Reward-related attentional capture and cognitive inflexibility interact to determine greater severity of compulsivity-related problems

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Highlights

Attentional capture was correlated with various impulsivity dimensions

Attentional capture was related to compulsivity above all impulsivity dimensions

Inflexibility of attentional capture was related to distress-driven impulsivity

Inflexibility moderated the relationship between attentional capture and behaviour

Abstract

Background and Objectives: Neurocognitive processes are key drivers of addictive and compulsive disorders. The current study examined whether reward-related attentional capture and cognitive inflexibility are associated with impulsive and/or compulsive personality traits, and whether these cognitive characteristics interact to predict greater compulsivity-related problems across obsessive-compulsive and drinking behaviors. **Methods:** One-hundred and seventy-three participants (mean age = 34.5 years, S.D = 8.4, 42% female) completed an online visual search task to measure reward-related attentional capture and its persistence following reversal of stimulus-reward contingencies. Participants also completed questionnaires to assess trait impulsivity, compulsivity, alcohol use, and obsessive-compulsive behaviors. **Results:** Greater reward-related attentional capture was associated with trait compulsivity, over and above all impulsivity dimensions, while greater cognitive inflexibility was associated with higher negative urgency (distress-elicited impulsivity). Reward-related attentional capture and cognitive inflexibility interacted to predict greater compulsivity-related problems among participants who reported obsessive-compulsive behaviors in the past month (*n* = 57) as well as current drinkers (*n* = 88). Follow-up analyses showed that, for OCD behaviors, this interaction was driven by an association between higher reward-related attentional capture and more problematic behaviors among cognitively inflexible participants only. For drinking, the same pattern was seen, albeit at trend level. **Limitations:** This study includes a non-clinical, online sample and is cross-sectional, thus its findings need to be interpreted with these limitations in mind. **Conclusions:** Reward-related attentional capture and cognitive flexibility are related to trait compulsivity and impulsivity (negative urgency) respectively, and interact to determine more problematic behaviors.

KEYWORDS: reward learning, cognitive inflexibility, compulsivity, impulsivity

Introduction

Impulsivity and compulsivity are regarded as separable dimensional constructs that underlie distinct patterns of behavior. Impulsivity refers to the tendency to act without thinking, especially when the consequences of such action are inappropriate to the situation (Evenden, 1999; Whiteside & Lynam, 2001). By contrast, compulsivity is the tendency to engage in repetitive, habitual behaviors that are difficult to control or interfere with current goals (Figee et al., 2016; Robbins, Gillan, Smith, de Wit, & Ersche, 2012; Voon et al., 2015); and often accompanied by the feeling that they must be performed (Luigjes et al., 2019). While typically viewed as distinct are distinct constructs, impulsivity and compulsivity each constitute a transdiagnostic risk for psychopathology. For example, impulsivity is a well-established risk factor for the development and maintenance of addictive behaviors and disorders (Verdejo-García, Lawrence, & Clark, 2008); but addictive behaviors can also be compulsive (Yücel et al., 2018). Similarly, compulsive behaviors are a defining feature of obsessive-compulsive disorder (OCD); but impulsivity can also characterize this disorder (Benatti, Dell'Osso, Arici, Hollander, & Altamura, 2014). For instance, there is evidence that people with OCD have reduced response inhibition (Sohn, Kang, Namkoong, & Kim, 2014) and higher levels of self-reported impulsivity (Frydman et al., 2019; Grassi et al., 2015) than healthy controls. This in turn has contributed to the behavioral addiction model of OCD (Grassi et al., 2015), in which obsessive compulsive behaviors are seen as driven by the need for immediate gratification as opposed to risk aversion. Finally, the comorbidity of impulsivity and compulsivity in addictions and OCD has contributed to the idea that these constructs can interact to increase risk for problematic impulsive-compulsive behaviors (Chamberlain, Stochl, Redden, & Grant, 2018; Robbins et al., 2012). Studies have supported this interaction using self-report measures (Chamberlain et al., 2019; Prochazkova et al., 2018), but no study to date has examined whether such an interaction can be detected using cognitive measures.

