EMOTIONAL IMPULSIVITY AND THE RELATIONSHIP BETWEEN IMPULSIVE CHOICE AND IMPULSIVE ACTION

A Dissertation

by

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ABSTRACT

The standard definition of impulsivity implies that impulsive individuals demonstrate abnormal reward processing (i.e., impulsive choice, IC) and a penchant for immediate and maladaptive action (i.e., impulsive action, IA). Although IC and IA rarely correlate, both impulsive choice and impulsive action are strongly influenced by emotions. Several studies to date implicate that an individual's impulsive choice and impulsive action levels depend on his/her susceptibility to the influence of emotions (emotional impulsivity, EI). However, we do not know exactly how emotional impulsivity exacerbates maladaptive actions (IA) and abnormal reward processing (IC). The traditional view suggests that the core deficit of emotional impulsivity is a predisposition for impulsive action. The alternative view postulates that the core deficit for emotional impulsivity is the inability to focus and maintain attention, i.e., attentional impulsivity.

Both of these theories are largely based on the findings in clinical populations; in the normal population, the evidence does not favor either of these positions. A possible remedy for this problem is a more sensitive mouse-tracking technique that allows to monitor the subjects' behavior continuously. Using this technique, I contrasted the traditional and the alternative view in two studies. In Study 1, participants completed stop-signal task and delay discounting tasks, as well as UPPS, BIS, and CAARS questionnaires. I investigated whether EI and impulsive choice can be predicted by impulsive action (suggesting the traditional view) or by attentional impulsivity (suggesting the alternative view). Study 1 showed that the model incorporating attentional impulsivity had a better fit and more significant relationships between AImp, IC, IA, and EI than the model incorporating impulsive action alone; these results imply that attentional impulsivity best predicts IC and IA.

Study 2 manipulated the participants’ affect as they were completing SST and DDT. Specifically, I examined how emotionally salient pictures change the relationship between attentional impulsivity and EI/IC/IA by 1) comparing performance in DDT and SST when emotional and neutral pictures are present; 2) analyzing what facets of emotional impulsivity moderate the relationship between IC and IA/AImp when participants are exposed to emotional and neutral pictures. The results show that 1) emotional stimuli primarily increase attentional impulsivity, but not IC or IA; 2) Emotional impulsivity moderates the relationship between impulsive choice and attentional impulsivity, but not between impulsive choice and impulsive action. In sum, the results are consistent with the view that inattention is the core deficit in emotional impulsivity.

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NOMENCLATURE

GNG	go/No-go task
SSRT	Stop-signal reaction time
SST	Stop-signal task
DDT	Delay discounting task
IC	Impulsive choice
IA	Impulsive action
EI	Emotional impulsivity
CAARS	Conners’ Adult ADHD Rating Scales
BIS	Barrat Impulsiveness Scale
UPPS	Urgency-Premeditation-Perseverance-Sensation Seeking-Positive Urgency questionnaire
SPQ-BRU	Schizotypal personality questionnaire – brief revised (updated)
ERS	Emotional reactivity scale
AS	Affective slider
PANAS-X	Positive and Negative Affect Schedule

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1. INTRODUCTION

Cognitive control—the ability to override one's impulses and make decisions based on one's goals rather than habits or reactions—is perhaps one of the most distinctive characteristics of human cognition (Stout, 2010). This ability is integral for everyday functioning: deficits in cognitive control—called impulsivity—affect the quality of life universally (Victor et al., 2011). Impulsivity is a central component of mental disorders, including attention-deficit/hyperactivity disorder (ADHD; Winstanley et al., 2006), borderline personality disorder (BPD; Sebastian et al., 2013), gambling addiction (Verdejo-García et al., 2008), as well as drug abuse (Perry and Carroll, 2008), smoking, and alcoholism (Granö et al., 2004).

Impulsivity includes at least three different facets: impulsive choice (IC), also known as "delay discounting," impulsive action (IA), otherwise called "behavioral disinhibition" (Diergaarde et al., 2008), or "poor response inhibition" (Horn et al., 2003), and attentional impulsivity (AImp), i.e., inability to focus and maintain attention (Cservenka and Ray, 2017). Impulsive choice can be characterized as a preference for smaller and more immediate rewards over larger and later ones. The propensity for risk-taking is also considered a characteristic of impulsive choice (Ríos-Bedoya et al., 2008), although recent studies postulate that risk-taking is a distinct construct (Isles et al., 2019). Impulsive action can be understood as an inability to inhibit a prepotent motor response.

Impulsive choice and impulsive action are often assessed by cognitive tasks: delay discounting tasks (Rung et al., 2019), and go/No-go and stop-signal tasks (Brevers et al., 2012), respectively, along with relevant questionnaires (for example, Barrat Impulsiveness Scale, BIS; Patton et al., 1995). Attentional impulsivity is commonly gauged by questionnaires, e.g., BIS (Barrat Impulsiveness Scale), as well as performance in attention-demanding cognitive tasks, such as random dot kinematogram (Motoyoshi et al., 2015).

Traditional theories of impulsivity focus on the relationship between IC and IA. IC and IA are considered to be two primary facets of the general construct of impulsivity (Sharma et al., 2014); indeed, elevated levels of IC and IA are found in many disorders, including ADHD and addictive disorders (e.g., steeper discounting rates, longer stop-signal reaction times, and worse Stroop performance among individuals abusing cocaine). When impulsivity is studied through self- or other-reports, impulsive individuals often show elevated impulsive choice and impulsive action levels. However, when impulsivity is studied using behavioral/cognitive tasks (e.g., delay discounting tasks and stop-signal tasks), a wide discrepancy emerges. For example, individuals with strong impulsive choice tendencies show little impulsive actions (Broos et al., 2012). Likewise, attentional impulsivity is not correlated with either impulsive action (Khng and Lee, 2014) or impulsive choice (Martinez-Loredo et al., 2017) outside of the clinically impaired population.

One way to resolve this disagreement is to consider impulsive choice (IC), impulsive action (IA), and attentional impulsivity (AImp) distinct constructs. As MacKillop and colleagues postulate, while the concept of impulsivity “may be desirable for expediency or heuristic value” (MacKillop et al., 2016, p. 8), there is little empirical support for the single impulsivity construct. However, this view does not explain why elevated IC, IA, and AImp levels are often observed in impulse control disorders. For example, if impulsive choices and impulsive actions are unrelated**,** why do individuals who abuse cocaine have steep discounting rates (IC; Heil et al., 2006), long stop-signal reaction times (IA; Fillmore and Rush, 2005), and report the inability to maintain attention (Vázquez et al., 2020)? That is, if impulsive choice, impulsive action, and attentional impulsivity are (un)related, how are they related or unrelated?

A component of impulsivity that is frequently observed in impulsive choice, impulsive action, and attentional impulsivity is emotions (Figure 1, upper panel). As Johnson and colleagues (2017) show, the tendency to respond impulsively in the presence of emotions (emotional impulsivity) constitutes a distinct form of impulsivity. Recent studies suggest that emotions are crucial for understanding the psychopathology of impulsive disorders (Johnson et al., 2013), as well as daily impulsivity-related behavioral problems, e.g., aggression and substance abuse (Sharma et al., 2014). However, the specific neurocognitive mechanism by which emotions increase impulsive behaviors is unclear (Figure 1).

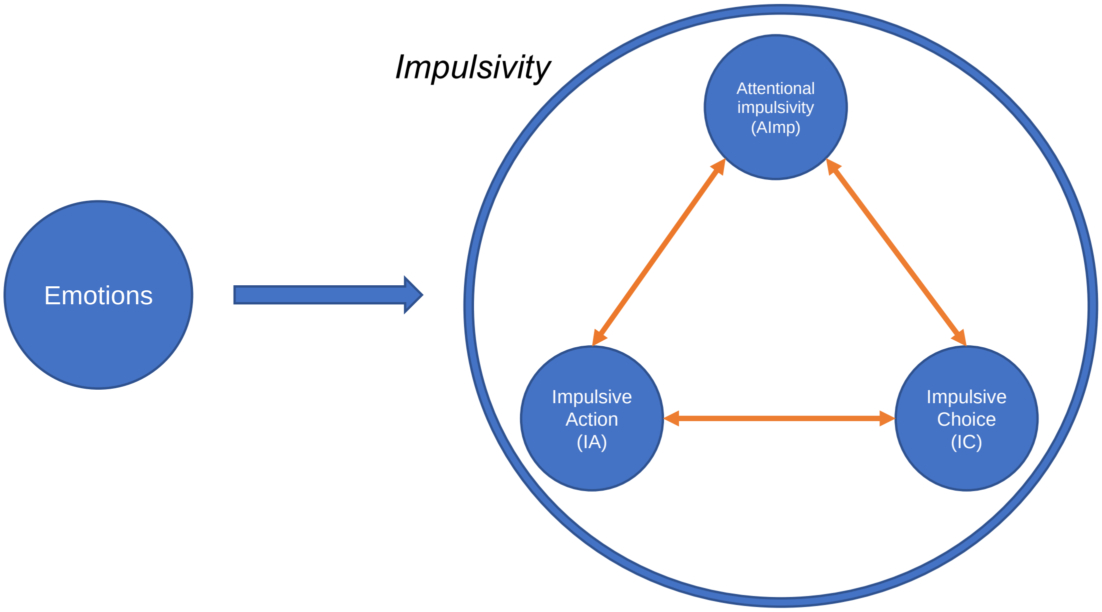

Figure 1. Emotions and impulsive behaviors

The traditional view on the putative mechanism of emotion-related impulsivity posits that response inhibition (e.g., troubles with suppressing inappropriate/interruptive behavior) is the main cognitive trait that underlies emotional impulsivity (Johnson et al., 2020). This weak response inhibition is evident even without an emotion present, i.e., regardless of the mood manipulation (Peckham et al., 2021). Finally, activity in the serotonergic system – the primary neural circuit that underlies impulsive behaviors – can be reliably linked to response inhibition. In short, the traditional view suggests that response inhibition, which is manifested in impulsive action, is the core cognitive deficit of emotional impulsivity.

However, this view is challenged by emerging evidence. First, recent studies do not replicate the predicted correlation between response inhibition performance and emotional impulsivity scores. Developmentally, response inhibition (impulsive action) does not appear to be a precursor of emotional impulsivity or other impulsive behaviors. Second, the evidence for response inhibition is mainly found in the clinical population, where it might stem from general cognitive deficits. Third, serotonergic malfunction does not exclusively influence response inhibition; it also impacts other forms of executive functions such as attention.

Particularly, attentional impulsivity appears to be an alternative cognitive trait underlying emotion-related impulsivity. First, the serotonergic function determines the ability to focus and sustain attention as well as response inhibition. Second, attentional impulsivity is often comorbid with emotional dysregulation (Jakubczyk et al., 2018). Finally, emotional stimuli restrict attention to themselves; impulsive choices and impulsive actions commonly entail attentional bias (Pessoa, 2008). However, the direct correlations between attentional impulsivity measures and emotional impulsivity are weak.

