includes specific reports across many psychological disorders, including anxiety, depression, and Autism Spectrum Disorders (Hofmann, Sawyer, Witt, & Oh, 2010; Langer & Ngnoumen, 2017; Reed, 2019; Segal & Teasdale, 2018). However, there is little research on the impact of mindfulness on operant conditioning processes, which may play a role in controlling behaviours noted for these conditions, and in treatments for their alleviation. This is a gap in knowledge, especially given the degree to which mindfulness has been adopted by many clinically-relevant behavioural techniques that rely, in part, on such mechanisms (Hayes, Strosahl, & Wilson, 2009; McCracken, 2011). The current study examines the extent to which one aspect of mindfulness (focused attention to the current environment) impacts on operant conditioning processes, and explores the suggestion that mindfulness training serves to make humans more sensitive to the current reinforcement contingencies with which they are presented (Brewer, 2019; McHugh, Procter, Herzog, Schock, & Reed, 2012).

The ability of humans to be fully aware of current contingencies of reinforcement has been debated with respect to operant conditioning (cf. Kirsch, Lynn, Vigorito, & Miller, 2004; Scott, Samaha, Chrisley, & Dienes, 2018; Skora, Yeomans, Crombag, & Scott, 2021). In part, the impacts of this awareness can be seen in human's ability to verbalise about the contingencies and their performance, which can have important impacts on human sensitivity to operant schedules (Bradshaw & Reed, 2012; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986). Human behaviour does not always follow patterns associated with nonhumans, but sometimes is influenced by verbal rules formed (correctly or incorrectly) about the contingency (Bradshaw & Reed, 2012; Hayes et al., 1986). For example, Hayes et al. (1986) required humans to respond to move a light through a matrix according to a particular schedule of reinforcement. They were also given different instructions about the task that were, or were not, consistent with

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schedule. Performance was consistent with the presented instructions, rather than the contingency. In later extinction, instructed participants showed little reduction in responding compared to those with minimal instructions. Thus, it has been suggested that human sensitivity to schedules can be limited by the formation of verbal rules based on past experience (see also Bradshaw & Reed, 2012; Matthews, Shimoff, Catania, & Sagvolden, 1977; Shimoff, Matthews, & Catania, 1986).

Some have suggested mindfulness training could produce greater sensitivity to currently operative schedules, eliminate behavioural control from previously learned rules, and enhance the effectiveness of instrumental conditioning (Hayes, Strosahl, & Wilson, 1999). McHugh et al. (2012) and Chen & Reed (2022) both investigated the effects of brief mindfulness training on human operant conditioning processes maintained by a multiple random ratio (RR) yoked random interval (RI) schedules. On an RR schedule, reinforcement is dependent on a number of responses being emitted, which vary from reinforcement to reinforcement; whereas, on an RI schedule, reinforcement is delivered for the first response after a variable passage of time. When presented with RR and RI schedules with equal rates of reinforcement, nonhumans respond at higher rates on the RR schedule (Ferster & Skinner, 1957; Peele, Casey, & Silberberg, 1984). This effect can be noted in humans under some circumstances (Raia, Shillingford, Miller, & Baier, 2000; Reed, Smale, Owens, & Freegard, 2018), but sometime is not (Bradshaw & Reed, 2012; Matthews et al., 1977; Shimoff et al., 1986. Chen & Reed (2022) found that mindfulness training increased differentiation between rates of response emitted by humans to RR and RI schedules in the expected direction. McHugh et al. (2012) reported that mindfulness training increased the speed of extinction, and reduced behavioural resurgence of previously learned responses, after VI and FI training compared to an unfocused attention procedure.

Although mindfulness procedures have been shown to impact conditioned behaviour, the precise focus of action in achieving these effects is not well understood. One suggestion is that mindfulness brings into conscious awareness aspects of the current environment controlling behaviour (Brewer, 2019; Brown & Cordon, 2009; Levesque, Copeland, & Sutcliffe, 2008; Norman, 2017; Shapiro, Carlson, Astin, & Freedman, 2006). For example, mindfulness acts to allow greater control of habits of which individuals may not be consciously aware (Chatzisarantis & Hagger, 2007; Chong, Kee, & Chaturvedi, 2015). This suggestion implies that behaviours driven by unconscious processes may benefit from mindfulness training to a greater extent than those which are already accessible to conscious awareness. Much of this evidence is derived from studies of clinical phenomena, conducted using conceptual frameworks and procedures very different from those employed in conditioning (see Norman, 2017; Shapiro et al., 2006). Several clinically-oriented papers concerning addiction, using reinforcement-based frameworks, have suggested mindfulness acts to make individuals more aware of the operative reinforcement contingencies, and remove control by previously established habits (see Brewer, 2019; Garland, 2016). Using a classical conditioning procedure, Hanley and Garland (2019) demonstrated that mindfulness disrupted this conditioning, and they suggested that mindfulness served to de-automate conditioned behaviour. However, these suggestions have not been developed conceptually in relation to contemporary work on operant conditioning and schedules of reinforcement.

