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State impulsivity amplifies urges without diminishing self-control

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ABSTRACT

A disproportionate amount of research on impulsivity has focused on trait-related aspects rather than state fluctuations. As a result, the relationship between state impulsivity and moment-to-moment behaviour is unclear. Impulsivity is assumed to negatively affect self-control, but an alternative explanation, yet to be tested, could be that changes in state impulsivity and its homeostatic drivers influence the intensity of urges. We tested whether state impulsivity and hunger affected behaviour through a dual-process model, affecting both the experience of various urges, and self-control, using a smartphone-based experience sampling approach. We found that state impulsivity is associated with stronger urges, but we found no evidence of an association with diminished self-control. Being hungry amplifies urges across different types of urges, and both hunger and late hours are negatively related to the likelihood of controlling urges. These findings imply that the influence of hunger is not limited to the food domain, and provide new insight into the role of state impulsivity in daily life.

1. Introduction

Impulsivity, the predisposition to trigger rapid responses without sufficient forethought, is associated with numerous addictive behaviours (Berg et al., 2015; Verdejo-García et al., 2008). Impulsivity research has steadily grown in the last two decades (Sharma et al., 2014; Strickland & Johnson, 2021; Verdejo-García et al., 2008; Whiteside & Lynam, 2001), but advances have focused on trait characteristics and inter-individual differences, with comparatively much less progress on state impulsivity, state-related fluctuations such as those linked to energy input (hunger, satiety) and intra-individual variability.

Trait-focused research typically relies on 'distal' self-reports where individuals report what they typically do, which introduces uncertainty about how those traits are expressed in moment-to-moment behaviour. Understanding how the effects of impulsivity on behaviour unfold over time requires 'proximal' information on people's mental states when these behaviours occur (Curran & Bauer, 2011; Fisher et al., 2018; Kenrick & Funder, 1988).

It thus remains unclear how moment-to-moment impulsive drives influence behaviour. It is often posited that impulsivity increases the tendency toward maladaptive behaviours because it negatively affects self-control (the capacity to override or alter predominant response tendencies in support of the pursuit of long-term goals; Baumeister et al., 2007). This is evidenced, for example, by the inclusion of some version of 'lack of self-control' subscales in many impulsivity scale questionnaires (Gough, 2000; Parker & Bagby, 1997; Whiteside & Lynam, 2001; Wiers et al., 2010). In addition, evidence from cross-sectional studies suggests that people with stronger impulsivity traits experience stronger urges (or cravings; Doran et al., 2007; Papachristou et al., 2012; Yarmush et al., 2016), but little is known about the relationship between state impulsivity and the experience of urges.

To understand the relationship between state impulsivity and behaviour, we turn to dual-systems theories of behaviour. Dual-systems theories conceptualise human behaviour as a conflict between automatic and deliberative modes of behavioural control (Kahneman, 2011; Loewenstein, 1996; Metcalfe & Mischel, 1999). In support of this, both sensitisation of responses towards a range of incentives (i.e., urges), and low inhibitory control have been independently linked to vulnerability and escalation of addictive behaviours (Bechara, 2005; Feltenstein & See, 2008; Goldstein & Volkow, 2002, 2011; Potenza et al., 2003).

For this study, we conceptualise the intensity of urges as being regulated by a 'bottom-up' process, in contrast to self-control as a 'top-down' process, regulating behaviour. Thus, here we investigate whether state impulsivity affects behaviour through a dual-process model: a

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bottom-up influence, amplifying urges through up-regulating the stimulus–response system and a top-down influence on the deliberative system, down-regulating goal-directed behaviour, by affecting people's self-control. For example, an individual in an impulsive state might experience a stronger urge to gamble when they see an electronic gambling machine in a pub (bottom-up influence – upregulating the stimulus–response relationship). In addition, they may be less well-equipped than normal to curb urges of a fixed intensity, thus finding it harder to resist engaging in gambling (top-down influence – down-regulating self-control).

Like state impulsivity, hunger is an important common motivational drive and a state fluctuation that is implicated in many of the same behaviours. Hunger is an adaptive motivational state that drives us to eat, restoring homeostatic balance (Saper et al., 2002). There is extensive evidence that hunger enhances the valuation of food (Cameron et al., 2014; Gilbert et al., 2002) although it is unclear if this effect is domain-general, rather than just stimulus-specific, or whether it can trigger impulsive behaviours. More generally, hunger increases impulsive behaviour in non-human animals (Anderberg et al., 2016; Laude et al., 2012; Zheng et al., 2019). There is also emerging evidence in support of a domain-general effect of hunger in humans: people are more likely to choose an impulsive option when gambling hungry (Li et al., 2020), they are more likely to acquire non-food items (Xu et al., 2015), and the effect of hunger on delay discounting (i.e., that hungry people discount delays more) spills over into non-food domains, but the effect size is a quarter of that for food stimuli (Skrynka & Vincent, 2019). However, these experiments were mostly conducted in laboratory settings, and most used measures that do not provide much mechanistic information. In this study, we segregate the two pathways posited by dual system models, to assess how hunger influences the emergence of impulsive behaviour in real-world scenarios.