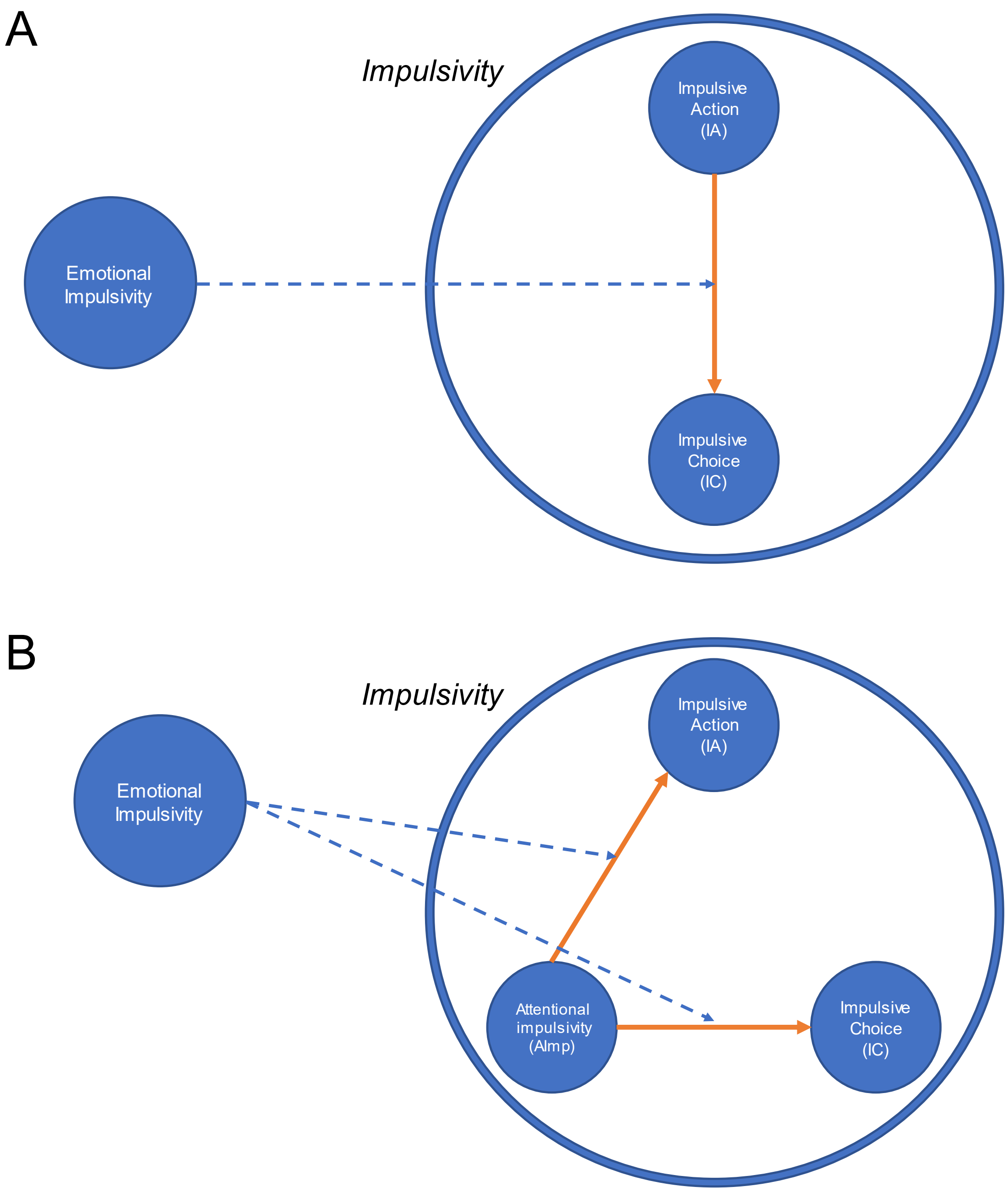

Figure 2. "Core Impulsive Action" and "Core Attentional Impulsivity" theories of impulsive behaviors.

Note: Dashed lines illustrate hypothesized pathways of emotional influence. Panel A: "Core Impulsive Action" theory. In this theory, emotional impulsivity mediates the relationship between impulsive action and impulsive choice. Panel B: "Core Attentional Impulsivity" theory. In this theory, emotional impulsivity mediates the relationship between attentional impulsivity and impulsive choice/action.

This dissertation investigates which cognitive trait gives rise to emotional impulsivity (Figure 2); in particular, I examine whether impulsive action/poor response inhibition (Figure 2, upper panel) or attentional impulsivity (Figure 2, lower panel) is the main cognitive component (cognitive trait) of emotional impulsivity. Section 1.1 documents the relationship between emotions and impulsive choice, impulsive action, and inattention. Section 1.2 describes the serotonergic system as the primary neural mechanism underlying emotion-related impulsivity and examines which behaviors the serotonergic function governs. Sections 1.3-1.6 summarizes the evidence in favor of each primary cognitive trait that corresponds to this neural mechanism: attentional impulsivity (inattention) and impulsive action (poor response inhibition).

Section 2 experimentally tests which cognitive trait best predicts other impulsive behaviors. In Study 1, I presented participants with stop-signal and delay discounting tasks, followed by impulsivity questionnaires (BIS, UPPS, CAARS, and others). I formed structural equation models and contrasted the extent to which the two models, “core impulsive action” and “core attentional impulsivity,” accounted for the variance/covariance structures of cognitive tasks and impulsivity questionnaires.

Section 3 evaluates whether attentional impulsivity or impulsive action is the core deficit in emotional impulsivity when participants are induced with emotions. In Study 2, participants completed SST and DDT while observing standardized emotional pictures from IAPS and OASIS. I then tested whether participants displayed more impulsive behaviors (IA/IC/AImp) while observing emotional pictures than neutral pictures. Finally, Section 4 discusses the theoretical significance of the findings and outlines the directions for future research. Overall, results from two experiments and my literature review demonstrate that the core deficit of emotional impulsivity is most likely to involve attentional impulsivity but not impulsive action.

1.1. Emotions impact inattention and impulsive action

An individual under a strong emotional influence is more likely to engage in impulsive actions (Kalanthroff et al., 2013) and impulsive choices (Malesza, 2019, 2021). Emotions frequently accompany impulsive motor reactions and monetary choices (i.e., delay discounting situations) in disorders such as ADHD (Utsumi et al., 2016; Thorell et al., 2020). Sharma and colleagues' (2014) meta-analysis shows that most self-report impulsivity measures loaded onto two affect-related factors: conscientiousness-like and extraversion-like, implying that most impulsive behaviors are driven by an affect. Although the specific mechanism by which emotions promote impulsive choice and impulsive action is unclear, some researchers hypothesize that emotion exacerbates response inhibition (impulsive action) (Chester et al., 2016), while others hypothesize that emotion interferes with attention (Pessoa, 2008).

Evidence suggests that the connection between emotional impulsivity and impulsive action (malfunction in response inhibition) is evident on behavioral and neural levels. For example, patients with schizophrenia and a history of violence tend to show less activation in inhibition-related regions of the brain (e.g., dlPFC) and make more commission errors during an emotional go/No-go task compared to non-violent individuals with schizophrenia (Tikasz et al., 2018). That is, individuals with schizophrenia and impaired processing of negative emotions display less activation in the inhibitory and attention-related regions of the brain than those diagnosed with schizophrenia but not classified as violent offenders. The activation of attention-related regions suggests that attention plays a role in impulsive action in the presence of emotional stimuli.

The predisposition to react impulsively under emotional influences (emotional impulsivity) correlates with impulsive choice, impulsive action, and inattention most strongly in the clinical population. However, the correlations between EI and IA are stronger in the clinical samples (mean r = .34) and are much weaker (mean r = .14) in community samples (Johnson et al., 2020). Thus, whether the association between impulsive action and emotional impulsivity can be detected outside the clinical population is still unclear. These findings also suggest that the relationship between emotional impulsivity and response inhibition might result from a general cognitive deficit and not a specific IA-EI relationship, as Johnson and colleagues suggest.

There is also inconclusive evidence about the strength or existence of the relationship between emotional impulsivity and impulsive action when an affect (negative or positive) is not present. Jauregi (2018) showed no significant relationship between measures like SSRT (stop-signal reaction time) and negative urgency, as measured by UPPS (Urgency-Premeditation-Perseverance-Sensation Seeking-Positive Urgency scale, a common questionnaire for emotional impulsivity) but found significant differences in UPPS scores between low- and high-impulsivity groups. In contrast, other studies report strong associations between emotional impulsivity and performance in the go/No-go task or the stop-signal task even when mood induction fails (Gunn and Finn, 2015) or report no interaction with mood strength (Dekker and Johnson, 2018). Yet other studies report a strong relationship between emotional impulsivity and behavioral inhibition measures in stop-signal and other inhibition tasks (e.g., Flanker task; Gabel and McAuley, 2018, 2020) when an affect is present.

The same pattern can be observed in the relationship between emotion-related impulsivity and inattention. For example, emotional stimuli in a Stroop task were found to exacerbate attention (Strauss et al., 2005). Dysregulation of emotions frequently accompanies inattention in impulsivity-related disorders such as ADHD (O’Neil & Rudenstine, 2019). Positive emotional impulsivity (i.e., tendency to react impulsively under positive emotions) was correlated with Stroop task performance (Sharma et al., 2014). However, many other tasks and questionnaires show little to no correlation between inattention measures and emotional impulsivity, particularly negative urgency (discussed in detail in Section 1.3 below).

Finally, the tendency to react impulsively under the influence of negative emotions (negative urgency) is correlated with the discounting rate (i.e., the rate at which an individual prefers smaller immediate rewards to larger/delayed rewards) among heavy drinkers and gamblers (e.g., Stojek et al.,2014; Steward et al., 2017), and negative urgency scores predict addiction (Torres et al., 2013). There is also an overlap in neural basis: Cyders et al. (2014) found strong activation in the ventromedial prefrontal cortex (vmPFC) among individuals high in negative urgency when presented with alcohol odors. As vmPFC is heavily involved in assigning and comparing subjective values of different stimuli, i.e., the choice process, these findings suggest that emotional impulsivity influences impulsive choices. Interestingly, vmPFC is also heavily involved in mediating visual attention during the recognition of emotional stimuli (Wolf et al., 2014).

It should also be noted that the correlation between impulsive choice and emotional impulsivity rarely replicates in the normal population (e.g., between discounting rates and Urgency-Premeditation-Perseverance-Sensation Seeking-Positive Urgency, UPPS, scores; Burnette et al., 2019; Jauregi et al., 2018), although Jauregi and colleagues (2018) found significant differences between high and low emotional impulsivity groups by comparing their proportions of larger/later vs. sooner/smaller choices in the delay discounting task (DDT). In summary, emotional impulsivity and impulsive choice have some connections on behavioral and neural levels. Despite that, in the normal population, EI and IC are scarcely correlated.