It could be argued that the clinical distinction between ‘unconscious’ and ‘conscious’ processes parallels a theoretically-relevant distinction in the conditioning literature between ‘habits’ and ‘actions’ (Adams, 1982; Dickinson, 1985; Thrailkill & Bouton, 2015). This view suggests that operant responses may either be stimulus-driven ‘habits’ that are sensitive to contextual factors (e.g., the value or strength of the conditioning context), or goal-driven ‘actions’ that are sensitive to the status of the outcome (e.g., the value or strength of the reinforcer). For example, altering the status of the outcome by a reinforcer-devaluation procedure reduces rates of instrumental responding, but it will not completely abolish responding (Thrailkill & Bouton, 2015). It has been suggested that those instrumental responses that are controlled by the value of the reinforcer (i.e. actions) are impacted by devaluation procedures (Adams, 1982). However, responses that are not so impacted (i.e. habits) are assumed not to be goal-directed and controlled by the current status of the outcome, but controlled by factors such as the associative strength (value) of the context, and, thus, to be insensitive to manipulations impacting that outcome or goal (Thrailkill & Bouton, 2015). Extrapolating across literatures, it may be that mindfulness training would have a greater impact on instrumental responses that are ‘habits’ (i.e. those which are driven by the context) by bringing them under the control of the outcome, than it would on ‘actions’ (i.e. those which are already currently controlled by the goal).

Methods that might help explore whether mindfulness impacts stimulus-driven responses (analogous to unconscious habits) more than goal-driven responses (analogous to conscious actions) in free-operant paradigms has been developed from theorising regarding the component structure of free-operant responding (Killeen, Hall, Reilly, & Kettle, 2002; Reed et al., 2018; Shull, 2011). Two different response components have appeared with relative consistency in investigations of the structure of schedule-controlled behaviour, using a variety of experimental procedures and analytic techniques: ‘bout-initiation’ and ‘within-bout’ responding. These two different elements of free-operant performance are sensitive to different aspects of the prevailing contingency (Killeen et al., 2002; Reed, 2015; Reed et al., 2018; Shull, 2011), and appear to map onto unconscious stimulus-driven habits, and conscious goal-directed actions (Chen, Osborne, & Reed, 2020; Reed, 2020).

Bout-initiation responses are controlled by overall rates of reinforcement experienced in a particular context (Killeen et al., 2002; Shull, 2011; Shull, Gaynor, & Grimes, 2001), and appear related to the conditioned strength of the context (Reed et al., 2018). Bout-initiation rates do not follow the same patterns as overall rates of response on various schedules; they do not show typical RR versus RI response rate differences controlled by the action of the reinforcer in shaping behaviour patterns (Reed et al., 2018). Whereas, RR schedules produce higher overall rates of response than RI schedules, even with the same rate of reinforcement, rates of bout-initiation responding are similar on the two schedules (Chen et al., 2021; Shull, 2011; Reed et al., 2018). Furthermore, this type of responding appears relatively insensitive to verbal control (Chen & Reed, 2021; Reed, 2020). All of which suggests that bout-initiation behaviours may be considered analogous to stimulus-driven, unconscious habits. In contrast, within-bout responses are controlled by schedule-specific reinforcement factors acting to shape particular response patterns; within-bout rates on RR schedules are higher than within-bout rates on RI schedules, even on schedules matched for reinforcement rate (Reed, 2011; Reed et al., 2018). Moreover, within-bout responses appear to be goal-directed (Reed, 2020), and are susceptible to conscious alteration through instructions (Chen & Reed, 2020). Thus, within-bout responses may be considered analogous to goal-directed, conscious actions.

Given this argument, it may be expected that, if mindfulness training acts to bring behaviours under conscious control (Norman, 2017), then it should impact differentially the micro-structure of human schedule performance. Mindfulness training should alter rates of bout-initiation responding, but not within-bout responding; perhaps making the former previously unconscious bout-initiation habits more like the latter goal-directed within-bout behaviours. That is, if free-operant responding is maintained by an RR and a reinforcement-yoked RI schedule, a mindfulness procedure should make rates of bout-initiation responding on these schedules (typically similar to one another) more discrepant from one another, and resemble the differences in the rates of within-bout responding on such schedules. This is because within-bout responses are already controlled by the goal to a greater extent than the bout-initiation responses, which are driven by the context stimulus (Chen et al., 2021; Reed et al., 2018), and mindfulness should act more strongly on these but-initiation responses.

A number of approaches have been used to explore the micro-structure of free-operant responding (Killeen et al., 2002; Mellgren & Elsmore, 1991; Reed, 2011). These techniques tend to produce the same results as one another (Chen & Reed, 2021; Reed et al., 2018). Thus, the main questions posed by this study are: whether a mindfulness exercise would affect schedule-controlled behaviour; by what processes mindfulness might affect such schedule-controlled behaviour, as revealed by a study of bout-initiation (habits) and within-bout (actions) responding; and would effects be seen when using both approaches to analysing the micro-structure of free-operant performance?