To test the dual-process models of state impulsivity and hunger, we use smartphone-based ecological momentary assessment (EMA), where we ask participants whether they had an urge to smoke, snack, consume alcohol, gamble, shop, or commit an act of aggression, and whether they were able to control these urges. Controlling such urges normally leads to better long-term goal performance (Finne et al., 2019; Mischel et al., 1989; Rawn & Vohs, 2006); these urges usually pertain to short-term gratification, and succumbing to such temptations can cause disturbances to people's lives in professional, health, and social domains (Bembenutty, 2011; Koomen et al., 2020; Schlam et al., 2013).

The EMA setup allows for unique insights into the influence of the time of day, state impulsivity, and hunger fluctuations on behaviours in different domains (Hofmann et al., 2012), which we can leverage to study the effect of the time of day on self-control—a new angle on the ongoing discussion about the evidence surrounding ego depletion (Friese et al., 2019). EMA studies diminish recall bias (Shiffman et al., 2008), are less laborious and artificial than laboratory studies, and do not rely on beliefs about the self ("What am I typically like?"). To maintain brevity of the surveys in the EMA procedure, we use the Momentary Impulsivity Scale (MIS; Tomko et al., 2014) to assess state impulsivity in each survey. This is a well-validated and reliable measure of state impulsivity.

The main question asked in this study is, therefore, whether state impulsivity and hunger influence behaviour according to a dual-process model, with a bottom-up influence that upregulates stimulus–response relationships, operationalised as the intensity of urges, and a top-down influence that downregulates self-control, operationalised as the likelihood of controlling urges. We will also investigate the differences between the various types of urges people face, and whether this interacts with the effect that hunger has on an urge (to test whether the effect of hunger is domain-general). In addition, we investigate whether there is an effect of the time of day on both dependent variables.

2. Methods

2.1. Participants

Efforts were undertaken to sample participants who would not normally take part in psychological research, to enhance the generalisability of findings. Specifically, we conducted a broad community-based recruitment strategy including flyers posted across different suburbs of Melbourne, Australia and different social media platforms, in addition to the more typical student-based recruitment systems (e.g., SONA).

This study is part of a larger project with a three-hour lab component (procedure here) in addition to the current EMA-based component. The EMA component always occurred after the lab study, so there was no overlap or influence from the lab study. Participants received $75 as remuneration for completing the entire study.

Based on the main aim (i.e., learning more about the context-evoked fluctuations in the intensity of urges) and the effect size of these fluctuations in previous data (Cohen's $d = 0.5$) (Verdejo-Garcia et al., 2015) we required 45 participants to test our hypothesis with 80% power and an alpha level of 0.05.

Inclusion criteria were based on requirements for the overarching project, in which participants completed, in addition to the EMA surveys, nutritional manipulations and a cognitive test battery. Thus, to be included, participants were required to have normal or corrected-to-normal vision, be fluent in English, have no food allergies or food intolerances that would impact the food provided in the satiety manipulation, no history of head trauma (e.g., traumatic brain injury), neurological (e.g., epilepsy, Parkinson's disease) or metabolic impairments (e.g., diabetes, indicated by blood glucose tests), and no current mental health conditions (i.e. psychosis, depression, substance use and eating disorders), indicated by screening interviews based on Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition criteria (American Psychiatric Association, 2013). Exclusion criteria included cannulation contraindications (i.e., HIV, Hepatitis A, B or C diagnosis, low or high blood pressure, blood-thinning medication) because the experimental protocol for the other facets of the project included blood-drawing.

2.2. Apparatus

This study used an online EMA paradigm, administering the surveys through SEMA3 (Koval, 2019). SEMA3 uses an app that can be downloaded by participants on their phones. To complete their surveys, participants must respond to a notification on their phone, prompting them to open the app. Upon opening the app, SEMA3 would commence the survey and the participant would be able to respond to questions by using a horizontal slider and check-boxes.

2.3. Measures

We used purpose-built surveys to assess the presence, intensity and ability to control 6 different urges: snacking, drinking alcohol, gambling, shopping, smoking, and committing an act of aggression (operationalised as hitting something). Participants responded to the question of whether they were experiencing each type of urge listed above using a slider [0,10], where 0 indicated no urge, 1 indicated a very weak urge, and 10 indicated a very strong urge; we call the responses on this scale 'urge intensity'. After each question, participants were also asked whether they were hungry (Yes, No), and whether they were able to control the urge (Yes, No). The hunger question had a binary response mode because we wanted to make the measurements computationally easy for participants, and because questions about hunger are often posed in this binary manner colloquially. The urge control question also has a binary response mode because reporting partially controlling an urge, while possible, likely feels less natural than indicating whether the urge was controlled or not.

In addition, participants completed the Momentary Impulsivity Scale (MIS) to measure state impulsivity (Tomko et al., 2014). The MIS is a well-validated measure of state-impulsivity for use in EMA setups, and correlates with the Barratt Impulsiveness Scale (BIS-11) total score ($r = 0.44$) and with two subscales of the Impulsive Behaviour Scale (UPPS) (Urgency, $r = 0.45$; Lack of Perseverance, $r = 0.35$). These subscales are particularly relevant in light of our interest in impulsive behaviour and self-control. Participants were asked to indicate how much each statement described their experience since the last completed prompt using a 5-point Likert scale (1 = very slightly or not at all; 2 = a little; 3 = moderately; 4 = quite a bit; 5 = extremely). The 4 statements were "I said things without thinking", "I spent more money than I meant to", "I have felt impatient", "I made a 'spur of the moment' decision".