1.2. Neural mechanism of emotional impulsivity

One of the most important brain circuits that underlie emotion-related impulsive behaviors is the serotonergic system, which includes basal ganglia, amygdala, and several areas of the prefrontal cortex (PFC). While Johnson and colleagues (2020) focus on response inhibition, the serotonergic system governs other executive functions, particularly attentional control.

Impulsive behaviors arise from the interaction between reflexive and reflective systems (Carver and Johnson, 2008). Individuals choose an action by processing information either quickly and associatively (through the *reflexive* system) or slowly and deliberately (through the *reflective* system). The reflexive system produces habitual behaviors (Osatuyi and Turel, 2018) and momentary responses to situational cues, while the reflective system overrides the reflexive responses and habits by engaging effortful control. Carver and Johnson (2008) suggest that impulsive behaviors arise mainly from a relative deficiency of reflective (deliberative) control over behavior, be it action (e.g., aggression or engaging in drug abuse) or inaction (e.g., depression apathy). Emotions easily trigger reflexive systems; emotional events frequently exacerbate the automatic/reflexive responses (Strack and Deutsch, 2004).

The reflexive (automatic) system is based mainly on the basal ganglia and the amygdala. Basal ganglia processes reward information (e.g., craving and looking for rewards). The amygdala assigns emotional values to stimuli, either positive (appetitive) or negative (aversive). The reflective system is based on the anterior cingulate cortex (ACC) and lateral and dorsal prefrontal cortex (PFC). These two systems are often activated concurrently. The relative activation of both systems depends on the task at hand: for example, when asked to suppress emotional reactions, people showed increased activation in dlPFC and ACC and less activation in the amygdala.

The individual differences in impulsivity are ascribed to the amount of serotonin available in the brain (serotonergic function; Carver and Johnson, 2008). Serotonin constrains amygdala activity; higher serotonergic function facilitates better response inhibition when these impulses are triggered by the emotional stimuli (impulsive action, as predicted by Johnson and colleagues view). In line with Johnson and colleagues' prediction, the amount of serotonin primarily (of all executive functions) affects an individual’s penchant for impulsive action, as evidenced by lesion studies (Logue and Gould, 2014). Similarly, depleting serotonin led to more immediate choices in a delay discounting task (impulsive choice), whether emotional stimuli were present (Bari et al., 2010; see Puig Pérez, 2018 for review) or not (Schweighofer et al., 2008; Crockett et al., 2010).

However, serotonin is also strongly related to the allocation of attention. For example, primate studies (Weinberg-Wolf et al., 2018) show that depleting serotonin also leads to reduced stimulus looking times, i.e., inattention. Individuals with a chronic deficit of serotonin (5-HT) show worse performance in an attentional task (Banerjee and Nandagopal, 2015). Variation in the serotonin transporter gene is associated with attentional biases towards positive and negative emotional stimuli (Fox et al., 2009). Depleting serotonin leads to lapses in attention (Zepf et al., 2010).

In sum, emotional impulsivity is closely tied to the serotonergic function. However, serotonergic function influences a diverse array of behaviors, including response inhibition and attentional control. What is the main cognitive trait component of emotional impulsivity, i.e., the core deficit in emotional impulsivity? That is, what is the neurocognitive mechanism that corresponds most closely to the tendency to react impulsively under the influence of emotions? There are at least two candidates for this role: impulsive action (poor response inhibition) and attentional impulsivity.

1.3. Impulsive action as the core deficit in emotional impulsivity (“Core Impulsive Action")

Several researchers postulate that impulsive action (poor response inhibition) is the core deficit in emotion-related impulsivity, although recent evidence contradicts this assertion.

According to Pearlestein et al. (2019, p. 2), the main cognitive trait underlying emotional impulsivity is impulsive action (troubled response inhibition). In the same vein, Johnson et al. (2020) postulate that emotional urgency (emotional impulsivity) manifests primarily as impulsive action. The capacity for response inhibition, i.e., the ability to override impulsive actions, is a stable, heritable characteristic (Anokhin et al., 2016).

Elevated scores on both positive and negative emotional impulsivity were linked to worse performance in the stop-signal task and continuous performance task (Cyders and Coskunpinar, 2011), especially among the clinical population (Johnson et al., 2016). Higher emotion-related impulsivity scores were found to be related to worse performance on the antisaccade task (Dekker and Johnson, 2018) and a higher number of commission errors (i.e., trouble with inhibiting a prepotent response) in a go/No-go task (Chester et al., 2017).

Negative emotion-related impulsivity and impulsive action have overlapping bases in basal ganglia and prefrontal cortices, particularly in vmPFC (Cyders et al., 2014). In sum, as Johnson and colleagues (2020, p. 343, underscore supplied) postulate, “Across behavior and imaging methods, evidence supports difficulties in response inhibition (<u>but not facets of executive function such as attention problems</u>) for both PU and NU [Positive and Negative Urgency].”

Recent studies, however, contradict the idea of impulsive action as a core deficit of emotion-related impulsivity (i.e., “Core Impulsive Action”). Most significant associations between impulsive action and attentional impulsivity are observed in the clinical samples (Johnson et al., 2020), which suggests that the strong correlation between impulsive action and emotions might stem from a general cognitive deficit and not from a true relationship.

Furthermore, contrary to the predictions of the “Core Impulsive Action” view, we often do not observe correlations between emotional impulsivity and impulsive actions even when emotions are present. Pearlestein et al. (2022) have found no correlation between emotional impulsivity and performance for an antisaccade task. Importantly, neither pre- nor post-stress impulsive action levels were related to emotional impulsivity in their study. In other words, it cannot be said that the impulsive action metrics were not correlated with EI because participants were insufficiently aroused/emotional.

On a trait level, impulsive action was not confirmed to predict emotional impulsivity, as implied by Madole and Johnson’s original model (Madole et al., 2020, illustrated in Figure 3, panel A). The final structural model in Madole et al.’s study included response inhibition not as a cause but as a correlate of emotional impulsivity and aggression (Figure 3, panel B).

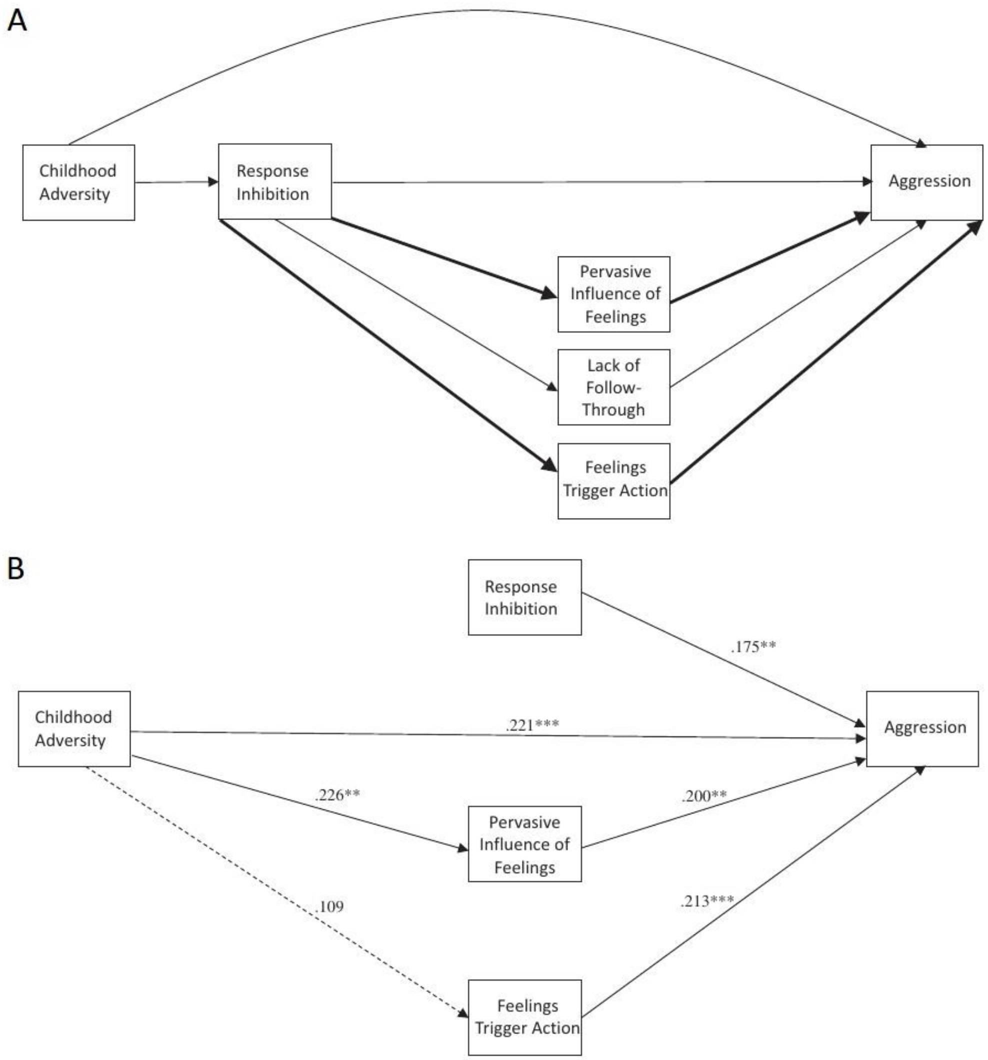

Figure 3. Madole et al.’'s models of emotional impulsivity.
Note: A: original hypothesized model; B: final model. Adapted from Madole et al. (2020)

Furthermore, although the serotonergic function can be reliably linked to impulsive action, it does not affect *just* impulsive action ability. Among other facets of executive functioning, the amount of serotonin in the brain and the amygdala activity are related to an individual’s ability to suppress attending to distracting information (Iordan et al., 2013). Together, these findings point to the idea that attentional control as an alternative to response inhibition for the core mechanism of emotional impulsivity.

1.4. Inattention as the core deficit in emotional impulsivity ("Core Attentional Impulsivity")

Attentional impulsivity, i.e., inability to focus and sustain attention (Meule et al., 2017), is considered an integral part of impulsivity, although correlations between attentional and emotional impulsivity are weak.

Dickman (1993) suggested that insufficient focusing of attention leads to impulsive behaviors, including both impulsive choices and impulsive actions. Emotional dysregulation frequently overlaps with attention-related disorders such as ADHD (Nigg, 2000). Questionnaire measures of inattention were found to be correlated with poor emotion regulation (O'Neill and Rudenstine, 2019). Individuals with a history of intimate partner violence (a form of behavior closely linked with emotional impulsivity) show significantly worse performance on the attention switching task (Romero-Martinez et al., 2019).

Impulsive actions often involve attentional bias. Individuals with high impulsive action tendencies overattend to the information pertaining to the impulsive action and neglect any other data (Wiers et al., 2010). Among individuals with ADHD, longer stop-signal reaction times are often driven by inattention (Weigard et al., 2019). According to Verbruggen and De Houwer (2007) and Pessoa (2009), emotionally significant stimuli draw attentional and inhibitory resources away from stimuli that indicate the need for inhibition (e.g., stop-signals). Barrat Impulsiveness Scale Attentional Impulsiveness scores were significantly related to the performance in the go/No-go task (Hege et al., 2015).