One such cognitive measure, linked especially to impulsivity, originates in the phenomenon of sign tracking, first described in laboratory animals (Boakes, 1977; Hearst & Jenkins, 1974). Sign-tracking refers to a pattern of behavior wherein responding is directed towards reward-signaling cues rather than towards the reward itself. For example, when exposed to a signaling (Pavlovian) relation between the appearance of a lever and the imminent arrival of a food pellet, some rats approach the lever (sign-trackers), whereas others use the lever as a signal to approach the location of food delivery (goal-trackers). Critically, sign-trackers show higher levels of impulsivity across diverse paradigms (Lovic, Saunders, Yager, & Robinson, 2011; Tomie, Aguado, Pohorecky, & Benjamin, 1998) and are more likely than goal-trackers to develop addictive behaviors, such as cue-elicited reinstatement of extinguished drug-seeking (Yager & Robinson, 2013).

Le Pelley and colleagues (2015) developed a visual search task to assess an analogue of sign-tracking in people. In this task, participants were required to search for a target in an array of distractors. The faster they responded (correctly) to this target, the larger the reward they earned. One of the distractors in the display could be colored (either blue or orange). If the colored distractor appeared in the *high-reward* color (say blue) this signaled that the current trial was a bonus trial on which reward would be multiplied by a factor of 10; if it was in the *low-reward* color (orange in this case) the current trial was not a bonus trial. While the distractor signalled reward magnitude, it was not the target that participants responded to in order to receive that reward. Nonetheless, participants were significantly slower for trials with a high-reward distractor compared to trials with a low-reward distractor, suggesting that the former was more likely to capture attention, slowing response to the target. This effect of the signal for reward, referred to as *value-modulated attentional capture* (VMAC), constitutes 'attentional sign-tracking', and—like sign-tracking in animals—has been linked to addiction-related behaviors in humans (Albertella et al., 2017; Colaizzi et al., 2020).

Another cognitive measure that has been linked to impulsive-compulsive behaviors is cognitive inflexibility (Chamberlain, Fineberg, Blackwell, Robbins, & Sahakian, 2006; Izquierdo & Jentsch, 2012; Veale, Sahakian, Owen, & Marks, 1996). Cognitive flexibility refers to the ability to update an established pattern of thinking or behavior in response to changes in circumstances. By contrast, cognitive inflexibility is characterized by rigidity and resistance to change in the face of new information. While the relationship between compulsivity and cognitive inflexibility has often been studied using instrumental procedures (in which an outcome is contingent on some behavioral response), recent research suggests that compulsivity is also associated with inflexibility in adapting behavior to a change in a Pavlovian relationship (i.e., where an outcome is signaled by the presentation of some stimulus, and occurs independently of the person's response (e.g., van den Boom, Mooij, Misevičiūtė, Denys, & Willuhn, 2019). For instance, if the Pavlovian color–reward relationships in the VMAC task are reversed—so that the color previously associated with high reward now signals low reward, and vice versa—participants' attentional bias should adapt to these new contingencies. Notably, however, a persistence of the "old" pattern of attention in the face of this change in color–reward contingencies has been associated with problem drinking in university students (Albertella, Watson, Yücel, & Le Pelley, 2019). Thus, persistence of Pavlovian conditioned behavior following reversal (as an index of cognitive inflexibility) may reflect a transdiagnostic risk marker for compulsivity.

These considerations suggest that reward-related attentional capture (as an index of sign-tracking) and its persistence following reversal (as an index of cognitive inflexibility) may reflect separable cognitive risk markers, related to the phenotypes of impulsivity and compulsivity. However, exactly how impulsivity and compulsivity map onto attentional capture and its resistance to updating across reversal is not clear. Further, while evidence suggests that these phenotypes can interact to increase risk of addiction and compulsivity-related problems (e.g., Chamberlain et al., 2019), no study to date has examined if the cognitive constructs that underlie impulsivity and compulsivity also interact. To address this gap in the literature, the current study examined whether enhanced reward-related attentional capture (as the cognitive marker for impulsivity) interacts with cognitive inflexibility (as the cognitive marker for compulsivity) to predict more problematic compulsive behaviors than either risk factor alone. There were two aims. The first was to determine whether impulsive and compulsive traits were indeed associated with reward-related attentional capture and its inflexibility. The second aim was to examine whether reward-related attentional capture and its inflexibility (assuming their independence) interact to predict severity of compulsive drinking among current drinkers, and/or more compulsive OCD-related behaviors among individuals who report current compulsions (checking, washing, and ordering/arranging). A better understanding of how cognitive risk markers interact to promote the expression of problematic compulsive behaviors will help clarify the underlying mechanisms and inform targeted interventions.

Method

Participants and Procedures

Adult participants, aged 18 years and above, were recruited via Amazon Mechanical Turk for a study advertised as exploring compulsivity, in return for payment of US$6[1]. Each individual provided written informed consent prior to taking part. Participants then completed a series of questionnaires, followed by a modified value-modulated attentional capture

[1] The study reimbursement was advertised as US$6 with the potential of an additional US$3 bonus based on task performance. All participants who completed the study actually received US$9.