2.4. Procedure

The experiment was conducted between 6 April 2018 to 18 December 2019, and the EMA protocol took 7 days to 10 days per participant, depending on their survey completion percentage. Informed consent was obtained from all participants and the project was approved by the Monash University Human Research Ethics Committee (Project ID: 11999).

To assess participants' eligibility, they were first sent a survey through Qualtrics, in which they entered basic demographic information, filled out several trait questionnaires, and completed an intertemporal choice task (which will not be used for this study). Afterwards, they were asked to come to the university twice where they would complete the Cognitive Impulsivity Suite (Verdejo-Garcia et al., 2021) in either a fasted or a sated state and in between these sessions they would complete the EMA experiment.

Participants received four daily surveys that were available for 120 min. The first survey would arrive between 9.30 and 10am, the second between 1 pm and 1.30 pm, the third between 4.30 pm and 5 pm, and the last between 8 pm and 8.30 pm. In these surveys, participants were asked questions about their urges and actions since the last survey. They were asked whether since the last survey they had felt an urge to snack, drink alcohol, gamble, shop, smoke, or commit an act of aggression (hit something).

2.5. Analysis

The main aims of the study were to investigate how state impulsivity and hunger influence the intensity of urges and self-control, and whether hunger affects urges in non-food domains. Accordingly, the main analysis was two-tiered: the first part of the analysis concerned the effects of hunger and state impulsivity on the intensity of urges, and the second part concerns the effect of state impulsivity and hunger on the likelihood of controlling an urge. We operationalise a bottom-up effect of hunger and state impulsivity as an effect on the intensity of urges, while we operationalise a top-down effect on self-control as an effect on the probability of controlling an urge. We also report analyses on the effects of the time of day on both dependent variables.

For completeness, we also provide tables comparing the models used in the current work with models where all interactions between variables of interest are included in the Supplementary Materials.

A linear mixed model was used for the analysis concerning perceived urge intensity during the EMA study. The predictors were the total score on the Momentary Impulsivity Scale (MIS; a continuous variable), the type of urge participants had, whether participants were hungry (indicated as 'yes' or 'no'), the time of day (rounded to the hour), and as control variables, participants' age, sex, and the day of the week. We included an interaction term for the type of urge and whether the participant was hungry (e.g., the urge to drink alcohol while hungry). The model also included the participant as a random intercept and the type of urge as a random slope.

For the analysis on the probability of controlling urges, we used a binomial generalised linear mixed model (GLMM) because the dependent variable is binary. The predictors were the responses on the Momentary Impulsivity Scale (MIS), the type of urge participants had, the intensity of the urge, whether participants were hungry (indicated as 'yes' or 'no'), the time of day, and as control variables, participants' age, sex, and the day of the week. The model included an interaction term between the type of urge and hunger. The model included the participant as a random intercept and the type of urge as a random slope.

Using the afex package (Singmann et al., 2015), the p-values for the variables in the LMM were calculated by means of F-tests using the Kenward-Roger approximation for degrees-of-freedom (because these are easier to interpret for factors than tests on regression coefficients), and the p-values for the GLMM were calculated by comparing the likelihoods of the full and restricted models using likelihood ratio tests (with corresponding Pearson's χ^2 statistics). We then investigated any significant effects of factors and their interactions in the models described above using the emmeans package (Lenth et al., 2018) to identify the differences between the estimated marginal means of each factor, where we report Bonferroni adjusted p-values. For significant effects of numeric predictors, we also report the model coefficient.

All data and code are available here.

3. Results

The final sample consisted of 47 participants and none who participated in this part of the project were excluded from the study. Of these, 28 (59.6%) were female $M_{age} = 24.7$ ($SD = 6.3$), 18 (38.3%) were male $M_{age} = 25.9$ ($SD = 6.4$), and one preferred not to reveal their sex. Participants missed 21.1% of prompts (350 out of 1666). Of the 1316 surveys returned, in 874 participants reported to have experienced an urge.

Some urges had a much higher base rate than others. For example, the urge to snack was reported 731 times, while the urge to gamble was only reported 111 times and the urge to smoke 109 times. The other most common urges were online shopping (n = 344) and drinking alcohol (n = 269). As is to be expected, there was large interpersonal variability in the occurrence of different types of urges. Every participant reported the urge to snack at least twice over the experiment (max. 39 times). In comparison, only 14 participants reported the urge to smoke, and 19 to commit an act of aggression, at least twice.

Participants' age did not significantly affect the strength of their urges [1, 10], $b = 0.016$, 95% CI [-0.280, 0.312], $F(1, 38) = 0.01$, $p = .93$, or the probability of controlling those urges, odds ratio (OR) = 0.902, 95% CI [0.646, 1.259], $\chi2(1) = 0.3$, $p = .58$. Sex also did not impact the strength of urges, $F(2, 19) = 2.01$, $p = .16$. Males (estimated marginal mean (EMM) = 3.64, 95% CI [3.02, 4.26]) did not report significantly different urge intensities than females (EMM = 3.15, 95% CI [2.62, 3.68]). The same held for the influence of sex on the probability of controlling urges: there was no significant difference in the probability of controlling urges for males versus females OR = 0.662, 95% CI [0.309, 1.419], $\chi2(2) = 1.93$, $p = .38$.