1. Method

1.1. Participants

In total, 52 students (20 males and 32 females) were recruited via the Psychology Department's subject-pool system. G-Power calculation implied that for 80% power, with a $p < .05$ criteria, and a medium effect size ($f' = 0.25$), that 42 participants would be required. Participants received subject-pool credits, but no financial remuneration. Participants' ages ranged from 18 to 30 years (mean = 19.96 ± 1.90 SD). The sample had no self-reported previous experience with mindfulness or meditation techniques, nor any mental-illness history. Previous studies have demonstrated that those with high levels of depression (Dack, McHugh, & Reed, 2009), or schizotypy (Randell, Ranjith-Kumar, Gupta, & Reed, 2009), do not show typical schedule performance. Given this, psychometric measurements of these characteristics were taken, but all participants scored the under cut-offs. Sample mean depression score (BDI) = 3.76 (±3.77; range = 0 9), and unusual experience score (O-LIFE) = 2.63 (±1.51; range = 0–5). The study was approved by the Department of Psychology Ethics Committee, and performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, and its later amendments.

1.2. Materials

Beck's Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) assesses depression (Cronbach α = 0.73 to 0.92: Beck, Steer, Ball, & Ranieri, 1996). A score greater than 10 was taken as the cut-off for depression (Dack et al., 2009).

Oxford Liverpool Inventory of Feelings and Experiences - Brief Version (O-LIFE(B); Mason, Linney, & Claridge, 2005) measures schizotypy (Cronbach α = 0.62 to 0.80). A score one standard deviation above the mean (i.e. of 6, or more) on the Unusual Experiences scale was the cut-off for schizotypy (Randell et al., 2009).

1.3. Apparatus

The experiment was presented on a standard desktop computer, programmed using Visual Basic 6.0. The task had two reinforcement schedules: an RR-30 schedule that awarded points (reinforcers) for space-bar presses; each response had a 1/30 probability of reinforcement. Following each RR trial, a RI schedule trial was presented that awarded points, following the first response after a specified time. The RI schedule was yoked to the preceding RR schedule. Each successive reinforcement in the RI schedule was delivered after the time taken for the corresponding reinforcer to be awarded on the preceding RR trial.

Reinforcers on both schedules consisted of 40 points being added to the total, which started at 100 points, and this total was reset for each new schedule exposure. Participants lost one point for every response. A response cost was used as previous work has shown that a response cost generates human schedule performance similar to nonhumans' performance (Raia et al., 2000). The absence of a response cost creates little reason to regulate performance according to the schedule, given the minimal effort needed to make a response (Bradshaw & Reed, 2012).

The experimental task was presented on a white screen. An 8 cm wide by 3 cm high stimulus box (either blue or pink) was placed in the central upper portion of the computer screen. Each schedule was associated with one colour for each participant, which alternated as the schedule alternated. For half of the participants, it was blue for the RR trials and pink for the RI trials; these colours were reversed for the other half of the participants. Participants were informed that the box would change colour on commencement of a new trial, but not of the schedule indicated by the colour. The word "POINTS" was presented under the stimulus box, and the accumulated total of points for that trial appeared beneath that word.

1.4. Interventions

Participants in two groups experienced one of two separate exercises (participants in the third group received no intervention). One group received a brief focused attention induction (mindfulness), and participants in another group received an unfocused attention induction procedure, the third group received no intervention. Three groups were employed in the current study, as an unfocused attention condition, which is akin to a mind wandering task, may have impacts of its own, different to receiving no intervention (Jordano & Touron, 2018; Reed, 2019; Seli et al., 2018). The interventions were based on those used by Arch and Craske (2006), shown as effective for nonclinical populations (McHugh et al., 2012); each 15-min exercise was delivered as a recording by a clinically-qualified female (Appendices 1 and 2).

Participants in the control condition were asked to wait in the cubicle for 15 min, and could anything that they wanted during this time. Participants had any possessions that they brought with them in the cubicle, so could potentially have used mobile phones, and so forth.

1.5. Procedure

Participants were tested individually in a cubicle containing a desk and a computer, with the monitor approximately 60 cm from them. Participants gave written consent, provided basic demographic details, and were asked whether they had experience of mindfulness or mediation procedures. They then completed the psychometric tests.

Participants were allocated randomly to one of the three groups using a random number generator that could give a value between 1 and 3: focused attention mindfulness group ($n = 18$), unfocused attention group ($n = 21$), and no intervention ($n = 13$). Participants in the first two groups were asked to close their eyes, and the relevant recorded instructions for each induction were played: Appendix 1 for the focused-attention instructions; and Appendix 2 for the unfocused-attention instructions. Participants in the non-meditation group sat in the room for 15 min. After this time, they all continued with the experiment.

All participants were presented with instructions on the computer screen. All participants were instructed to click a 'start' button to continue with the experiment. Each schedule presentation (trial) was 4min long; that is, participants were exposed to a 4min RR schedule, then to the yoked RI schedule for 4min. There were four such presentations of the yoked RR–RI pairs. An RR schedule was always presented immediately prior to the yoked RI schedule, to ensure that reinforcement in the RI schedule was delivered after a similar time had elapsed to the corresponding reinforcer on the RR trial.