(VMAC) task including a contingency-reversal phase. Stimulus presentation in all tasks was controlled by Inquisit. All procedures were approved by the Human Research Ethics Committee at Monash University, Australia.

Measures

Demographic information, such as age and gender, was collected, and participants completed the measures described below.

Short UPPS-P Impulsivity Scale (S-UPPS-P; Cyders, Littlefield, Coffey, & Karyadi, 2014). This is a 20-item scale that measures impulsivity with five subscales: Negative Urgency (the tendency toward impulsivity when experiencing strong negative emotions; i.e., distress-elicited impulsivity, e.g., “When I feel rejected, I will often say things that I later regret”); Positive Urgency (the tendency toward impulsive action when experiencing strong positive emotions, e.g., “I tend to act without thinking when I am really excited”); Lack of Perseverance (e.g., “Once I get going on something I hate to stop”, reverse scored); Lack of Premeditation (e.g., “I usually think carefully before doing anything”, reverse scored); and Sensation Seeking (e.g., “I quite enjoy taking risks”). We included all subscale scores except positive urgency due to the potential of multi-collinearity issues given a VIF value of > 2.5 (Allison, 1999).

Cambridge-Chicago Compulsivity Trait Scale (CHI-T; Chamberlain & Grant, 2018). This is a 15-item scale covering broad aspects of compulsivity including the need for completion, feeling relieved when things are completed, getting stuck in a habit, failure to resist urges, doing things for immediate reward even if detrimental to other needs, desire for high standards, and avoidance of situations that are hard to predict or control. For each item, participants selected whether the statement applied to them by selecting “strongly disagree”, “disagree”, “agree”, or “strongly agree”, scored as 0-3 respectively. The measure of interest was the total score.

Brief Assessment Tool for Compulsivity-Associated Problems (Albertella, Chamberlain, et al., 2019). This is a six-item questionnaire to measure the severity of compulsivity-related problems in addictive and obsessive-compulsive behaviors in the present study, alcohol use and OCD-related compulsions (checking, washing, and ordering/arranging). The six items are adapted from the Yale-Brown Obsessive Compulsive Scale (Goodman et al., 1989), Florida Obsessive-Compulsive Inventory (Storch et al., 2007), and Penn Alcohol Craving Scale (Flannery, Volpicelli, & Pettinati, 1999). These items cover: time spent in these behaviors, as well as distress, loss of control, functional impact, and anxiety if prevented from doing the behavior, and strongest urge, in the past week. Importantly, BATCAP items intend to cover transdiagnostic aspects of compulsive behavior: its persistence and repetitive nature, its maladaptive nature, and the presence of urges. Finally, BATCAP scores have been shown to correlate with well-validated measures of corresponding behaviors, such as the Alcohol Use Disorders Identification Test (AUDIT) and the Obsessive Compulsive Inventory (OCI-R) (Albertella, Le Pelley, et al., 2019).

Each item was rated on a 5-point scale, scored 0 to 4 (e.g., ranging from none/not at all [0] to extreme/constant [4]) with the total score for all 6 items calculated. Only participants who endorsed such behaviors in the previous month were asked to complete the BATCAP. For each behavior in question (here: drinking, checking, washing, and ordering), participants were first asked whether they engaged in a given behavior (e.g., for checking behaviors, participants were asked: 'Do you or have you ever checked things repeatedly, more than necessary, for example checking locks, windows, gas, and switches?'). For drinking, participants were asked if they had consumed a standard alcoholic drink. While drinking alcohol, say once, in the past month is not necessarily *compulsive*, nor is washing your hands excessively once in the past month, we were interested in gauging compulsive behaviors dimensionally, in line with the shift seen in psychiatry away from categorical classification of mental disorders (e.g., Insel et al., 2010).

Finally, to clarify, while both the BATCAP and CHI-T may be applied transdiagnostically and measure aspects of compulsivity, the BATCAP assesses the extent to which compulsive behaviors are associated with various problems while the CHI-T is a trait-level measure.

Modified Value-Modulated Attentional Capture Task and Reversal (mVMAC-R). The visual search task used a modified, reward-only version[2] of Le Pelley et al.'s (2015, Experiment 2) VMAC task, to reflect reward-related attentional capture more specifically (indicated by the 'm' prefix). The task also included a reversal phase following the training phase (as in Albertella, Watson, et al., 2019), in which the color–reward contingencies were reversed (indicated by the '-R' suffix).