3.1. The influence of state impulsivity and hunger on the intensity of urges

Participants' responses on the MIS significantly predicted the strength of urges, $F(1, 1494) = 99.04$, $p < .001$. For each 1 SD increase on the MIS, participants reported a 0.622-point increase in the strength of the urge ($b = 0.622$, 95% CI [0.503, 0.741]). See Fig. 1 for a plot of the model output on the linear relationship between the intensity of urges and MIS scores.

Participants' hunger state was also a significant predictor for urge intensity $F(1, 1485) = 7.80$, $p < .01$. They reported more intense urges when they were hungry, $b = 0.385$, 95% CI [0.115, 0.656]. When participants indicated they were hungry, the intensity of urges went up by 0.385 points.

There was also a significant effect of the type of urge on the perceived

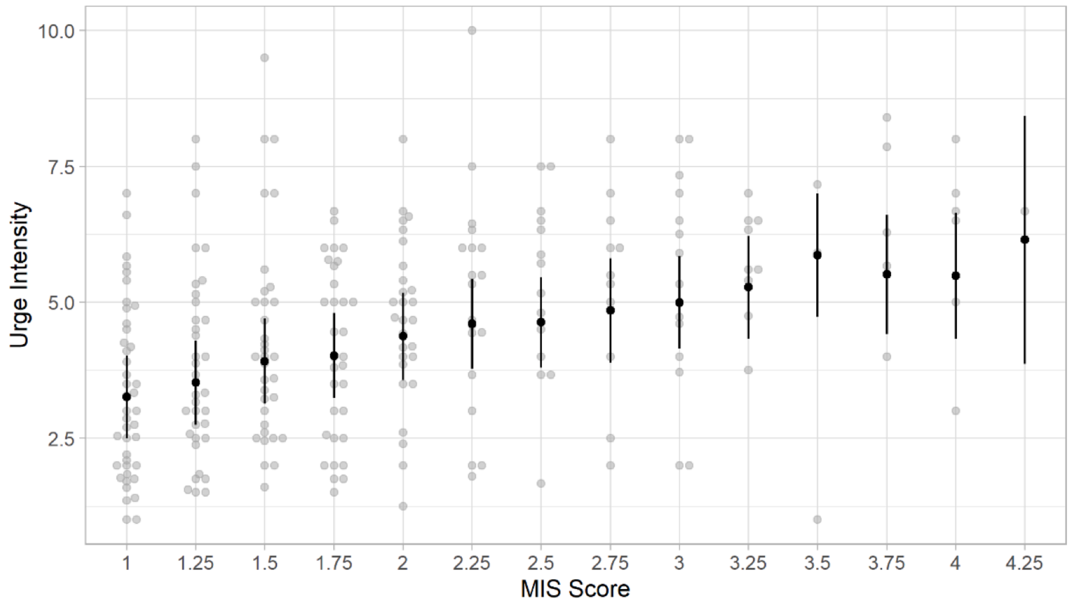

Fig. 1. The association between state-impulsivity (MIS) scores [1,5] (x-axis) and the urge intensity (y-axis) in the linear mixed model (MIS scores are presented as a factor here but is a continuous variable in the model). The error bars represent 95% CIs.

strength of urges, $F(5, 11) = 6.14$, $p < .01$. The urge to snack produced the strongest urges (estimated marginal mean (*EMM*) = 5.04, 95% CI [4.22, 5.85]), second strongest were urges to shop (*EMM* = 4.36, 95% CI [3.52, 5.20]), third were urges to drink alcohol (*EMM* = 4.13, 95% CI [3.28, 4.99]), fourth were urges to smoke (*EMM* = 3.38, 95% CI [2.21, 4.54]), followed by aggression-related urges (*EMM* = 3.76, 95% CI [2.68, 4.83]), and urges to gamble (*EMM* = 3.08, 95% CI [1.80, 4.36]).

There was also a significant interaction effect between the type of urge and hunger $F(5, 1079) = 2.72$, $p = .02$. Hungry participants reported stronger urges to snack (*EMM* = 5.46), $b = 0.846$, 95% CI [0.495, 1.196], $t(886) = 4.734$, $p < .0001$), but also to drink (*EMM* = 4.63), $b = 0.993$, 95% CI [0.488, 1.499], $t(1159) = 3.853$, $p < .001$) than participants who reported that they were not hungry (*EMM* = 4.61; EMM = 3.63, respectively). This means that the effect of hunger on the intensity of urges was stronger for urges to drink and snack than for other urges. See Fig. 2 for the relationship between the urge intensity of various urges and the hunger state of participants.

3.2. *The influence of state impulsivity and hunger on the ability to control an urge*

There was no significant effect of state impulsivity on the probability of controlling an urge OR = 0.871, 95% CI [0.739, 1.027], $\chi^2(1) = 2.72$, $p = .1$. This means that an increase of one standard deviation in a participants' response on the MIS would result in a (non-significant) change in the odds of controlling that urge between 0.739 and 1.027. Importantly, the 95% confidence interval includes 1 – the odds would stay the same.