2. Results

Fig. 1 shows the group-mean overall responses rates for the mindfulness, unfocused, and no intervention groups, for the two schedules (RR and RI), averaged across all four trials. Inspection of these data shows that, for all three groups, responding on the RR schedule was greater than that on the RI schedule. A two-factor mixed-model analysis of variance (ANOVA), with group (mindfulness x unfocused x no intervention-meditation) as a between-subject factor, and schedule (RR x RI) as a within-subject factor, was conducted on these data. The

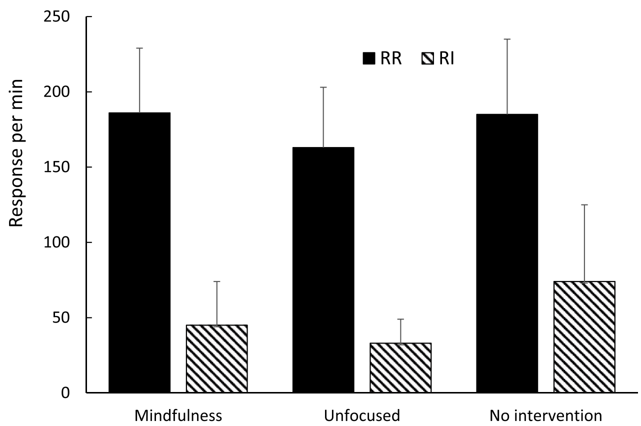

Fig. 1. Group-mean overall response rates for RR and RI schedules for the three groups across all trials (Mindfulness group, Unfocused group, and No intervention group). Error bars = 95% confidence intervals.

associated Bayes statistic (pH$_1$/D for the alternative hypothesis, and pH$_0$/D for the null hypothesis) is also presented for each analysis. This analysis revealed a statistically significant main effect of schedule, $F(1,49) = 124.74$, $p < .001$, $\eta_p^2 = .718$[95%CI = 0.568:.796], pH$_1$/D = 0.999, but not of group, $F(2,49) = 1.05$, $p > .30$, $\eta_p^2 = .041$[0.000:.164], pH$_0$/D = 0.946, and there was no interaction between the factors, $F < 1$, $\eta_p^2 = .020$[0.000:.119], pH$_0$/D = 0.968.

The difference between the overall rates of response for the RR and RI schedules was calculated for each participant. For the mindfulness group, the mean RR-RI difference was 141.13 ± 82.67, with 17/18 (95%) of participants showing higher RR than RI rates. For the unfocused group, the mean RR-RI difference was 129.81 ± 90.41, with 19/21 (91%) of participants showing higher RR than RI rates. For the no intervention group, the mean RR-RI difference was 111.53 ± 57.32, with 13/13 (100%) of participants showing higher RR rates. There was no significant difference between these scores, $F < 1$, $\eta_p^2 = .020$ [0.000:.095], pH$_0$/D = 0.999, nor was there a significant difference between the numbers of participants showing higher RR rates, $X^2(2) = 1.342$, $p > .50$, $\varphi = 0.161$.

Fig. 2 shows the group-mean bout-initiation rates, averaged across all trials, for the three groups (mindfulness, unfocused, and no intervention), and two schedules (RR and RI). 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), where b and d represent the rates of within-bout and bout-initiation, respectively, for each participant individually. The longest 1% of IRTs were excluded, as long IRTs often result from extra-experimental factors. Fig. 2 reveals little difference between the rate of bout-initiation for between the two schedules for the no intervention and the unfocused attention groups. However, the mindfulness group showed a larger difference between the RR and RI schedule bout-initiation rates, with the former being much higher than the latter. A two-factor mixed-model ANOVA (group x schedule) revealed a statistically significant main effect of schedule, $F(1,49) = 8.98$, $p = .004$, $\eta_p^2 = .155$[0.017:.331], pH$_1$/D = 0.917, but not of group, $F(2,49) = 1.41$, $p = .254$, $\eta_p^2 = .054$[0.000:.186], pH$_0$/D = 0.924. There was a significant interaction between schedule and group, $F(2,49) = 3.33$, $p = .044$, $\eta_p^2 = .120$[0.000:.276], pH$_1$/D = 0.655. Simple effect analyses demonstrated a significant different between the schedules for the mindfulness group, $F(1,49) = 13.38$, $p = .044$, $\eta_p^2 = .215$ [0.045:.392], pH$_1$/D = 0.986, but not for the unfocused attention group, $F < 1$, $\eta_p^2 = .001$[0.000:.016], pH$_0$/D = 0.999, or no intervention group, $F(1,49) = 1.86$, $p = .179$, $\eta_p^2 = .036$[0.000:.179], pH$_0$/D = 0.732.

The difference between the bout-initiation rates, as determined by the log survivor method, for the RR and RI schedules was calculated for each participant. For the mindfulness group, the mean RR-RI bout-initiation rate difference was 8.88 (±14.96), with 15/18 (83%) of participants showing higher RR than RI bout-initiation rates. For the unfocused group, the mean RR-RI bout-initiation rate difference was .33 ± 6.91, with 10/21 (47%) of participants showing higher RR rates. For the no intervention group, the mean RR-RI bout-initiation rate difference was 3.90 ± 6.15, with 9/13 (70%) of participants showing higher RR than RI bout-initiation rates. There was a significant difference between these scores, $F(2,49) = 3.32$, $p = .044$, $\eta_p^2 = .120$[0.011:.251], pH$_1$/D = 0.745, and there a significant difference between the numbers of participants showing higher RR than RI initiation rates, $X^2(2) = 6.347$, $p = .042$, $\varphi = 0.349$.