Poor attentional control also influences impulsive choices. For example, compulsive buyers often report the narrowing of attention while making impulsive purchases (Khachatryan et al., 2018). Impulsive choices among patients with alcohol addiction correlate with high attentional bias (Field et al., 2015). Individuals with gambling addiction, a form of impulsive choice, also report the inability to divert their attention from gambling-related stimuli once these stimuli have captured their attention; chronic gamblers also show an attentional bias for gambling-related topics (Sancho et al., 2021).

Attention and impulsive behaviors are related on the neural level as well. The vmPFC and dlPFC were found to mediate attentional control while recognizing emotional faces (Wolf et al., 2014). The anterior cingulate cortex, which is implicated in impulsive behaviors and emotion regulation, is also in charge of attentional control in both rats (Wu et al., 2017) and humans (Kondo et al., 2004). Finally, a lack of activation in the ventrolateral prefrontal cortex (vlPFC, a region critical for emotional regulation) was related to sustaining attention on arousing stimuli (He et al., 2018; Viviani, 2013).

In terms of direct associations with emotional impulsivity scores, however, inattention measures do not fare well. Cyder and Coskunpinar’s (2011) meta-analysis showed no association between negative/positive urgency and resistance to distracting stimuli. Another meta-analysis by Sharma et al. (2014) shows a very weak (0.07) correlation between UPPS Negative Urgency scales and any of the inattention measures, although the mean correlation between Stroop task errors and positive emotionality measures was stronger (0.28). Mean correlations between behavioral measures of inattention (performance in Delayed/Immediate Memory tasks) and negative emotional impulsivity measures were also moderate (mean $r = 0.25$ and 0.24, respectively), suggesting at least some relationship. Interestingly, later studies (Sanchez-Roige et al., 2019) reported a significant relationship between the BIS Attentional impulsivity subscale and both Negative and Positive Urgency subscales of UPPS.

1.5. “Core Impulsive Action” versus “Core Attentional Impulsivity” theories

While both impulsive action and attentional impulsivity are strong candidates for the core deficit in EI, a conclusive answer is hard to reach due to small sample sizes and the unreliability of experimental designs.

Johnson and colleagues advance the position that *the* core deficit in emotional impulsivity is impulsive action (“Core Impulsive Action”). According to this view, emotions exacerbate troubles with response inhibition, and as a result, an unwanted response is emitted. This position is supported by a large number of correlations between emotional impulsivity and impulsive action. However, developmentally the predictions of the “Core Impulsive Action” theory are not confirmed: poor response inhibition (IA) is not a precursor of emotional impulsivity (Madole et al., 2020). Moreover, the correlations between impulsive action and emotional impulsivity measures are found mostly in the clinical population. Finally, sample sizes used in these studies are often small (less than 60); thus, these studies are plagued by weak effect sizes.

An alternative view (“Core Attentional Impulsivity” theory) postulates that impulsive action is merely *a* deficit in EI; instead, the inability to focus and sustain attention (attentional impulsivity) is the main cognitive trait in EI. Emotional stimuli restrict attention to themselves at the expense of stimuli that signal the need for inhibition. Many studies confirm the link between emotions and the inability to focus attention. However, the direct correlations between emotional impulsivity and attentional impulsivity are weak. Likewise, many studies investigating the relationship between attentional and emotional impulsivity are also plagued by the small sample sizes.

In addition to the sample size, another problem in relating emotional impulsivity and impulsive action/attentional impulsivity lies in the way impulsive action and attentional impulsivity are measured. It might be possible that behavioral tasks (as they are usually designed) are not sensitive enough to capture the relationship between EI (emotional impulsivity), IC (impulsive choice), IA (impulsive action), and AImp (attentional impulsivity). Most behavioral tasks that are designed to assess impulsivity (particularly impulsive action, e.g., stop-signal task) require a participant to respond by pressing a key or a button. Then, a subject’s performance is evaluated based on their accuracy and response times. All other measures, for example, stop-signal reaction time (SSRT), are estimated from the accuracy and distribution of RTs. Although this approach provides much information about the decision-making process, anything that happens between the start and end (i.e., response) of the trial is omitted. Thus, if impulsivity affects performance in a behavioral task continuously, keypress-based designs of impulsive action tasks (e.g., go/No-go or stop signal tasks) are not sensitive enough to show the in-depth working of impulsivity.

This lack of continuous assessment can be remedied by integrating “mouse tracking” into impulsivity tasks, such as stop signal and delay discounting tasks. Mouse tracking, a new action-based measure of behavior, has advanced theories of decision-making with the notion that cognitive and social decision-making is fundamentally dynamic (Spivey, 2008; Leontyev & Yamauchi, 2021). Mouse movement features, such as the area under the curve or the deviation from the straight line between the start and end point, were found to be indicative of perceptual and numerical judgment (Song and Nakayama, 2008; Chapman et al., 2010; Xiao and Yamauchi, 2014, Yamauchi and Xiao, 2018), semantic categorization (Dale et al., 2007), linguistic judgment (Spivey et al., 2005; Farmer et al., 2007), and racial and gender judgment of morphed face pictures (Freeman and Ambady, 2009; Freeman et al., 2010). Additionally, mouse movement has been found to be related to attitudinal ambivalence toward certain topics (e.g., abortion; Wojnowicz et al., 2009; Schneider et al., 2015), uncertainty in economic choices (Calluso et al., 2015) as well as general emotional states, such as anxiety (Yamauchi, 2013; Yamauchi and Xiao, 2017). With respect to impulsivity, our recent research shows that the correlations between mouse movement measures and questionnaire-based impulsivity scores are considerably stronger than correlations between traditional RT/accuracy-based behavioral measures and the same questionnaire scores, e.g., Conners Adult ADHD Rating scales subscales C (Impulsivity/Emotional lability) or F

(DSM-IV: Hyperactive/Impulsive symptoms; Leontyev & Yamauchi, 2019; Leontyev et al., 2018).

1.6. Interim conclusions

While evidence suggests that emotional impulsivity connects attentional impulsivity and impulsive choice/action, *how* they are related is not well understood. First, there is inconsistent evidence for whether impulsive behaviors arise from the inability to sustain attention on the inhibitory stimuli or from the poor response inhibition ability (impulsive action). The traditional view (Johnson et al., 2020) suggests that impulsive action is the core deficit in emotional impulsivity and other forms of impulsive behavior, such as aggression; emotions exacerbate the difficulties in response inhibition. Recent evidence, however, suggests that inability to sustain attention is at the heart of impulsive behavior. Emotional stimuli draw observers' attention (Pessoa, 2009). As a result, the observer provides little attention to the primary task (i.e., stop signal or delay discounting task).

Empirical findings are inconsistent with both accounts. On the one hand, there are mixed results on whether impulsive action is related to emotional impulsivity, especially given that the most significant correlations between impulsive action and emotional impulsivity scores arise in clinical samples. Many experimental studies of impulsivity and cognitive control are unreliable. This unreliability can be attributed to the studies' small sample sizes (Carver and Johnson, 2018) but also to the low sensitivity of the tasks: as our previous studies (Leontyev and Yamauchi, 2019; Leontyev et al., 2018; Leontyev et al., 2019) show, the traditional response time-based tasks are not sensitive enough to reveal a relationship between behavioral metrics (e.g., SSRT) and questionnaire scores.

On the other hand, attentional impulsivity measures are weakly correlated with emotional impulsivity measures. Furthermore, it is unclear how much of this weak correlation can be attributed to the way attentional impulsivity was assessed. That is, the weakness/strength of the relationship between inattention and emotional impulsivity measures might be attributed to the general problems in relating experimental and self-report measures of behavior. Finally, many of the aforementioned studies are concerned with impulsive action, but not impulsive choice. To the best of our knowledge, no studies have systematically investigated the involvement of emotion in impulsive action *and* impulsive choice.

In sum, the literature review suggests that two theories can explain the mechanism of emotional impulsivity: the “Core Impulsive Action” view and the “Core Attentional Impulsivity” view. These two theories give two sets of predictions. “Core Impulsive Action” suggests that the mechanism behind emotional impulsivity is impulsive action. Consequently, this view suggests that the inclination to impulsive action can predict other forms of impulsivity, such as impulsive choice. Moreover, this theory predicts that the effect of emotions will be more apparent in impulsive action but not in other executive functions, e.g., attentional control. In contrast, the “Core Attentional Impulsivity” theory posits that when an attentionally salient emotional stimulus restricts attention to itself, this increases impulsive choice and impulsive action. This theory postulates that at the core of impulsive behavior lies an individual’s inability to maintain attention (Diamond, 2013). This theory points to inattention as the main predictor of other impulsive behaviors. In addition, this theory suggests that emotions primarily weaken attentional control.

1.7. Overview of experiments

Studies 1 and 2 tested different cognitive traits that might constitute the basis of emotional impulsivity. Study 1 employs structural equation modeling analysis to evaluate what mechanism underlies emotional impulsivity and impulsive choice or impulsive action on a trait level. Study 2 tested the attentional impulsivity hypothesis directly.

More specifically, Study 1 compares two models: 1) the traditional model with impulsive action as the predictor of emotional impulsivity and impulsive choice ("Core Impulsive Action"); and 2) the "Core Attentional Impulsivity" model, which has the inability to sustain attention as the core deficit in emotional impulsivity.

In Study 2, I tested the "Core Impulsive Action" and "Core Attentional Impulsivity" models in the context of elicited emotions. If the impulsive action is the core deficit in emotional impulsivity, the effect of emotional stimuli will be observed primarily in the impulsive action measures. Specifically, significantly worse performance in impulsive action measures in the emotional condition is expected. Furthermore, impulsive choice and impulsive action will be strongly related among individuals rated high on the emotional impulsivity scales, especially when emotional stimuli are present.

If emotions give rise to impulsive behavior through attentional impulsivity ("Core Attentional Impulsivity"), the effect of emotional stimuli will be primarily on the inattention measures, such as direction discrimination accuracy or velocity in "go" trials in the stop-signal task. That is, we will see greater variability in velocity in "go" trials in trials with emotional stimuli compared to trials containing neutral stimuli. Moreover, attentional impulsivity will be strongly related to impulsive choice/action, especially among individuals with high levels of emotional impulsivity.

2. STUDY 1: IMPULSIVE ACTION VS ATTENTIONAL IMPULSIVITY AS PREDICTORS OF EMOTIONAL IMPULSIVITY AND IMPULSIVE CHOICE

The aim of Study 1 was to investigate whether the core deficit in emotional impulsivity is attentional impulsivity or impulsive action on a trait level. Participants completed SST (stop-signal task), DDT (delay discount task), and emotional impulsivity questionnaires (Figure 4). In Study 1, we employed two versions of SST and DDT: traditional (keypress) and mouse-tracking. Subjects were randomly assigned to either keypress or mouse-tracking version.