Hunger significantly predicted whether participants controlled their urges, $\chi^2(1) = 4.26$, $p = .04$. A follow-up test showed that the odds ratio

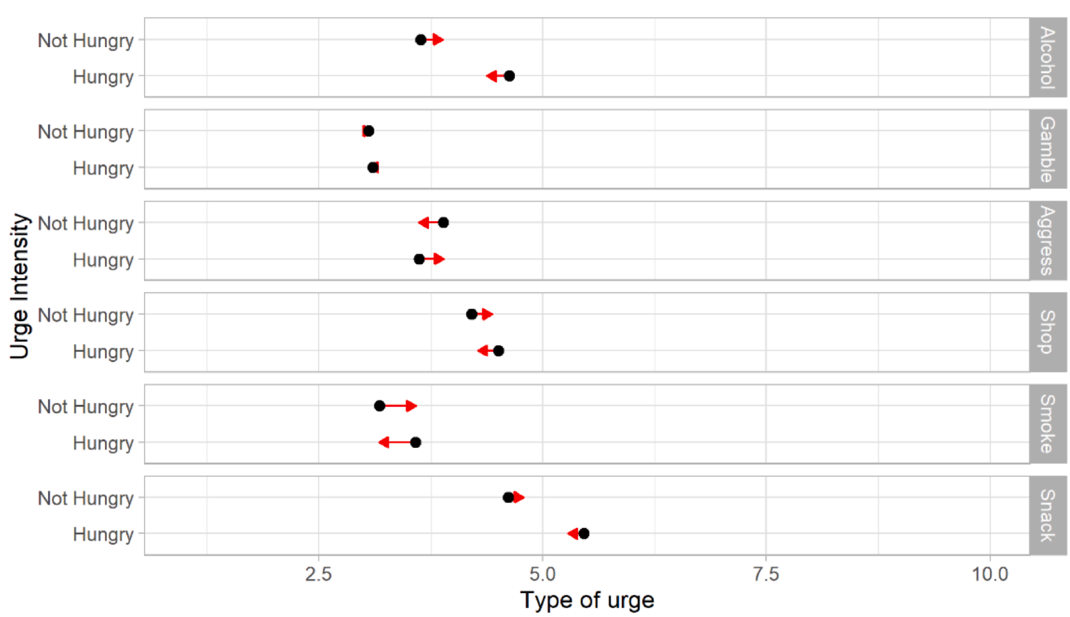

Fig. 2. The interaction effect between participants' hunger state (y-axis) and the different types of urge (panel labels) on urge intensity (x-axis). The comparison arrows represent the pairwise tests; arrows that do not overlap represent a significant difference at a bonferroni adjusted alpha level of 0.05.

of participants controlling an urge when participants were hungry, as opposed to when participants were not hungry was 0.644:1 (95% CI [0.426, 0.973].

The type of urge had a significant effect on the probability that participants controlled their urges, $\chi^2(5) = 28.38$, $p < .001$. Participants exhibited the lowest probability of controlling an urge to snack (*EMM* = 0.687, 95% CI [0.492, 0.833]). Second lowest probability of controlling an urge was for smoking (*EMM* = 0.758, 95% CI [0.461, 0.920]), third lowest was for drinking (*EMM* = 0.786, 95% CI [0.604, 0.898]). Participants were the most likely to control urges pertaining to gambling (*EMM* = 0.832, 95% CI [0.609, 0.940]), shopping (*EMM* = 0.866, 95% CI [0.725, 0.941]) and aggression (*EMM* = 0.949, 95% CI [0.833, 0.986]). This means that people had the lowest probability of controlling an urge to snack (holding all else equal), controlling on average 69/100 of these, whereas they had the highest probability of controlling an urge pertaining to aggression, controlling 95/100 of these. There was no significant interaction effect of hunger and the type of urge on the likelihood of controlling an urge $\chi^2(5) = 5.87$, $p = .32$. See Fig. 3 for the estimated marginal means of the probability of controlling an urge per urge type, partitioned by hunger state.

The perceived intensity of an urge significantly predicted the probability that a participant controlled that urge, $\chi^2(1) = 118.36$, $p < .001$. A more intense urge was associated with a lower probability of controlling the urge, OR = 0.694, 95% CI [0.647, 0.746]. This means that for every one-point increase on the 1–10 urge intensity scale, the odds of controlling the urge relative to the previous intensity level was 0.694. This roughly translates to the likelihood of controlling an urge with a '6' response on the urge intensity scale, being 0.694 as high as controlling an urge with a '5' response on the urge intensity scale. See Fig. 4 for the effect of the intensity of urges on the probability of controlling it.

3.3. *The influence of the time of day on urge intensity and the likelihood of controlling an urge.*

There was no effect of the time of day on the perceived intensity of urges, $b = 0.073$, 95% CI [-0.017, 0.163], $F(1, 1596) = 2.49$, $p = .12$.

The time of day had a significant effect on the probability that participants controlled their urges $\chi^2(1) = 12.39$, $p < .001$, as participants were less likely to control their urges later in the day, OR = 0.791, 95% CI [0.693, 0.902]. The coefficient in the model is in log odds, transforming this variable to odds would show that for each hour later in the day, the odds ratio would be 0.79:1 for controlling the urge compared to the previous hour. See Fig. 5 for the relationship between the time of day and the probability of controlling urges.