[2] In Le Pelley et al.'s original version of the task (and Albertella et al., 2019c), incorrect responses resulted in loss of the amount that would otherwise have been won as a reward. In contrast, in the current version of this task, errors simply resulted in no points and not a loss of points. This 'reward-only' modification was made so that performance would be less likely to be confounded by loss-related processes, which are not central to sign-tracking.

All stimuli were presented on a black background. Each trial began with a central fixation cross, followed after 500 ms by the search display. This contained six shapes—five circles, and one diamond (the target)—arranged evenly around an imaginary ring. Distractors were blue and orange circles, with assignment of blue and orange to the roles of high-reward and low-reward colors counterbalanced across participants. The diamond target contained a white line segment oriented either horizontally or vertically; other shapes contained a similar line segment tilted 45° randomly to the left or right. Participants' task was to report the orientation of the line within the target as quickly as possible—by pressing either the 'C' key (horizontal) or 'M' key (vertical)—with faster responses earning more points.

Each trial-block of the task consisted of 25 trials: 11 with a distractor rendered in the high-reward color, 11 with a distractor in the low-reward color, and 3 trials without a distractor (distractor-absent trials: all shapes were grey), in random order. For correct responses, on trials with a low-reward distractor and distractor-absent trials, participants won 0.1 points for every ms that their response time (RT) was below 1000 ms (e.g., a 600 ms RT would earn 40 points). Trials in which the display contained a high-reward distractor were bonus trials, and points were multiplied by 10 (so a 600 ms RT would earn 400 points). Correct responses with RTs greater than 1000 ms and incorrect responses earned no points. The search display remained on-screen until the participant responded or the trial timed-out (after 2000 ms). A feedback screen then appeared. On 'standard' (low-reward distractor or distractor-absent) trials, if the response was correct, feedback showed the number of points earned on that trial; if the response was incorrect, feedback showed "ERROR"; and if the trial timed-out, feedback was "TOO SLOW: Please try to respond faster". On bonus (high-reward) trials the corresponding feedback was accompanied by a box labelled "10 × bonus trial!" Location of the target and distractor, and target line segment orientation (vertical or horizontal) were randomly determined on each trial.

Participants were told to earn as many points as possible, and that the faster they responded, the more points they would get. They were also told that those who achieved a certain level of performance or above could receive a $3 bonus. Participants were further informed that: (1) when a circle in the high-reward color (say blue) was present in the search display it would be a bonus trial on which points were multiplied by 10; and (2) when a circle in the low-reward color (orange in this example) was present it would not be a bonus trial. Participants completed five blocks of 25 trials (the *training phase* of the task), with a break between blocks when they were shown the total number of points earned so far. Following the training phase, participants were informed that the color-reward contingencies would now be reversed: continuing the example above, the participant would be told that an orange circle would now signal bonus trials, and a blue circle would signal non-bonus trials (noting again that the color-reward assignments were counterbalanced across participants). Participants then completed the *reversal phase* (three blocks of 25 trials each) under these new color-reward contingencies.

To assess the effect of reward on attention during the training phase, we calculated a VMAC training score for each participant by subtracting reaction time (RT) on trials with a low-reward distractor from RT on trials with a high-reward distractor (as done in previous studies, e.g., Le Pelley et al., 2015). A higher VMAC score indicates slower responses on trials with high-reward distractor than trials with a low-reward distractor; that is, greater distraction by the high-reward distractor relative to the low-reward distractor; that is, a greater influence of the signal for reward on attentional capture. To assess the flexibility of the pattern of attentional bias formed during the training phase, we used data from the reversal phase to calculate a VMAC persistence score: for each participant, we subtracted RT on trials with a previously low-reward distractor (i.e., the color that had previously signaled low reward in the training phase) from RT on trials with a previously high-reward distractor. Greater values of VMAC persistence score therefore indicate greater persistence across the reversal phase of the VMAC effect previously established in the training phase: that is, greater cognitive inflexibility in the face of the changed color–reward contingencies.

Only correct responses were analyzed. Participants who scored less than 50% accuracy in the training phase (i.e., numerically below chance), or did not complete the task in its entirety (including reversal) were excluded from further analyses. Since we were interested in the effect of signals for reward when participants were practiced in the task, we calculated VMAC training scores using data from the final two blocks (50 trials in total) – as in previous research using this task (e.g., Albertella, Watson, et al., 2019). Similarly, we calculated VMAC persistence scores using data from the final two reversal blocks (50 trials in total). Using the last two blocks from each phase (training and reversal) allowed comparability of scores as well as exclusion of at least the first block from each phase (for which data are often noisy as participants readjust to the task).