Structural equation modeling was used to link emotional impulsivity (EI) to performance in DDT (IC) and SST (IA/AImp). If emotional impulsivity is a manifestation of impulsive action tendencies, this can be taken as evidence in favor of the "Core Impulsive Action" view. In contrast, if the model with inattentiveness as the core deficit fits the data better, the alternative theory, "Core Attentional Impulsivity," is more plausible.

Figure 4. Order of tasks in Study 1

2.1. Methods

2.1.1. Participants

A total of 505 individuals were recruited for this experiment (207 in the keypress condition and 298 in the mouse movement condition) from the Amazon M-Turk website (location limited to the United States of America). Only individuals who managed to attain at least 5% direction discrimination accuracy and successfully inhibit their responses in at least 5% of “stop” trials (“stop” accuracy”) were included in the final sample. Moreover, only participants who indicated their control device as a mouse were selected.

The final sample included 155 individuals in the keypress condition and 200 individuals in the mouse movement condition. Participants were randomly assigned to the keypress or mouse movement condition. Tables 1 and 2 summarize the demographic information of participants in keypress and mouse movement conditions.

Table 1. Demographic information in the Keypress condition

	N	***Age***
Total	155	42.17 (12.33)
Female	80	42 (12.1)
Male	72	42.2 (12.7)
Other	2	45 (12.7)

Note: scores in parentheses show standard deviations. One individual failed to disclose their age and gender.

Table 2. Demographic information in the Mouse movement condition

	N	***Age***
Total	200	44.03 (12.33)
Female	111	46.5 (12.1)

Male	88	40.9 (11.9)
Other	1	26 (n/a)

Note: scores in parentheses show standard deviations

In the mouse movement condition, we only employed individuals who used a computer mouse; of these individuals, 168 individuals completed the experiment on Windows, 20 using Apple/Mac, and 12 using Linux.

2.1.2. Procedure

After completing the virtual consent form, participants carried out the stop-signal task, delay discounting task, and answered impulsivity questionnaires (BIS, UPPS, CAARS, ERS, and SPQ). SST and DDT were offered in keypress (traditional SST or DDT) or mouse movement conditions. All experiments were programmed in *PsychoPy* environment (Peirce et al., 2019). Table 3 summarizes the two possible conditions.

Table 3. Conditions in Study 1

Conditions	**1st task**	**2nd task**
Key	Key SST	Key DDT
Mouse	Mouse SST	Mouse DDT

Stop-signal task. The stop-signal task followed the procedure adopted by Ma and Yu (2016). In 200 trials, participants were presented with a random dot kinematogram (100 dots). A varying proportion (10, 50, or 80%) of these dots was coherently moving left or right, while other dots were moving in random directions. The proportion of coherent dots was randomly set at the beginning of each trial.

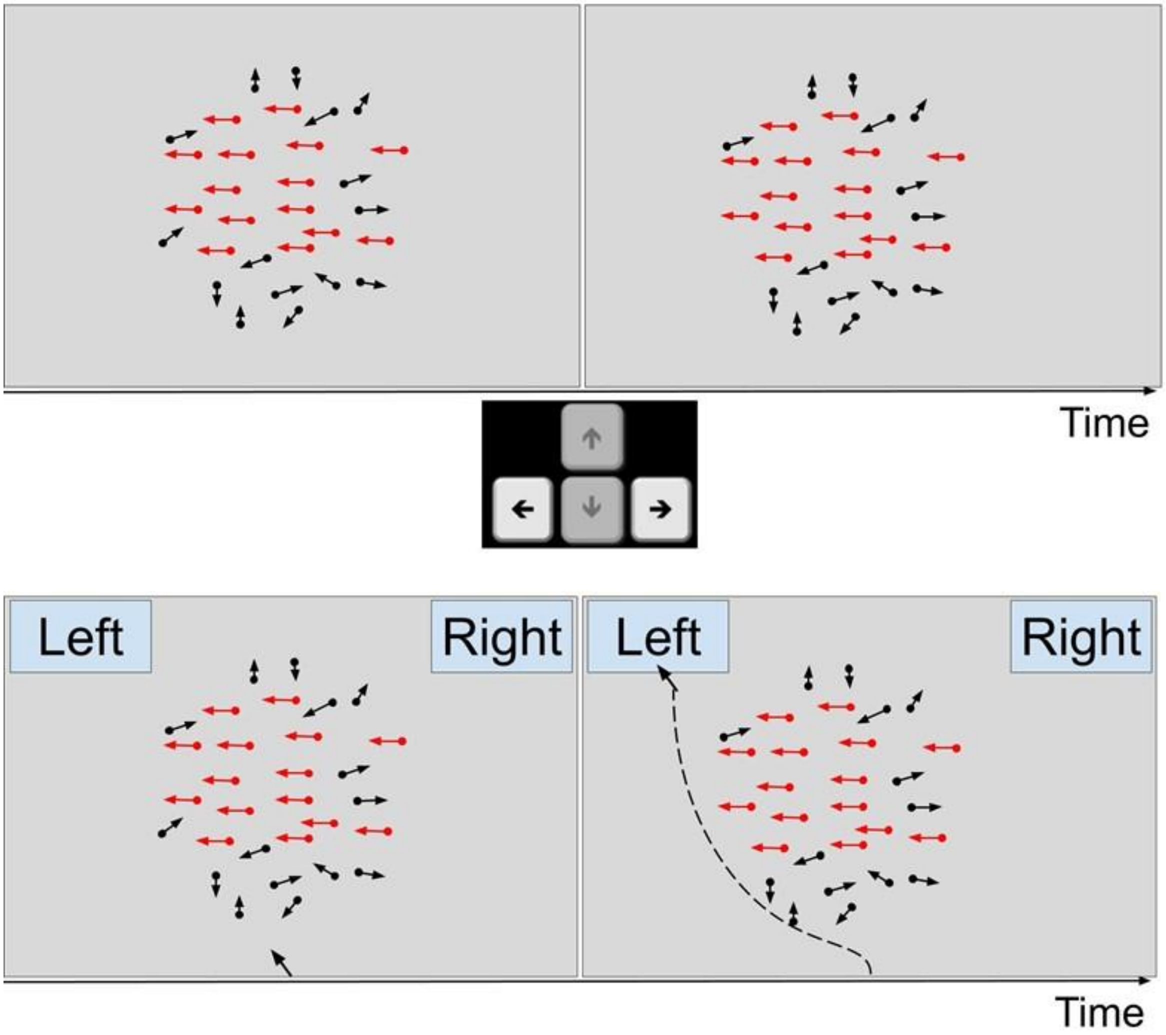

Figure 5. Stop-signal task in Study 1.
Note: Upper panel: keypress version. In the keypress version, the response is made by pressing the arrow keys on the keyboard. Lower panel: mouse movement version. In the mouse movement version, the response is made by moving a mouse and clicking on a response box. Red arrows indicate coherent dots.

The primary task, illustrated in Figure 5, was to indicate the direction the coherent dots are moving by pressing the left or right arrow key on the keyboard (keypress condition) or, in the mouse condition, clicking on a button drawn on the screen ("go" trials). In 25% of the trials (50 out of 200), participants were presented with an auditory stop-signal ("stop" trials); before the experiment, participants were instructed to cease their response if they hear the stop-signal. The delays after which the stop-signal is delivered were chosen randomly and uniformly from a predetermined set: 100, 200, 300, 400, 500, or 600 ms.

In the mouse-tracking condition, the mouse cursor was placed at the bottom-center of the screen (0, -0.8) at the beginning of each trial, where (0,0) is the center of the screen. The mouse cursor coordinates were recorded every 16 ms, starting at the beginning of the trial and continuing until either 3000 ms elapsed or a response was made (Leontyev and Yamauchi, 2019). The measures collected in the stop-signal task included accuracy as well as mean and standard deviation of response time in "go" and "stop" trials.

Based on accuracy and response times, I have also calculated the stop-signal reaction time (SSRT) – a common index of the inhibitory ability (Verbruggen and Logan, 2008). According to the independent horse-race model (Logan and Cowan, 1984), the process of response inhibition is a race between "go" and "stop" processes. "Go" processes are triggered by a "go" stimulus, while "stop" processes are triggered by a stop-signal. Whichever process finishes first determines whether the inhibition is successful ("stop" process finished first) or not ("go" process finished first). In other words, when go RT is longer than SSRT and stop-signal delay (SSD; go RT > SSRT + SSD; see Figure 6), the response is successfully inhibited. When go RT < SSRT + SSD, inhibition is unsuccessful, and the "go" response is erroneously emitted. Longer SSRTs are associated with ADHD (Crosbie et al., 2013), borderline personality disorder (Sebastian et al., 2013), and Parkinson's disease (Gauggel et al., 2004).

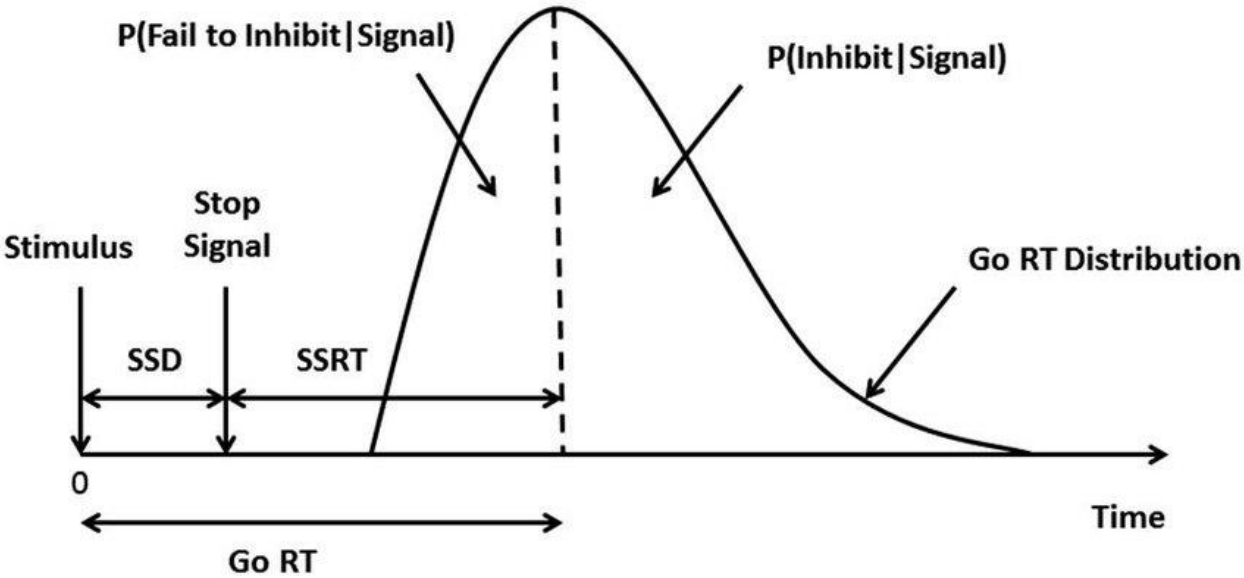

Figure 6. Horse-race model and calculation of the stop-signal reaction time (SSRT). ***Note: reprinted from Evans and Hampson, 2015.***

In addition to these measures, velocity, acceleration, total distance, and stopping distance of mouse movement were recorded using an R package *mousetrap* (Wulff et al., 2021), as these measures were shown to be indicative of impulsive action tendencies (Leontyev and Yamauchi, 2019, 2021; Leontyev et al., 2018).