Fig. 3 shows the group-mean within-bout rates for two schedules, averaged across all trials, for the three groups (mindfulness, unfocused, and no intervention). These data were calculated using the log survivor method (Shull, 2011), as described above. Inspection of these data shows that, for three groups, responding to the RR schedule was greater than that to the RI schedule. A two-factor mixed-model ANOVA (group x schedule) revealed a significant main effect of schedule, $F(1,49) = 19.01$, $p < .001$, $\eta_p^2 = .280$[0.087:.452], pH$_1$/D = 0.999, but not of group, $F < 1$, $\eta_p^2 = .032$[0.000:.145], pH$_0$/D = 0.954, and there was no interaction between group and schedule, $F < 1$, $\eta_p^2 = .034$[0.000:.151] pH$_0$/D = 0.958.

The difference between the within-bout rates of response, as

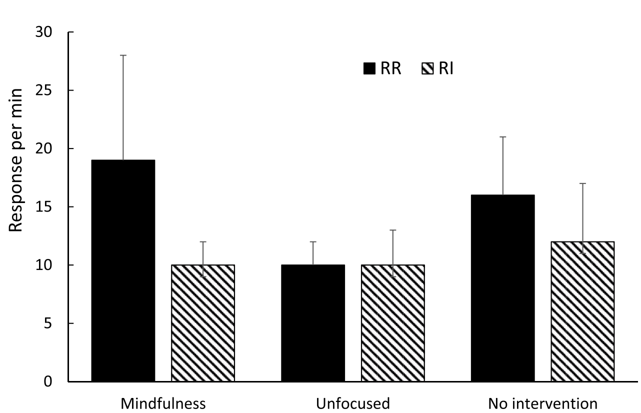

Fig. 2. Group-mean bout-initiation response rates for RR and RI schedules for the three groups over all trials (Mindfulness group, Unfocused group, and No intervention group), using the survivor plot method. Error bars = 95% confidence intervals.

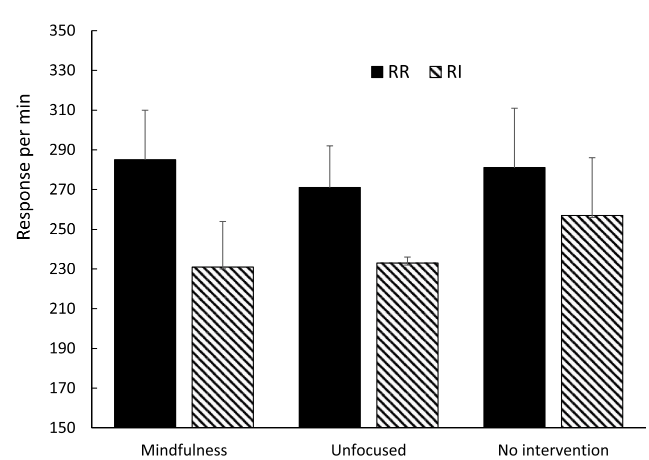

Fig. 3. Group-mean within-bout response rates for RR and RI schedules for the three groups over all trials (Mindfulness group, Unfocused group, and No intervention group), using the survivor lot method. Error bars = 95% confidence intervals.

determined by the log survivor method, for the RR and RI schedules, was calculated for each participant. For the mindfulness group, the mean RR-RI within-bout difference was 53.99 ± 60.74), with 13/18 (72%) of participants showing higher RR within-bout rates. For the unfocused group, the mean RR-RI within-bout difference was 37.65 ± 65.31), with 15/21 (71%) of participants showing this difference. For the no intervention group, the mean RR-RI within-bout difference was 24.21 ± 60.55), with 8/13 (69%) of participants showing higher RR within-bout rates. There was no significant difference between the mean scores, $F < 1$, $\eta_p^2 = .035[0.000{:}.153]$, $\mathrm{pH}_0/D = 0.913$, and no significant difference between the numbers of participants showing higher RR within-bout rates, $X^2(2) = 0.484$, $p > .70$, $\varphi = 0.097$.

The mean percentage variance accounted for (VAC) was calculated for each participant. The RR schedule mean VAC was 33.46 ± 19.10; range = 2–80), and the mean for the RI schedule was 29.06 ± 16.99; range = 1–64). This represents a moderate fit, with little difference between schedules, although with large individual variations in the goodness of fit. Some individual fits displayed small levels of VAC, but the manners in which these individuals diverged from the predicted pattern were quite idiosyncratic. Some individuals displayed shallow flat lines, some steep flat lines, and some displayed lines with many points of inflection.

Fig. 4 shows the group-mean bout-initiation rates for two schedules, averaged across all trials, for the three groups (mindfulness, unfocused, and no intervention), and two schedules (RR and RI). These rates were calculated using a cut-off analysis, whereby responses longer than 1000 ms were classed as bout-initiation responses, and those less than 1000 ms were classed as within-bout responses. This criterion has been used previously (Reed, 2020; Reed et al., 2018). Inspection of these data reveals that there was little difference between the rate of bout-initiation for between the two schedules for the no intervention and unfocused attention groups. However, the mindfulness group showed a larger difference between the RR and RI schedule bout-initiation rates, with the former being much higher than the latter.