Analyses

We first examined correlations between VMAC training scores and persistence scores to ensure their independence, which was the case. Linear regression analyses were then performed for VMAC training and persistence scores as dependent variables. The following independent variables were entered into the regression models simultaneously: negative urgency, lack of premeditation, lack of perseverance, sensation seeking; and trait compulsivity (CHI-T score).

Compulsive drinking (BATCAP for alcohol) scores and OCD-related BATCAP scores were not normally distributed (they were right-skewed) and thus were analyzed using negative binomial regressions. A robust estimator covariance matrix was specified as there were a few outliers in the BATCAP data. Independent variables across these regressions were: VMAC training score; persistence score; VMAC training × persistence score interaction term; negative urgency, lack of premeditation, lack of perseverance, sensation seeking; and trait compulsivity (CHI-T scores). Significant interactions were followed up by examining the association between VMAC training score and compulsivity-related problems among low and high cognitive flexibility groups separately, with 'flexible' and 'inflexible' groups determined using a median split based on the median VMAC persistence scores of the corresponding overall group (i.e., current drinkers, median = -5.6 ms, and current OC, median = -7.1 ms).

Results

Two-hundred and sixty participants agreed to participate. Forty-four participants dropped out before participating in the task. A further 43 participants were excluded from the statistical analysis as they did not complete the task (either training or reversal; $n = 23$) or scored 50% or below during the training phase ($n = 20$). Thus, 173 participants were included in the overall analyses. Of these, 88 (51%) participants had consumed alcohol in the past month and were included in the analyses of drinking behavior. Fifty-seven (33%) participants had performed a repetitive behavior (checking, washing and/or ordering/symmetry-related compulsions) in the past month and thus were included in the OCD-related behaviors analysis.

The 173 participants were on average 34.5 years old ($SD = 8.39$), and 58% were male. Across all participants, RT in VMAC training was significantly slower for trials with a high-reward distractor (M = 674.6, SD = 109.7 ms) than trials with a low-reward distractor (M = 659.5, SD = 107.9 ms), t172 = 3.23, p = .001, replicating previous findings using the VMAC task (Le Pelley, Pearson, Griffiths, & Beesley, 2015). Thus, participants were slower on trials with a high-reward distractor, replicating previous findings using the VMAC task. RT in the reversal phase was slower for trials with a "previously low-reward but now high-reward" distractor present ($M = 640.9$, $SD = 107.4$ ms) than trials with a "previously high-reward but now low-reward" distractor (M = 629.9, SD = 106.6 ms), t_{172} = 2.68, p = .008. This shows that, overall, participants adjusted their attentional responses to the changed stimulus-reward contingencies. Of more interest for the current study, however, is the ability of this measure to assess individual variations in either the expression of VMAC (training score) or its persistence, both which have been linked to addictive behaviours in past studies (Albertella et al., 2017; Albertella, Watson, et al., 2019).

Neither age nor gender were associated with VMAC training (age: r = - .08, p = .283; gender: t_{171}= .40, p = .692) or persistence scores (age: r = .013, p = .866; gender: t_{171}= -.35, p = .727). VMAC training and persistence scores were not significantly correlated with each other (r = .12, p = .104). Bivariate correlations across all measures are shown in Table 1.

The results from the linear regression models are shown in Tables 2 and 3, training and persistence scores, respectively. In the model with VMAC training score as the dependent variable, trait compulsivity was associated with greater VMAC score (β = 1.74, p = .028). Despite a significant correlation between Low Premeditation and VMAC training scores, there was only a trend-level association in the regression (β = 15.09, p = .095).

In the model with VMAC persistence score as the dependent variable, only negative urgency was associated with greater persistence of the pre-established VMAC during the reversal phase (i.e., greater cognitive inflexibility), β = 16.25, p = .029. Trait compulsivity was not associated with cognitive inflexibility. Finally, while positive urgency was significantly associated with both VMAC training and persistence scores, re-running both regressions with positive urgency included (and removing negative urgency) did not find it to be associated with either score.