Total distance was calculated by summing up the shortest distances between each of the successively recorded coordinates. Maximum velocity was estimated as the largest result of dividing each distance between successively recorded coordinates d (d_1, d_2, d_3 … d_n) by recording time t (~16 ms). Maximum acceleration was calculated as the largest difference between velocities on two adjacent segments d on the trajectory (e.g., $\frac{d_2}{t} - \frac{d_1}{t}$). The area under the curve (AUC) was calculated by subtracting the area below the ideal shortest distance between the starting point and a response button from the area above the shortest distance. Finally, the stopping distance was equal to the total distance that a cursor traveled after a stop-signal was delivered. Mouse measures are illustrated in Figure 7 and summarized in Table 4.

Table 4. Summary of SST measures in keypress and mouse movement conditions.

Condition	Measures
Key	SD RT, mean RT, accuracy in go and stop trials, direction discrimination accuracy, SSRT
Mouse	SD RT, mean RT, accuracy in go and stop trials, direction discrimination accuracy, mean acceleration, velocity, total distance in go and stop trials, SSRT, stopping distance

Note: SD = standard deviation; RT = response time; SSRT = stop-signal reaction time.

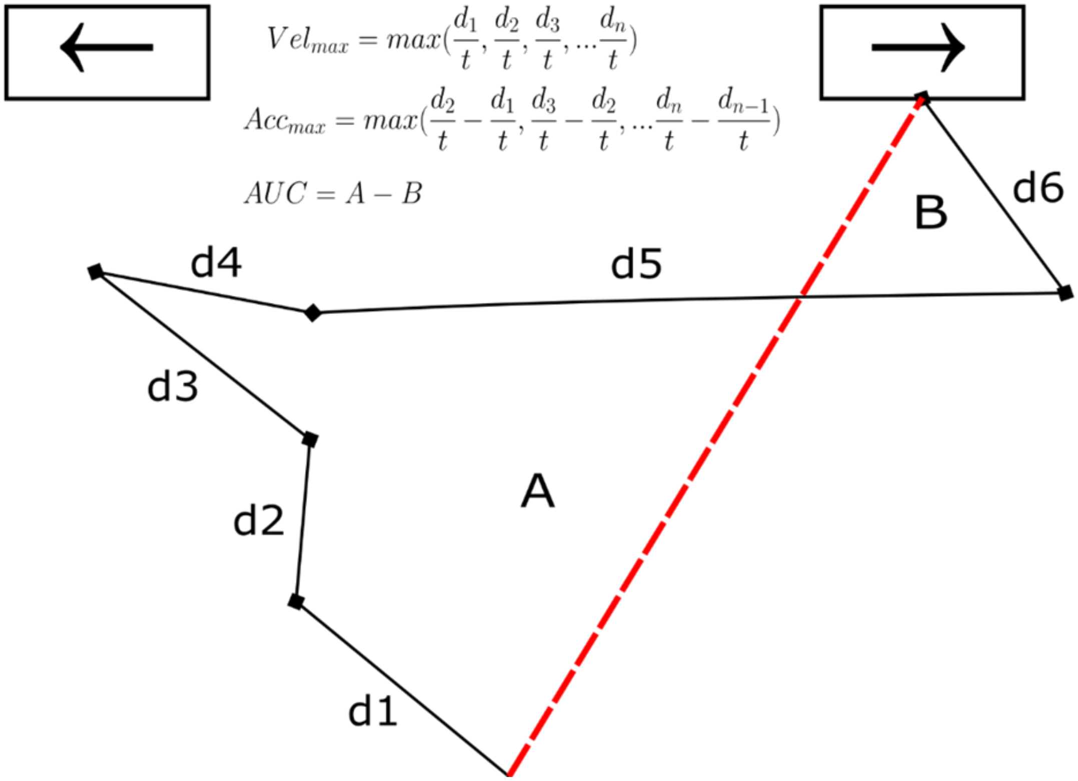

Figure 7. Calculation of mouse movement measures.
Note: The red dashed line shows the shortest path between the starting point and the response button. d1, d2, d3… d6 denote the shortest distances between successively recorded coordinates. AUC = area under the curve

As a measure of inattentiveness, I employed SD of maximum velocity in “go” trials in the stop-signal task as a mouse movement equivalent to the response time (Leontyev & Yamauchi, 2021). Performance in “go” trials (in the stop-signal and related tasks) is representative of one’s attentional control (Bocharov et al., 2021). For example, “go” accuracy in the Continuous Performance task is one of the best indicators of attentional deficits in ADHD (Berger et al., 2017). Likewise, “go” errors in a go/No-go task are indicative of inattentiveness among children (Bezdijan et al., 2009). Furthermore, the primary task in this experiment was a random dot kinematogram:

response times in a random dot kinematogram reflect an individual’s visual attention capacity (Hanning et al., 2019).

Delay discounting task. The present experiment employed the delay discounting task adapted from MacKillop et al. (2016). Participants were required to complete either keypress or mouse movement versions of the DDT (Figure 8). Participants were required to make a hypothetical monetary choice between an immediately available smaller reward and a larger reward available after a delay. Delay for the smaller/sooner option was held constant (immediately), while rewards were randomly and uniformly selected from $10, $20, $30, $40, $50, $60, $70, $80, $90, or $99. For the larger/later option, the reward amount was held constant at $100, while delays were chosen from 1, 7, 14, 30, 60, 90, 180, or 365 days.

Participants completed 90 trials in total, comprised of 80 trials representing all possible combinations of rewards and delays, and ten control trials in which both options were presented at no delay. In the keypress version, the choice was made using the keyboard keys: “L” for the larger option and “S” for the smaller option. In the mouse movement version, participants were required to make a selection by clicking on a button with options drawn on the screen. The positioning of an option on either left or right was randomly chosen at the beginning of each trial.

The discounting rate was calculated for each participant in accordance with the hyperbolic model:

$$V = \frac{A}{(1 + kD)^{\beta}}$$

In this model, *A* is the amount of reward, *V* is the subjective value of a reward, *D* is the delay associated with the reward, β is the choice temperature parameter (indicating choice consistency), and *k* is an individual's discounting rate (intertemporal impatience; Stillman & Freguson, 2019). The Bayesian delay discounting model was chosen because it allows for a more precise estimation of the discounting rate than traditional maximum likelihood estimation methods (Vincent, 2016). The R package *hBayesDM* (Ahn et al., 2017) was used to estimate the discounting rate.

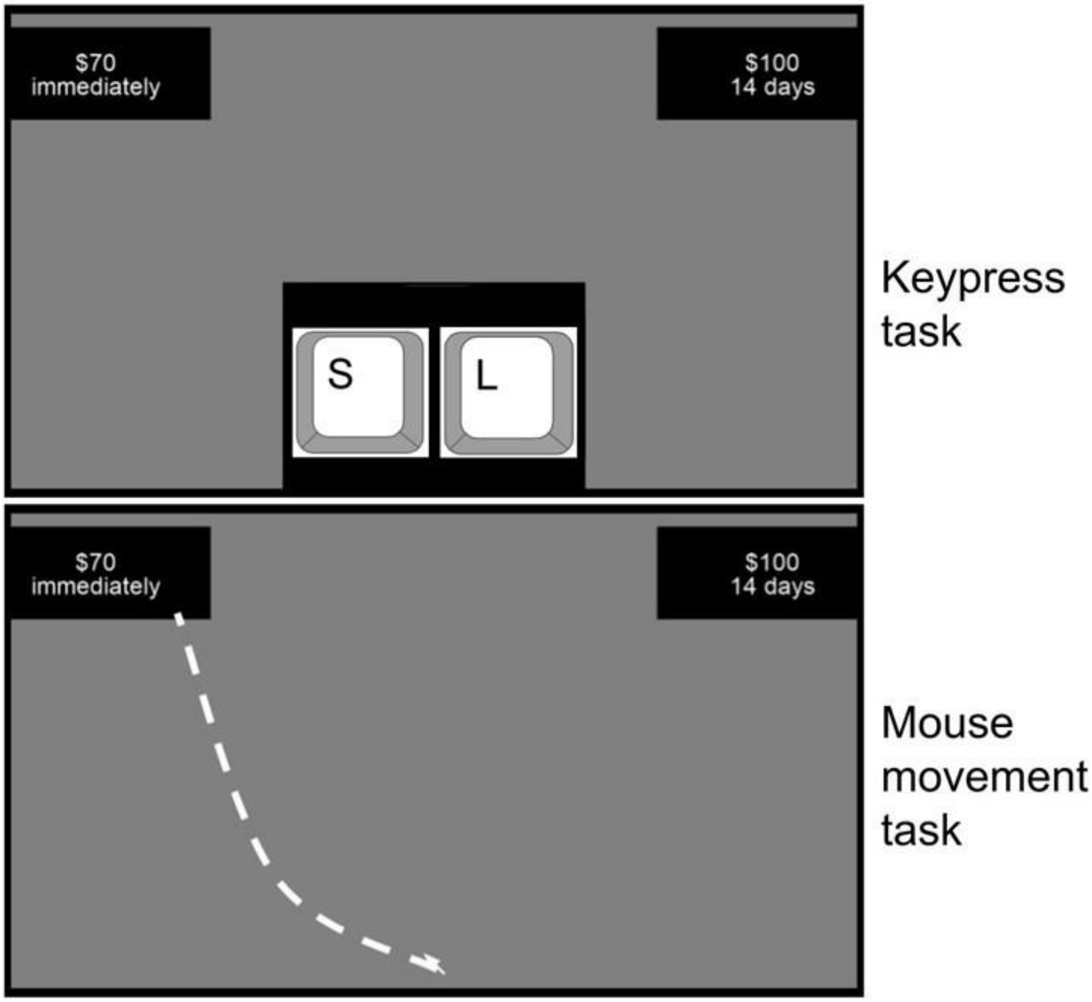

Figure 8. Delay discounting task.

Note: Upper panel: keypress version. In the keypress version, the response is made by pressing the "S" or "L" keys on the keyboard. Lower panel: mouse movement version. In the mouse movement version, the response is made by moving a mouse and clicking on a response box.

In addition to the discounting rate and choice consistency parameter, measures collected in DDT included velocity, acceleration, total distance, and area under the curve (AUC) of mouse movement. These measures were computed separately in trials with sooner-smaller and larger-later selection (see Figure 8). Table 5 summarizes the measures collected in both versions of the delay discounting task.

Table 5. Summary of DDT measures in keypress and mouse movement conditions.

Condition	Measures
Key	k, β
Mouse	k, β, acceleration, velocity, area under the curve

Note: k = delay discounting rate. β = choice consisentcy parameter.