A two-factor mixed-model ANOVA (group x schedule) revealed a statistically significant main effect of schedule, $F(1,49) = 12.69$, $p < .001$, $\eta_p^2 = .205[0.040{:}.383]$, $\mathrm{pH}_1/D = 0.982$, but not of group, $F(2,49) = 2.38$, $p = .102$, $\eta_p^2 = .088[0.000{:}.236]$, $\mathrm{pH}_0/D = 0.823$. There was a significant interaction between schedule and group, $F(2,49) = 3.19$, $p = .050$, $\eta_p^2 = .115[0.000{:}.270]$, $\mathrm{pH}_1/D = 0.588$. Simple effect analyses demonstrated that there was a simple effect of schedule for the mindfulness group, $F(1,49) = 16.87$, $p < .001$, $\eta_p^2 = .256[0.071{:}.431]$, $\mathrm{pH}_1/D = 0.996$, but not for the unfocused attention group, $F < 1$, $\eta_p^2 = .015$ $[0.000{:}.134]$, $\mathrm{pH}_0/D = 0.830$, or no intervention group, $F(1,49) = 1.70$, $p = .198$, $\eta_p^2 = .034[0.000{:}.174]$, $\mathrm{pH}_0/D = 0.749$.

The difference between the bout-initiation rates, as determined by the cut-off method, for the RR and RI schedules, was calculated for each participant. For the mindfulness group, the mean RR-RI bout-initiation rate difference was 13.06 ± 16.42, with 18/18 (100%) of participants showing higher RR bout-initiation rates. For the unfocused group, the mean RR-RI bout-initiation rate difference was 2.53 ± 5.99, with 15/21 (71%) of participants showing this difference. For the no intervention group, the mean RR-RI bout-initiation rate difference was 4.88 (±17.45), with 8/13 (69%) of participants showing higher RR bout-initiation rates. There was a significant difference between these scores, $F(2,49) = 3.10$, $p = .050$, $\eta_p^2 = .112[0.031{:}.211]$, $\mathrm{pH}_1/D = 0.676$, and a significant difference between the numbers of participants showing higher RR bout-initiation rates, $X^2(2) = 7.857$, $p = .020$, $\varphi = 0.389$.

Fig. 5 shows the group-mean within-bout rates for two schedules, averaged across all trials, for the three groups (mindfulness, unfocused, and no intervention). These data were calculated using the cut off method, as described above. Inspection of these data shows that, for three groups, responding to the RR schedule was greater than that to the RI schedule. A two-factor mixed-model ANOVA (group x schedule) revealed a significant main effect of schedule, $F(1,49) = 35.69$, $p < .001$, $\eta_p^2 = .412[0.208{:}.571]$, $\mathrm{pH}_1/D = 0.999$, but not of group, $F(2,49) = 2.24$, $p = .117$, $\eta_p^2 = .084[0.000{:}.229]$, $\mathrm{pH}_0/D = 0.981$, and there was no interaction between group and schedule, $F < 1$, $\eta_p^2 = .006[0.000{:}.076]$ $\mathrm{pH}_0/D = 0.978$.

The difference between the within-bout rates, as determined by the cut-off method, for the RR and RI schedules, was calculated for each participant. For the mindfulness group, the mean RR-RI within-bout rate difference was 241.59 ± 305.63, with 13/18 (72%) of participants showing higher RR within-bout rates. For the unfocused group, the mean RR-RI within-bout difference was 232.23 ± 238.95, with 19/21 (90%) of participants showing this difference. For the no intervention group, the mean RR-RI within-bout rate difference was 192.43 ± 233.40, with 10/13 (77%) of participants showing higher RR within-bout rates. There was a significant difference between these scores, $F < 1$, $\eta_p^2 = .006[0.000{:}.016]$, $\mathrm{pH}_0/D = 0.999$, and no significant difference between the numbers of participants showing higher RR within-bout rates, $X^2(2) = 2.244$, $p > .30$, $\varphi = 0.208$.

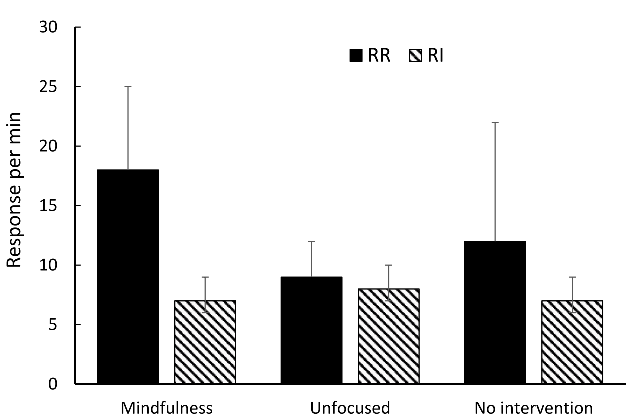

Fig. 4. Group-mean bout-initiation response rates for RR and RI schedules for the three groups over all trials (Mindfulness group, Unfocused group, and No intervention group), using the cut-off method. Error bars = 95% confidence intervals.