The negative binomial regression analysis with BATCAP OCD-related compulsivity (n = 57; see Table 4) as the dependent variable found that greater negative urgency, Wald χ^2= 9.84, p = .002, and greater trait compulsivity, Wald χ^2 = 4.37, p = .037, were significantly associated with compulsivity-related problems. Further, there was a significant interaction between VMAC training and persistence scores, Wald χ^2 = 9.96, p = .002. Follow-up analyses looking at the associations between VMAC score and OCD-related BATCAP scores among the cognitively flexible (n = 28) and inflexible (n = 29) groups separately found a positive correlation in the latter group only, r_s = .38, p = .040. Among the cognitively flexible group, the correlation between VMAC training score and OCD-related BATCAP score was not significant, r_s = .05, p = .808.

The negative binomial regression analysis with BATCAP compulsive drinking scores (n = 88: see Table 5) as the dependent variable found that higher negative urgency, Wald χ^2 =

10.58, p = .001, was significantly associated with greater drinking BATCAP scores. The interaction term (VMAC training x persistence score) was also significant, Wald χ^2 = 4.32, p = .038. Follow-up analyses based on a median split of these participants into inflexible (high VMAC persistence, n = 43) and flexible (low VMAC persistence, n = 45) found that among the cognitively inflexible group, VMAC training score was associated (at trend-level) with greater drinking BATCAP scores, r_s = .28, p = .074. By contrast, among cognitively flexible participants, drinking BATCAP and VMAC training score were not significant correlated, r_s = -.14, p = .356.

Discussion

The current study found that greater reward-related attentional capture was significantly associated with trait compulsivity. This association has been noted before in this sample (Albertella, Chamberlain, et al., 2019); the current study extends this finding by showing that the association between reward-related attentional capture and trait compulsivity is significant over and above all impulsivity dimensions. While a number of impulsivity dimensions were significantly correlated with reward-related attentional capture, once adjusting for trait compulsivity, none remained significant. Finally, persistence of attentional capture following reversal (an index of cognitive inflexibility) was associated with negative urgency, that is, the tendency toward impulsive action when strong negative emotions occur.

Among participants who reported an OCD-related compulsion in the past month, more problematic compulsive behaviors were associated with higher trait compulsivity and higher negative urgency. There was also a significant interaction between VMAC training score and persistence score, with follow-up analyses revealing this was due to greater reward-related attentional capture (VMAC training score) being associated with more problematic compulsive behaviors among cognitively inflexible participants only. Similarly, among current drinkers, greater compulsivity-related drinking problems were associated with higher negative urgency, and there was a significant interaction between VMAC score and persistence score, which follow-up analyses revealed was driven by reward-related attentional capture (VMAC training score) being associated (at trend level) with more drinking problems among cognitively inflexible participants only.

As explained in the introduction, reward-related attentional capture may be considered an index of attentional sign-tracking, which in turn is thought to reflect the tendency to attribute incentive salience to stimuli associated with reward such that they become attractive in their own right (e.g., Colaizzi et al., 2020; Flagel, Akil, & Robinson, 2009). Recently, researchers have extended this view, proposing that sign-tracking to reward cues may reflect a tendency to attribute incentive salience toward Pavlovian cues in general (regardless of valence of the event they predict), including safety signals (for details, see Albertella, Le Pelley, et al., 2019). In the context of OCD, behaviors such as checking and washing may be driven by excessive incentive salience attribution to safety signals, resulting in such cues attracting attention and approach as if they themselves were rewarding. While this approach tendency toward Pavlovian signals might not be too problematic in itself, when combined with cognitive inflexibility, these behaviors become maladaptive as they persist despite the cue in question no longer signaling safety or reward.

The finding that higher negative urgency was associated with higher levels of compulsivity-related problems across addictive and OCD-related domains replicates previously reported results (Berg, Latzman, Bliwise, & Lilienfeld, 2015; Verdejo-García, Bechara, Recknor, & Pérez-García, 2007; Zermatten & Van der Linden, 2008). Notably, while negative urgency is considered to be an impulsivity dimension, it may reflect elements of both impulsivity and compulsivity. On the one hand, negative urgency may reflect a propensity to emotional disruption of top-down control (e.g., Kalanthroff, Henik, Derakshan, & Usher, 2016), in turn promoting generally impulsive behaviors. On the other hand, emotions may trigger compulsive actions specifically. For instance, strong emotion could disrupt the inhibitory processes that support flexible behavior (such as those described by Trask, Thrailkill, & Bouton, 2017) or otherwise promote habitual behaviors (e.g., Schwabe & Wolf, 2009). Thus, when strong emotion triggers maladaptive behaviors via such compulsivity-related mechanisms, this form of 'negative urgency' might be better classified as distress-elicited *compulsivity*. Indeed, a distress-driven shift from goal-directed to habitual networks has recently been argued to underlie compulsive behaviours in OCD (van der Straten, van Leeuwen, Denys, van Marle, & van Wingen, 2020).