Participants were presented with the Urgency-Premeditation-Perseverance-Sensation Seeking-Positive Urgency scale (UPPS), Emotional Reactivity Scale (ERS), Conners Adult ADHD Scale (CAARS), the Barratt Impulsiveness Scale (BIS-11), and the schizotypal personality questionnaire (SPQ).

Urgency-Premeditation-Perseverance-Sensation Seeking-Positive Urgency scale (UPPS). Urgency-Premeditation-Perseverance-Sensation Seeking-Positive Urgency scale (UPPS; Whiteside and Lynam, 2001) is a 59-item questionnaire designed to assess emotional impulsivity. UPPS has five scales: Negative Urgency, Positive Urgency (assess tendencies to act rashly under negative/positive emotions), Lack of Premeditation (assesses the tendency to act without forethought), Lack of Perseverance (assesses the ability to remain focused on a task), and Sensation Seeking (assesses the tendency to seek out novel experiences). Consistency measures (Cronbach's α) range from 0.83 to 0.89 for the four subscales. The questionnaire presents statements to which participants respond by indicating their agreement or disagreement on a scale from 1 to 4, with 1 being "agree strongly" and 4 being "disagree strongly," e.g., "I have a reserved and cautious attitude toward life."

Emotional Reactivity Scale (ERS).To gauge how intensely individuals tend to experience emotions, I used the Emotional Reactivity Scale (ERS). The Emotional Reactivity Scale, a 21-item questionnaire developed by Nock and colleagues (2008), has three subscales: Sensitivity, Arousal/Intensity, and Persistence. The three subscales describe an individual's sensitivity to emotions, the arousal that he/she experiences, and the persistence of emotions. The reliability indices range from 0.81 to 0.88; Cronbach's α =.94. Like UPPS, ERS presents participants with statements about themselves (e.g., My emotions go from neutral to extreme in an instant). A participant indicates how well a particular statement describes them by answering on the scale from 0 to 4 (0 = not at all like me, 4 = completely like me).

Conners' Adult ADHD Rating Scale (CAARS). Impulsivity is a core component of the attention deficit/hyperactivity disorder (Winstanley et al., 2006). Comorbid ADHD might exacerbate impulsive choice and impulsive action tendencies; to control for this possibility, I used Conners' Adult ADHD Rating Scale (CAARS). Conners Adult ADHD questionnaire – self-report long version (CAARS-S: L) is a widely accepted ADHD assessment tool. CAARS is a 66-item measure that asks participants to indicate how accurately the questionnaire's statements describe participants' personal feelings from the past two weeks until the present time. Responses are coded on a scale of 0 to 3. Higher scores represent a statement's stronger indication of a participants' current condition. Internal consistency estimates for CAARS range from 0.79 to 0.90 for all subscales (Conners et al., 1999).

Barrat Impulsiveness Scale (BIS-11). As a self-report measure of impulsive choice and impulsive action, I used the Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995). It has 30 items, organized into three subscales: Attentional (BIS-A), Motor (BIS-M), and Nonplanning (BIS-N) impulsivity. The items are descriptions of an individual, e.g., "I make-up my mind quickly." A participant must indicate how often a given statement describes them on a scale of 1 to 4, with 1 being "Rarely/Never" and 4 being "Almost Always/Always." Internal consistency estimates range from 0.79 to 0.83 (Reid et al., 2014).

Schizotypal personality questionnaire – brief revised (updated; SPQ-BRU). As Ragsdale and Bedwell (2013) show, individuals with elevated schizotypal traits often also show increased impulsive behaviors. To examine the relationship between impulsivity and schizotypy, we employed a schizotypal personality questionnaire – brief revised (updated; SPQ-BRU). SPQ-BRU is a 32-item questionnaire designed to assess an individual's schizotypal traits. The responses are given on a five-point scale, ranging from "strongly disagree" to "strongly agree." Higher scores indicate greater schizotypy. The SPQ-BRU has four factors: Cognitive-Perceptual, Interpersonal, Disorganized, and

Social Anxiety. Internal consistency scores range from 0.81 to 0.96 (Davidson et al., 2016).

2.2. Results

To investigate whether performances in DDT and SST are related through Negative or Positive Urgency, correlation and moderation analyses were used. Table 6 displays the average/SD of SST measures collected in keypress and mouse movement conditions. Table 7 displays the average/SD for DDT measures collected in the keypress and mouse movement conditions.

Table 6. Means and standard deviations for SST measures in the keypress and mouse conditions.

	Key		Mouse	
	Mean	SD	Mean	SD
Accuracy in “go”	0.90	0.12	0.90	0.15
Accuracy in “stop”	0.54	0.28	0.75	0.29
Mean RT in “go”	0.90s	0.30s	1.55s	0.36
Mean RT in “stop”	0.78s	0.26s	1.44s	0.42s
SD RT in “go”	0.28s	0.09s	0.35s	0.09s
SD RT in “stop”	0.26s	0.11s	0.35s	0.17s
SSRT	0.61	0.32	1.05	0.47

Note: RT is given in seconds

Table 7. Means and standard deviations for DDT measures in keypress and mouse conditions

	Key		Mouse	
	Mean	SD	Mean	SD

	Key		Mouse	
k	0.12	0.15	0.29	0.35
β	0.04	0.14	0.06	0.07

Note: k = delay discounting rate. *β* = choice consisentcy parameter.

Independent samples t-tests have shown significantly higher mean accuracy rate for “stop” trials in the mouse condition (M_{key} = 0.54, M_{mouse} = 0.74; *t* (333) = -6.68, *p* <.001), but no differences between key and mouse condition in mean “go” accuracy (*t* (352) = 0.56, *p* = 0.67). Significantly higher discounting rates in the mouse movement condition compared to the the keypress condition (M_{key} = 0.12, M_{mouse} = 0.28; *t* (278) = -5.96, *p* <.001) were observed. There were no differences in the choice consistency parameter (β; *t* (208) = -1.89, *p* = .05).

2.2.1. Are impulsive choice, impulsive action, and emotional impulsivity measures correlated with each other?

The focus of the correlation analysis is on the relationship between impulsive action and impulsive choice measures, namely, the discounting rate (*k*) and the choice consistency parameter (*β*). As Table 8 shows, measures collected in the mouse movement condition have stronger and more significant correlations with *k* or *β* than those in the keypress condition, both in terms of absolute values of the correlation coefficients and in the number of correlations that remained significant after controlling the false discovery rate .

Table 8. Spearman's correlation between SST and DDT measures

	DDT key			*DDT mouse*	
SST Key	*k*	*β*	*SST mouse*	*k*	*β*
Accuracy in "go"	**-0.34*****	0.18*	Accuracy in "go"	**-0.34*****	**0.27*****
DDA	**-0.24****	**0.24****	DDA	**-0.33*****	**0.29*****
Mean RT in "go"	0.08	0.14	Mean RT in "go"	**0.20****	-0.13
SD RT in "go"	**0.22****	**-0.22****	SD RT in "go"	**0.30*****	**-0.20****
Accuracy in "stop"	-0.10	0.20*	Accuracy in "stop"	**-0.26*****	**0.21****
Mean RT in "stop"	0.10	0.18*	Mean RT in "stop"	**0.19****	**-0.15***
SD RT in "stop"	**0.23****	-0.13	SD RT in "stop"	**0.22****	**-0.18***
SSRT	0.13	-0.08	SSRT	**0.38*****	**-0.31*****

Note: * *p* <.05, ** *p* <.01, *** *p* <.001. DDA = direction discrimination accuracy. SSRT = stop-signal reaction time. Values in bold face indicate surviving false discovery rate control (α = 0.05; Benjamini and Hochberg, 1995)

2.2.2. Variable selection

To construct the “Core Impulsive Action” and “Core Attentional Impulsivity” models, it is first necessary to identify what observed measures (i.e., questionnaires and performance indices) correspond to four latent constructs: attentional impulsivity, impulsive action, impulsive choice, and emotional impulsivity. To that end, a confirmatory factor analysis (CFA; Jacobucci et al., 2019) was conducted to find the behavioral measures that cluster under the four latent factors.

For impulsive action, we initially selected BIS-A (Barrat Impulsivity Scale – Motor subscale) as the major index of impulsive action and included additional behavioral measures (“stop” accuracy and stopping distance) that clustered with BIS-M. For impulsive choice, we selected delay discounting rate *k* and choice consistency parameter β obtained in the delay discounting task (Wilson and Collins, 2019; Odum, 2011), as well as BIS-Nonplanning (BIS-N) scores. For emotional impulsivity, we selected UPPS-Negative Urgency and UPPS-Positive Urgency (Whiteside and Lynam, 2001). For attentional impulsivity, we initially selected BIS-Attentional Impulsivity (BIS-A) scores and CAARS-Inattention (CAARS-A) scores as the major indices of impulsive attention and included additional behavioral measures (SD of velocity in “go” trials) that clustered with BIS-Attentional Impulsivity scores and CAARS-Inattention scores. All calculations were performed using R package *lavaan* (Rossell, 2012).

Latent factors in the “Core Impulsive Action” model. First, a three-factor model incorporating Impulsive action (IA), Impulsive choice (IC), and Emotional Impulsivity (EI) was fit to the mouse movement data.

In addition to the questionnaire measures of impulsive action (namely, Barrat Impulsiveness Scale Motor subscale, BIS-M), several behavioral measures of response inhibition were initially used as indicators of impulsive action: accuracy in “stop” trials (Broos et al., 2012), stop-signal reaction time (Verbruggen and Logan, 2008). In addition, stopping distance – a mouse movement measure of impulsive action well-correlated with other impulsivity measures (Leontyev et al., 2019) – was also included as an indicator. The initial model that included all four (SSRT, BIS-M, stopping distance, and “stop” accuracy) measures showed a poor fit: $\chi 2(24) = 65.81$, $p <.05$; SRMR = .07; CFI = .90; RMSEA = .09. After removing SSRT as an indicator, the model fit improved. The final model incorporated BIS-M scores, accuracy in “stop” trials, and stopping distance: $\chi 2(17) = 33.41$, $p <.05$; SRMR = .05; CFI = .96; RMSEA = .07).

Initial indicators of impulsive choice included two commonly used indices of impulsive behavior, discounting rate and choice consistency parameter β, as well as BIS-Nonplanning subscale scores. Following Dschemuchadse and colleagues, the area under the curve was also used as a mouse-movement measure of impulsive choice (Dschemudchadse et al., 2013). This model, however, showed a very poor fit: $\chi 2(24) = 124.12$, $p <.05$; SRMR = .11; CFI = .81; RMSEA = .14. After removing BIS-Nonplanning scores, the fit improved: $\chi 2(17) = 33.41$, $p <.05$; SRMR = .05; CFI = .96; RMSEA = .07.

Finally, Emotional Impulsivity factor included UPPS-Negative Urgency and UPPS-Positive Urgency scores as indicators. The final three-factor (IC, IA, EI) model indicated an acceptable fit: $\chi 2(17) = 33.41$, $p < .05$; SRMR = .05; CFI = .96; RMSEA = .07, with average factor loadings ranging from 0.39 to 0.80 (mean = 0.62). Initial and final "Core Impulsive Action" measurement models are illustrated in Figures 9 and 10.