4. Discussion

In this study, we studied the effects of state impulsivity and hunger on the intensity of various types of urges and on self-control. We found that state impulsivity influences urge intensity, but not the probability of controlling an urge, suggesting a bottom-up influence on impulsive behaviour. Further, we found that hunger affects both urge intensity and the probability of controlling an urge, suggesting support for a dual-process model for the effect of hunger on behaviour. Lastly, we found that the likelihood of controlling an urge was lower when it was later in the day, whereas there was no such effect on urge intensity.

4.1. *State impulsivity*

Participants reported stronger urges when they were in an impulsive state. However, they did not report diminished self-control in conjunction with higher levels of state impulsivity. That is, while state impulsivity was indirectly associated with the probability of controlling urges through urge amplification, it did not have a direct effect on self-control. This evidence is in support of a bottom-up influence of state impulsivity, whereas we find no support for a top-down influence (i.e., state impulsivity appears to sensitise urges, while we found no evidence that it down-regulates inhibition). The lack of support for a top-down effect is surprising given the prevailing view that impulsivity is closely tied with a lack of self-control (Carver & White, 1994; Nigg, 2017; Patock-Peckham et al., 2001; Wiers et al., 2010).

Moreover, our findings concerning state impulsivity have implications to qualify the predictions of dual-systems models. Specifically, even though trait impulsivity ought to correlate with both the automatic and the deliberative systems, the two systems may not be equally affected by state impulsivity. This study provides evidence for a different effect of state impulsivity on the urge control process than is proposed about trait impulsivity, that is, it suggests that state impulsivity primarily affects people's capacity to resist predominant response tendencies (i.e., self-control) indirectly, by strengthening the emphasis on

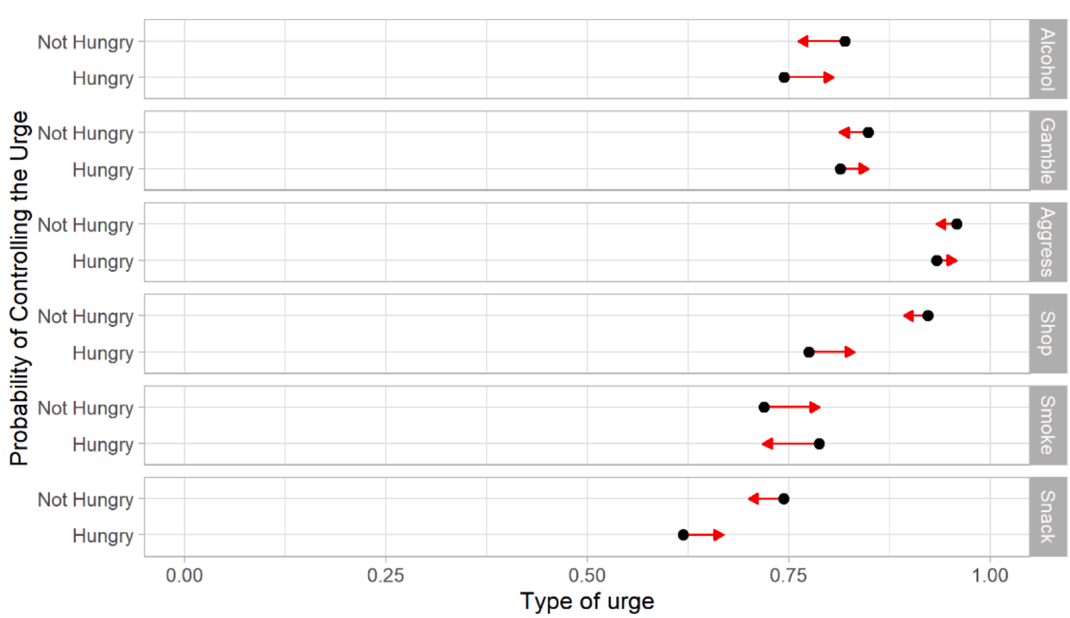

Fig. 3. The effect of hunger (y-axis) on the probability of controlling in urge (x-axis), partitioned by the type of urge (panel labels). The arrows represent pairwise comparisons; arrows that do not overlap represent a significant difference at a bonferroni adjusted alpha level of 0.05.