In line with the above view that negative urgency may reflect, at least in part, compulsive mechanisms, we found that negative urgency was related to cognitive inflexibility. This finding may be interpreted in various ways. For instance, the fast-paced nature of the task itself may have been mildly stressful. Following the above assumption that negative urgency reflects, at least in part, emotion-induced inflexibility, then this could explain why task-elicited stress resulted in deficits (for those prone to distress-elicited inflexibility) at the reversal stage only. Another interpretation of this finding could be that negative urgency and inflexibility share a common neurobiological substrate, such as impaired functioning of dorsolateral prefrontal cortex (dlPFC). Specifically, the dlPFC has been shown to support reversal learning (Rogers, Andrews, Grasby, Brooks, & Robbins, 2000), and abnormalities in dlPFC functioning have been linked with negative urgency (Boy et al., 2011). Indeed, the dlPFC supports emotion regulation through (indirect) connections with the amygdala (Etkin, Büchel, & Gross, 2015). While the exact mechanisms by which emotion disrupts flexibility cannot be determined from the current study, the current findings highlight a link between negative urgency and cognitive inflexibility that, with further research, could provide novel insights into the mechanisms driving impulsive-compulsive behaviors.

The current study has several limitations. Firstly, it was conducted online and thus conditions could not be tightly controlled. However, web-based methods of delivering cognitive tests have shown comparable results to lab-based studies (McGraw, Tew, & Williams, 2000). Another limitation is the relatively high number of participants who dropped out during the course of the study (either before or during the cognitive task), or who did not perform above chance level (50% correct responses). Future studies conducted under controlled laboratory conditions are needed to determine if this is related to the online format or the task itself, and whether raising monetary incentives might help. Also, this study did not target diagnostic groups and so its findings might not apply to clinically defined compulsive disorders. Also, this study did not use multiple cognitive inflexibility measures to compare the new measure of inflexibility against. Finally, this study was cross-sectional and as such is limited by the issues that apply to cross-sectional research.

Despite these limitations, the current study points to novel interventions for compulsive behaviors. For instance, cognitive flexibility training interventions may be promising for improving distress-driven compulsive behaviours. Also, interventions that teach coping skills under strong negative emotion may facilitate their use when such emotions arise. Alternatively, teaching coping skills *in response to* strong negative emotion might be most helpful as it would enable coping responses to be easily activated in the future when such feelings arise, regardless of emotion-induced impairments in cognitive control.

In conclusion, the current study highlights the use of a recently developed cognitive paradigm to explore two separable cognitive risk markers, reward-related attentional capture and cognitive inflexibility, which are associated with trait compulsivity and negative urgency respectively. Our findings support past research showing that impulsivity and compulsivity interact to increase risk for problematic impulsive-compulsive behaviors, but extend it to show that this interaction may occur at the cognitive level. They also emphasize the role of negative urgency as an especially important transdiagnostic risk-related construct linked to inflexible cognition and suggest new targets for treatment.

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Table 1. Correlations across VMAC training scores (1), persistence scores (2), compulsivity (3), impulsivity (4-8), and compulsivity-related problems (9 & 10)

		1	2	3	4	5	6	7	8	9	10
1. VMAC	r	–									
	p	–									
	n	–									
2. Persistence	r	.12	–								
	p	.104	–								
	n	173	–								
3. CHI-T	r	**.26**	.08	–							
	p	**.000**	.282	–							
	n	**173**	173	–							
4. Negative	r_s	**.25**	**.19**	**.39**	–						
Urgency	p	**.001**	**.011**	**.000**	–						
	n	**173**	**173**	**173**	–						
5. Positive	r_s	**.19**	**.16**	**.22**	**.68**	–					
Urgency	p	**.014**	**.037**	**.004**	**.000**	–					
	n	**173**	**173**	**173**	**173**	–					
6. Low	r_s	-.08	.01	**-.44**	.02	.08	–				
Perseverance	p	.316	.848	**.000**	.784	.325	–				
	n	173	173	**173**	173	173	–				
7. Low	r_s	**.18**	-.01	-.06	**.36**	**.47**	**.30**	–			
Premeditation	p	**.015**	.895	.456	**.000**	**.000**	**.000**	–			
	n	**173**	173	173	**173**	**173**	**173**	–			
8. Sensation	r_s	.12	-.03	.03	**.24**	**.36**	-.01	**.18**	–		
Seeking	p	.102	.714	.674	**.002**	**.000**	.935	**.016**	–		
	n	173	173	173	**173**	**173**	173	**173**	–		
9. OCD	r_s	.23	.00	**.40**	**.35**	.19	-.07	.00	-.02	–	
	p	.090	.976	**.002**	**.007**	.159	.611	.977	.854	–	
	n	57	57	**57**	**57**	57	57	57	57	–	
10. Alcohol	r_s	.08	.16	.16	**.24**	.06	.11	.11	.00	.03	–
	p	.442	.148	.134	**.022**	.579	.306	.312	.997	.862	–
	n	88	88	88	**88**	88	88	88	88	31	–
Mean/Median		15.1	-11.0	36.8	1.8	1.3	2.0	2.0	2.0	7.0	2.0
S.D/min-max		61.63	54.20	7.16	1-4	1-4	1-3.5	1-4	1-4	2-24	1-17