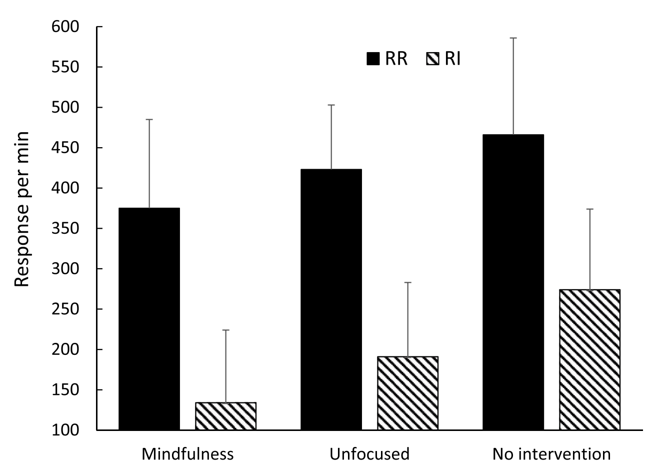

Fig. 5. Group-mean within-bout response rates for RR and RI schedules for the three groups over all trials (Mindfulness group, Unfocused group, and No intervention group), using the cut off method. Error bars = 95% confidence intervals.

3. Discussion

This study examined the effect of mindfulness on human schedule performance at micro-level. In particular, it was expected that mindfulness might impact bout-initiation responding to a greater degree than within-bout responding. This view was premised on the assumption that bout-initiation responses are habitual, stimulus-driven, and not under conscious control (Chen & Reed, 2020; Reed, 2020), but within-bout responses are taken to be goal-directed and conscious (Reed, 2020). Previous work has noted that habitual (Brewer, 2019; Chatzisarantis & Hagger, 2007; Chong et al., 2015), unconscious or fringe-conscious events (Garland et al., 2016; Norman, 2017), and/or automated classically-conditioned responses (Hanley & Garland, 2019), are impacted more by mindfulness training. However, this was the first demonstration that different aspects of operantly conditioned behaviour are differentially impacted by mindfulness.

Overall response rates were higher on the RR schedule than the RI schedule, replicating findings from many studies with nonhuman (Ferster & Skinner, 1957; Peele et al., 1984), and human (Chen & Reed, 2020; Reed et al., 2015), participants. The lack of difference between the bout-initiation rates for the RR and RI schedules yoked in terms of reinforcement rate for the no intervention group replicates previous demonstrations of this finding in nonhumans and humans (Killeen et al., 2002; Reed et al., 2018; Shull, 2011). This has been taken to suggest that rate of reinforcement experienced in the schedule-context (its discriminative cue) is the key driver of this type of responding (Reed, 2015; Shull, 2011). As the rate of reinforcement is equated across the two schedules in the current yoking procedure, there should be no difference in rates of bout-initiation. This has been taken to imply that such responding is stimulus-driven by the value of the conditioning context (Reed, 2020), and not subject to conscious control (Chen & Reed, 2021). In contrast, the current data replicate a higher rate of within-bout responding on RR compared to RI schedules (Chen & Reed, 2021; Reed et al., 2018). This form of responding is taken to reflect to shaping properties of reinforcement on the preceding responses (Reed, 2015), and have been shown to be consciously controllable (Chen & Reed, 2020).

That the mindfulness, but not unfocused attention, altered the pattern of bout-initiation responding, suggests that mindfulness may be working to bring such responses into conscious control in a manner suggested by contemporary views of mindfulness (Brewer, 2019; Garland et al., 2016; Levesque et al., 2008; Norman, 2017). It has been suggested that mindfulness may act to bring elements into conscious awareness (Brewer, 2019; Brown & Cordon, 2009; Levesque et al., 2008; Shapiro et al., 2006), and in classical conditioning procedures mindfulness has been taken to de-automate conditioning Hanley and Garland (2019). Brown and Cordon (2009) suggest that mindfulness may lead to a higher sensitivity to signals of which participants may not be aware or to which they are not attending (Levesque et al., 2008; Norman, 2017), which has also been employed as a suggestion to explain how mindfulness may reduce addictions through reinforcement-based processes (Brewer, 2019).

The current experimental procedure allowed an investigation into whether such concepts could be transposed to operant controlled behaviour. It is assumed that bout-initiation responses are controlled by contextual conditioning, and may be more habitual and less amenable to conscious control than within-bout responses (Reed, 2020). Typically, on schedules with the same rate of reinforcement, even with different response-reinforcer contingencies, there is no difference between bout-initiation rates (Reed et al., 2018; Shull, 2011; Shull et al., 2001). This was true in the two control conditions of the current study, but mindfulness partly removed this effect, and produced bout-initiation responding differences resembling those of within-bout responding (taken to be goal-directed and conscious). The current mindfulness procedure did not impact rates of within-bout responding. This may be because this form of responding is already under conscious control (Chen & Reed, 2020).