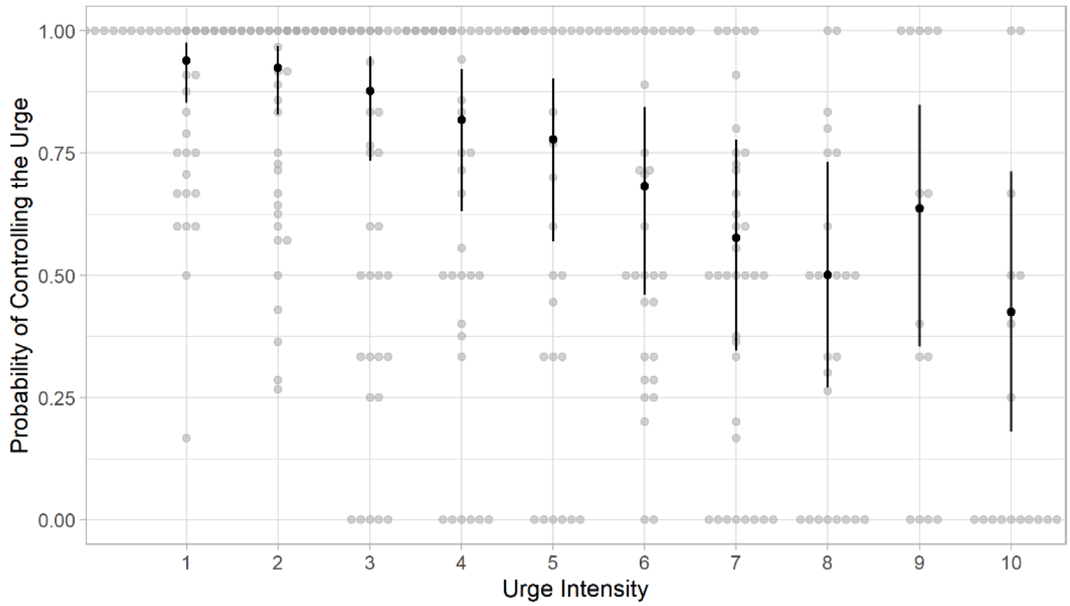

Fig. 4. The relationship between urge intensity (x-axis) and the probability of controlling an urge (y-axis). The grey dots represent data aggregated over participants in each urge intensity level. The error bars represent 95% CIs.

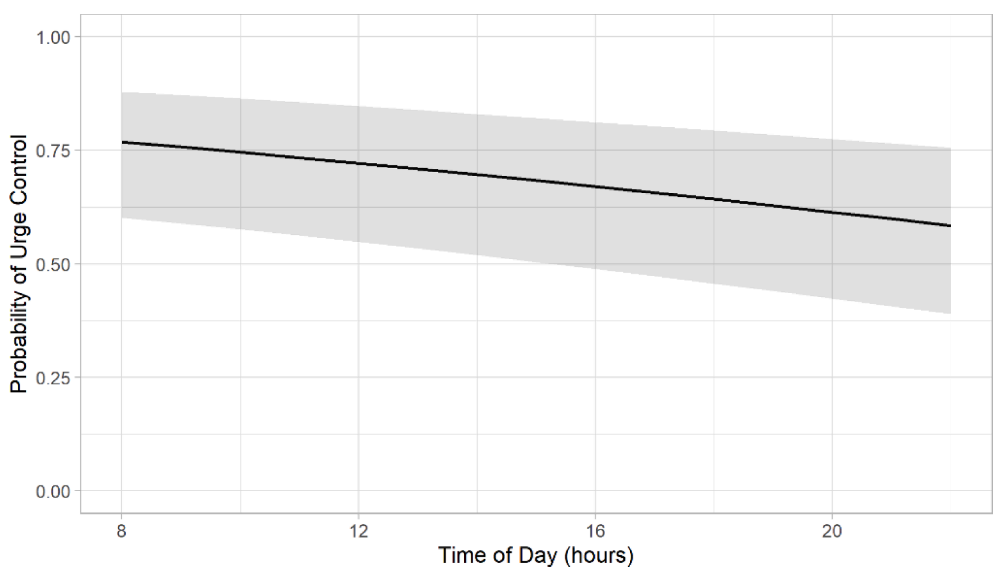

Fig. 5. The association between the time of day and the probability of controlling an urge. The grey band represents a 95% CI.

the impulse-response system—not by limiting people's ability to resist. More research needs to be done to determine whether state impulsivity is also directly associated with lesser self-control.

The implication is that state impulsivity impacts the salience of stimuli, which is significant because it has implications for clinical research on addiction. In people with drug addiction, drug-related stimuli are already more salient than other important stimuli (e.g., Lubman et al., 2008) and impulsivity is implicated in attentional bias toward drug-related stimuli (Coskunpinar & Cyders, 2013; Field & Cox, 2008), so fluctuations in state impulsivity might amplify this difference in salience and attention, temporarily making drug-related urges too strong to withstand.

Given the strong relationship between the intensity of urges and whether the urge is controlled, these results suggest that the effort exerted into improving the capacity to control urges when people are in an impulsive state could be better spent on other on-the-fly interventions that help reduce urges and cravings, or identifying and removing triggers for impulsive states (Hawker et al., 2021; Kakoschke et al., 2018).

4.2. Hunger

When participants were hungry, their urges were stronger, and they had a lower probability of controlling urges, even when controlling for urge intensity. More surprising, however, is that the effect of hunger on both urge intensity and the probability of controlling urges is not limited to eating-related stimuli (and thus is somewhat domain-general). That is, hunger amplifies the urges people experience, as well as decreasing the likelihood that they control an urge, holding fixed the intensity of the urge.

This effect corroborates the findings that hunger increases impulsive behaviour in non-human animals (Anderberg et al., 2016; Laude et al., 2012; Zheng et al., 2019), and some emerging evidence of the same effect in humans in the domains of gambling (Li et al., 2020) and delay discounting (Skrynka & Vincent, 2019), which is implicated in various addictive behaviours (Amlung et al., 2017). It also increases the confidence in the external validity of the effect of hunger on impulsive behaviour because this effect was observed in participants' natural environments.