N.B. Spearman's correlations were used for skewed data and Pearson's correlations were used if both variables were normally distributed. Similarly, median (min-max) and mean (S.D) were used for skewed and normally distributed data, respectively. Bolded font indicates $p < .05$.

Table 2. Linear regression with VMAC score as dependent variable (N = 173, R^2 = .121)

	B	SE	Lower	Upper	t	p	$Part^2$
NU	8.761	8.012	-7.057	24.579	1.093	.276	.006
LoPers	-6.440	9.723	-25.636	12.756	-.662	.509	.002
LoPre	15.092	8.997	-2.669	32.854	1.678	.095	.015
SS	8.764	6.151	-3.380	20.908	1.425	.156	.011
CHI-T	**1.743**	**.788**	**.188**	**3.298**	**2.213**	**.028**	**.026**

Note: NU = Negative urgency (distress-elicited impulsivity). LoPers = Lack of Perseverance. LoPre = Lack of premeditation (acting without forethought). SS = Sensation seeking.

Table 3. Linear regression with persistence score as dependent variable (N = 173, R^2 = .035)

	B	SE	Lower	Upper	t	p	$Part^2$
NU	**16.252**	**7.380**	**1.681**	**30.823**	**2.202**	**.029**	**.028**
LoPers	-.389	8.956	-18.071	17.294	-.043	.965	<.001
LoPre	-5.139	8.287	-21.500	11.223	-.620	.536	.002
SS	-2.264	5.666	-13.450	8.923	-.400	.690	<.001
CHI-T	-.062	.725	-1.494	1.370	-.086	.932	<.001

Note: NU = Negative urgency (distress-elicited impulsivity). LoPers = Lack of Perseverance. LoPre = Lack of premeditation (acting without forethought). SS = Sensation seeking.

Table 4. Negative binomial regression on OCD compulsivity scores

	B	SE	Lower	Upper	Wald χ^2	p
NU	**.272**	**.0867**	**.102**	**.442**	**9.839**	**.002**
LoPers	.132	.1277	-.119	.382	1.061	.303
LoPre	-.163	.0985	-.356	.030	2.723	.099
SS	-.027	.0707	-.165	.112	.143	.705
CHI-T	**.020**	**.0097**	**.001**	**.039**	**4.365**	**.037**
VMAC score	.003	.0012	.001	.005	6.144	.013
Persistence score	-.001	.0009	-.003	.000	2.088	.148
Interaction	**5.211E-5**	**1.6510E-5**	**1.976E-5**	**8.447E-5**	**9.964**	**.002**

Note: NU = Negative urgency (distress-elicited impulsivity). LoPers = Lack of Perseverance. LoPre = Lack of premeditation (acting without forethought). SS = Sensation seeking.

Table 5. Negative binomial regression on compulsive drinking scores

	B	SE	Lower	Upper	Wald χ^2	p
NU	**.477**	**.1466**	**.190**	**.764**	**10.584**	**.001**
LoPers	.192	.1676	-.136	.521	1.315	.252
LoPre	.025	.1202	-.210	.261	.043	.835
SS	-.036	.1014	-.235	.163	.126	.723
CHI-T	.016	.0176	-.019	.051	.829	.362
VMAC score	.000	.0014	-.003	.002	.092	.761
Persistence score	.000	.0013	-.003	.002	.072	.788
Interaction	**4.703E-5**	**2.2624E-5**	**2.691E-6**	**9.137E-5**	**4.322**	**.038**

Note: NU = Negative urgency (distress-elicited impulsivity). LoPers = Lack of Perseverance. LoPre = Lack of premeditation (acting without forethought). SS = Sensation seeking.