It should be noted that previous experiments have noted mindfulness was related to greater sensitivity the currently operative contingencies (Hayes, Strosahl, & Wilson, 1999; Kabat-Zinn, 2003), and this can make a difference to overall response rate when free-operant schedules are employed (McHugh et al., 2012; Reed, 2022). Results from the analysis of overall response rate did not reveal this effect: overall response rates of participants in all groups were differentiated manner according to schedule, and there were few effects of giving mindfulness induction procedure or not. That the mindfulness intervention impacted the bout-initiation rates, but did not impact overall response rates, may be due to the small contribution of bout-initiation responses to the overall numbers of responses (representing about 5–10% of the total number of responses). However, there are procedural differences between the current experiments, and those using free-operant schedules reported by McHugh et al. (2012) and Reed (2022), which might account for the different pattern of findings. In the study by McHugh et al. (2012) a range of different training schedules were used, and mindfulness training was implemented after training and before extinction. The impacts of different contingencies on mindfulness may be an interesting area to study, especially given the suggestion that RI schedules tend to promote more habit-based responding than RR schedules (Dickinson, 1985). In the study by Reed (2022) longer schedule training was given, and the effect of length of schedule training on mindfulness may also be of interest to future studies, as longer training has been suggested to produce more habit-based responding (Adams, 1982; Dickinson, Nicholas, & Adams, 1983).

The current mindfulness-intervention was very brief, and other mindfulness-based interventions are delivered over a longer period often around 2.5 h per week for 8 weeks, and often include a range of other characteristics (such as: 'sitting mediation', 'body scanning', 'Hatha yoga' (Kabat-Zinn, 1982; Shapiro, Schwartz, & Bonner, 1998). It could be argued that the brevity of the exposure reduced the effectiveness of the mindfulness procedure, or that some participants did not comply with the intervention. Future studies could use a mindfulness measure the assess the degree to which mindfulness had an effect, and the extent to which conditions produced different effects in this regard. However, that there was a differential impact of the procedures suggests some level of effectiveness of the brief interventions. Experimentally, it has been shown that mindfulness can be induced after inductions as short as 10–15min using the current procedures (Arch & Craske, 2006; Reed, 2019; Roemer & Orsillo, 2003). However, it is not clear if these other procedures would impact responding in different manners to the current intervention. For example, it might impact abilities to experience intrinsic reinforcement, and, thus, affect motivation levels for external rewards. That the intervention is short might mean that 'state mindfulness' rather than 'trait mindfulness' is operative.

In sum, in the present study, sought to investigate the effects of mindfulness intervention on human schedule performance. The results suggested that mindfulness overcomes the 'mechanistic' 'automatic' responding determined by context. The procedures used here could also be developed to further explore the behavioural and cognitive mechanisms of mindfulness on learning.

Ethical approval

Ethical approval was obtained from the Department of Psychology Ethics Committee, and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

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Informed consent

All participants gave informed consent for their participation.

CRediT authorship contribution statement

Xiaosheng Chen: Conceptualization, Methodology, Software, Data curation, Investigation, Writing – review & editing. **Phil Reed:** Conceptualization, Methodology, Software, Data curation, Writing – original draft, Supervision, Software, Writing – review & editing.

Declaration of competing interest

Neither author declares any conflict of interest.

Appendix 1. Mindfulness induction

Much of the emotional distress people experience is the result of thinking about upsetting things that have already happened or anticipating negative events that have yet to occur.

Distressing emotions such as anger, anxiety, guilt and sadness are much easier to bear if you only focus on the present – on each moment one at a time.

This is an exercise to increase your mindfulness of the present moment so that you can clear away any thoughts about past and future events.

Start by focusing on your breathing.

Don't try to change anything about your breathing, just notice the air moving in and out of your body.

Try to focus all your attention on your breathing.Notice the sensation of breathing air in. Notice the sensation of breathing air out. As you breath air into your body, fill your mind with the thought "just this one breath". As you breathe air out of your body, fill your mind with the thought "just this one exhale".

Focus on the actual sensation of breath entering and leaving your body.

Just this one breath in.Just this one exhale out. If you notice that your awareness is no longer on your breath gently bring your awareness back.Just this one breath. Just this one exhale. Continue focusing only on each breath in and each breath out, do not anticipate anything – even your next breath. Only focus on one breath at a time.

If anything else pops into your mind, push it aside and refocus your attention to each breath.

Continue focusing on each breath in and each exhale out until you hear the sound of the bell.

Appendix 2. Unfocused-attention induction

Much of the emotional distress people experience is the result of thinking about upsetting things that have already happened or anticipating negative events that have yet to occur.

Distressing emotions such as anger, anxiety, guilt and sadness are often brought to mind.

With this exercise let your mind wander freely amongst thoughts about past and future events.

Start by allowing your mind to roam.

Don't try to focus on your thoughts, just let them drift without hesitation.

There is no need to focus on anything in particular. Allow yourself to think freely.Try not to focus on any one thing. Just let your mind wander.

Openly let your thoughts flow.Continue to let yourself think freely. There is no need to think of anything in particular. Just let your mind wander. Think about whatever comes to mind. Let your thoughts drift. Continue your flow of thoughts. Continue to let your thoughts flow until you hear the sound of the bell.

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