It initially seems that hunger and the time-of-day influence self-control (i.e., the *capacity* to control urges). However, we did not ask participants whether they resisted the urge, so it may be that they merely resisted their urges less when they were hungry, or when it was late (i.e., the *motivation* to control urges). It may still be that the time of day influences self-control, but it is likely that as it gets later in the day, people switch task priorities as they transition from pursuing 'have-to' goals, to 'want-to' goals (Inzlicht et al., 2014). This motivational effect has been proposed as an alternative to ego depletion, which is closely related to the time of day. However, to identify whether the effect is motivational or whether self-control is affected, more research is needed to assess whether participants are less likely to attempt to resist urges later in the day, and when hungry.

There was also an interaction effect of hunger with the type of urge; urges pertaining to drinking alcohol and snacking were more strongly amplified by hunger than the other types. It could be that hunger leads to stronger amplification of the urge to drink alcohol and snack because these both address the homeostatic need for energy. Indeed, there is some evidence that interoceptive capacity for differentiating hunger from thirst might be limited (Eiselt et al., 2021). Thus, trouble dissociating an urge to snack from hunger is to be expected, though specific food cravings often occur without the urge to snack (Massey & Hill, 2012), and trends in snack-food cravings and general hunger are dissociable (Reichenberger et al., 2018). But, this is a further leap for alcoholic drinks—there should be good dissociability between hunger and alcohol cravings. A conjecture for future research is that it is due to the association of alcoholic drinks with food (Escrivá-Martínez et al., 2020).

4.3. Methodological considerations

We were able to find these effects because of the smartphone-based EMA methodology used for the experiment, which allowed us to study the effects of hunger on impulsive behaviour in people's everyday environment. This is necessary to show that the effects of hunger on impulsive behaviour is present in the outside world, rather than just in the laboratory. Moreover, it allowed us to tease apart the effect of hunger on the urge, rather than just on the likelihood of controlling various types of urges without creating an unwieldy design with various experiments testing different types of urges.

Through its better ecological validity, EMA methodology has distinct advantages over other approaches, which bolsters confidence that findings in the study replicate in real life. However, researchers also to some extent must relinquish control over the environment. This means that researchers are unable to fully ascertain whether participants are paying attention and what other variables might be interfering with the experiment.

The lack of an effect for a top-down influence of impulsivity in this study may be due to the limited interoceptive abilities of participants. Participants might inflate the experienced intensity of urges in hindsight to justify their failure to control them. But, if this were the case, then we should not have found the top-down influence of hunger, as it would be unlikely that participants would not have the same interoceptive issue for the influence of hunger. Alternatively, the lack of a top-down influence in our sample could be caused by a lack of power for a smaller effect size, which could be addressed in future research.

There were some limitations to our design. In particular, the effect sizes of hunger on urge intensity and self-control in our study might be imprecise because we used a binary measure for measuring hunger; a continuous measure could provide more information on the effects of hunger on behaviour. In addition, our sample skewed towards female participants, and although there was no effect of sex on either of the dependent variables, this skew could affect the external validity of the results. As such, further research on sex differences in the experience and impact of state impulsivity is needed.

Future research could clarify the implications of impulsivity traits on daily life by correlating them with behaviour patterns in EMA experiments. Research in this area is sparse, but initial work has been completed on affective instability (Solhan et al., 2009). It is important to know how self-reported 'typical' behaviour or experiences, which is what trait measures usually rely on, translate to real-time behaviour. Especially because humans are prone to recall biases, and this information is often used to diagnose psychiatric disorders. Recall bias could cause misdiagnosis or overdiagnosis leading to overmedication, unnecessary treatment, and increased burden on the healthcare system (Bruchmüller et al., 2012). Shedding light on potential systematic errors in answering trait scales would be useful in clinical settings and could be utilised to improve trait scales.

The findings in the current work could aid clinical research, as impulsivity is a key symptom of many neurological and mental disorders, including brain injury, dementia, substance and behavioural addictions, bipolar, eating or personality disorders, and many psychopathological symptoms show variability (American Psychiatric Association, 2013; Ebner-Priemer et al., 2009; Moeller et al., 2001). A focus on the effects of state impulsivity and hunger on behaviour in clinical settings, using an EMA paradigm like the one presented in the current study, will be useful considering that these states are more proximal and thus highly relevant to behaviours of interest. Acquiring new insights on the influence of fluctuations in state impulsivity, hunger could aid in identifying better ways to maintain goal-directed behaviour and thus better treatment outcomes.

CRediT authorship contribution statement

Simon Thomas van Baal: Conceptualization, Methodology, Software, Data curation, Visualization, Validation, Writing – original draft, Writing – review & editing, Project administration. **Neda Moskovsky:** Resources, Methodology, Software, Data curation, Project administration. **Jakob Hohwy:** Writing – original draft, Writing – review & editing, Visualization, Supervision. **Antonio Verdejo-García:** Conceptualization, Methodology, Investigation, Resources, Funding acquisition, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval

Informed consent was obtained from all participants and the project was approved by the Monash University Human Research Ethics Committee (Project ID: 11999).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2022.107381.

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