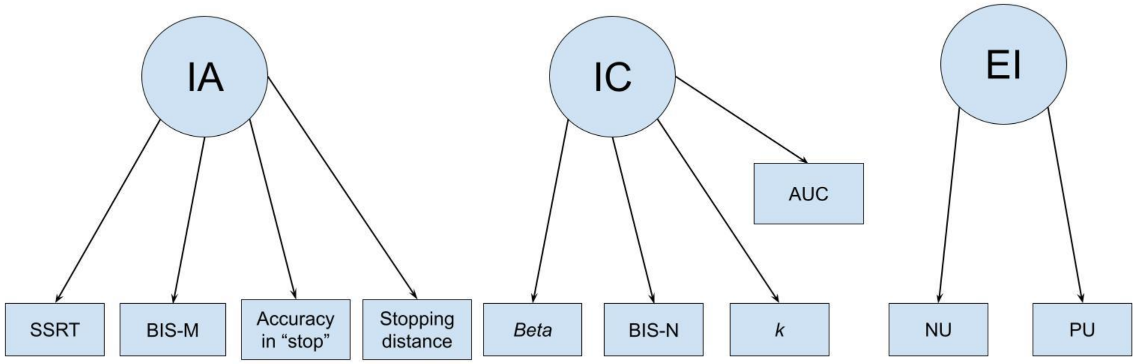

Figure 9. Initial "Core Impulsive Action" measurement model.

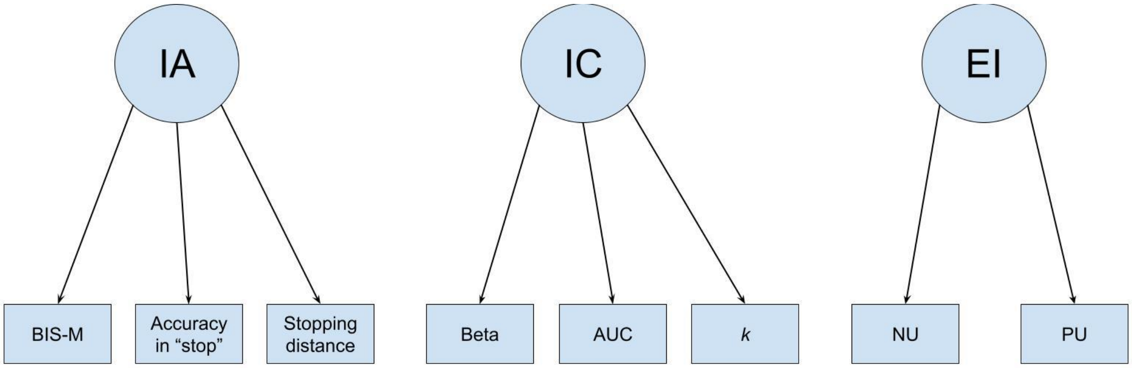

Figure 10. Final (revised) "Core Impulsive Action" measurement model.

<u>Latent factors in the "Core Attentional Impulsivity" model</u>. The "Core Attentional Impulsivity" model was largely based on the "Core Impulsive Action" model described above, with the addition of the Attentional Impulsivity (AImp) latent construct. EI, IC, and IA latent constructs remained the same as obtained in the final “Core Impulsive Action” model.

The candidate indicators for Attentional Impulsivity included BIS-Attentional Impulsivity scores, CAARS-Inattention scores, and random dot kinematogram direction discrimination accuracy (Felisberti and Zanker, 2005). As mouse movement equivalents to “go” RT (a measure of inattention in RDK; Levy et al., 2018), I considered velocity and acceleration “go” trials. Because variability in performance is sometimes a better indicator of attentional control than average performance (Hauser et al., 2016), standard deviations were used instead of means for velocity and acceleration.

The model with direction discrimination accuracy and acceleration in “go” trials showed a poor overall fit: $\chi2(48) = 136.36$, $p <.05$; SRMR = .08; CFI = .89; RMSEA = .08. After excluding direction discrimination accuracy and replacing acceleration with velocity, the final four-factor (IC, IA, EI, AImp) model showed a good fit: $\chi2(38) = 67.09$, $p <.05$; SRMR = .06; CFI = .96; RMSEA = .06. The average factor loadings ranged from 0.38 to 0.81 (mean = 0.61). Initial and final measurement models are illustrated in Figures 11 and 12.

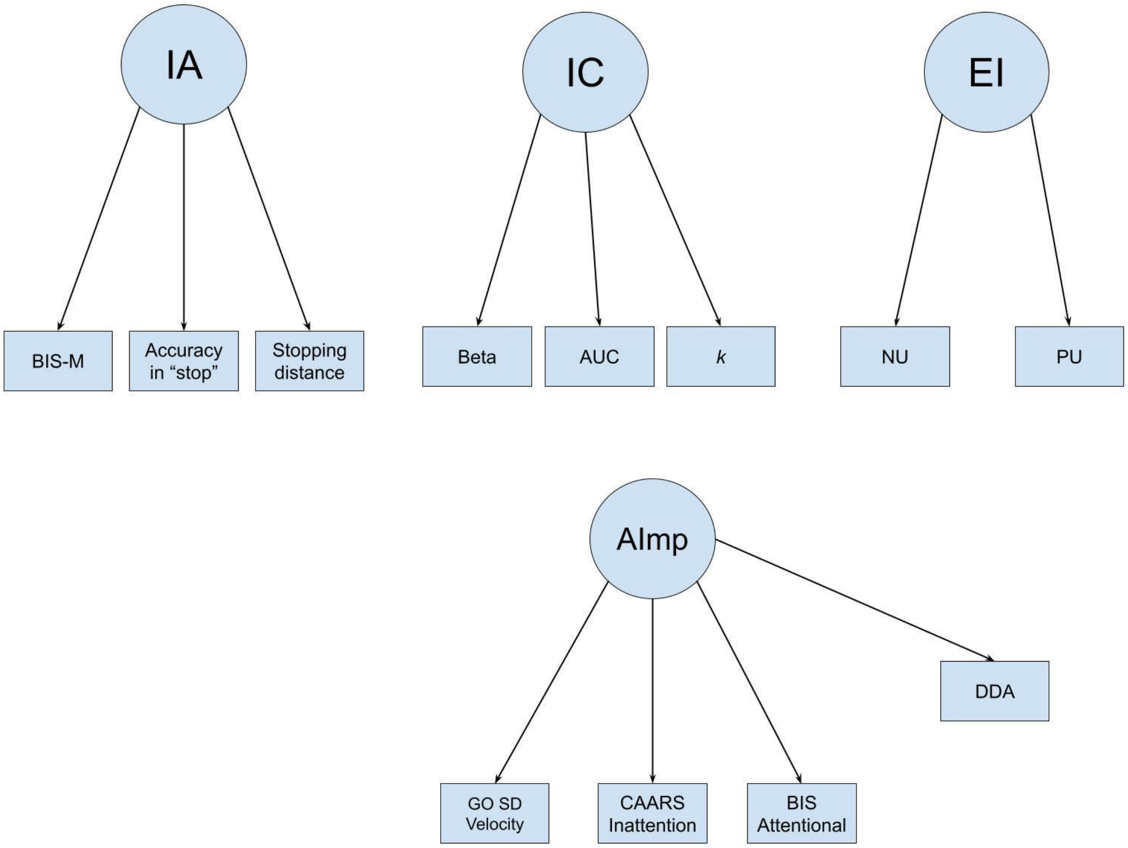

Figure 11. Initial "Core Attentional Impulsivity" measurement model.
Note: IA, impulsive action; IC, impulsive choice; EI, emotional impulsivity; AImp, attentional impulsivity

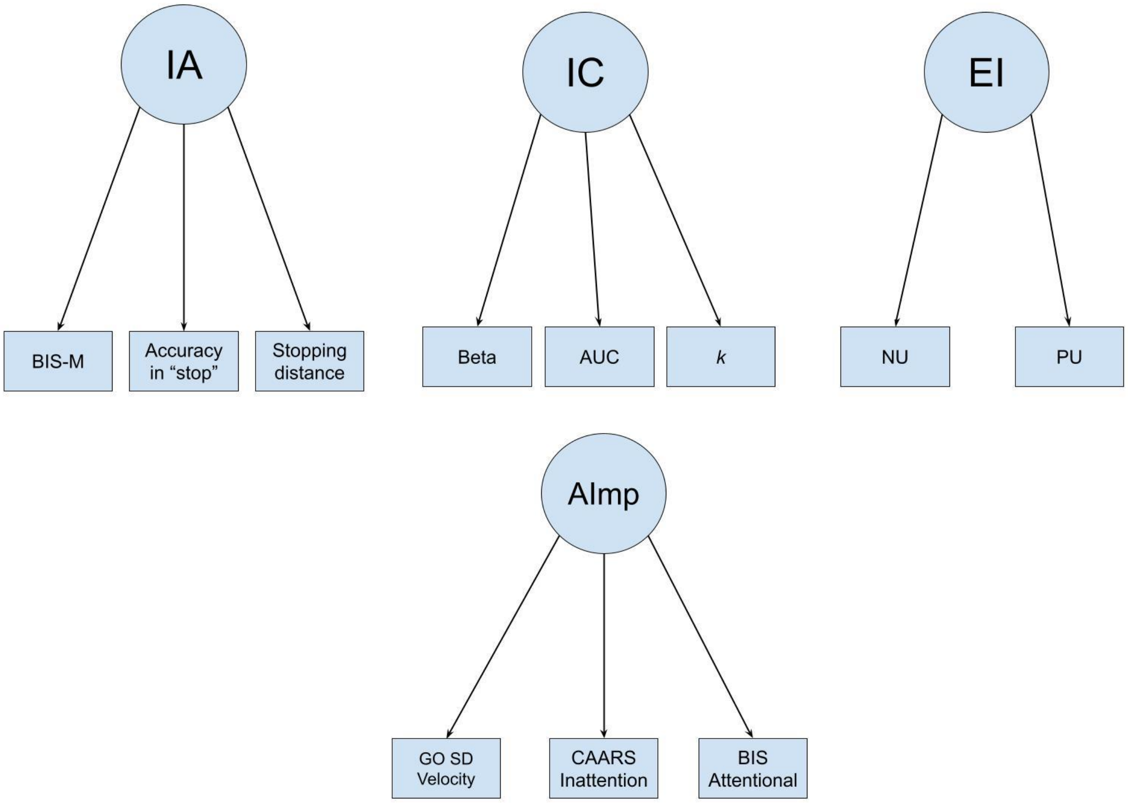

Figure 12. Final (revised) "Core Attentional Impulsivity" measurement model.

2.2.3. Structural Equation Modeling: Core Impulsive Action versus Core Attentional Impulsivity models

Is impulsive action or attentional impulsivity a better predictor of emotional impulsivity and impulsive choice? To answer this question, I compared structural equation models that correspond to “Core Impulsive Action” and “Core Attentional Impulsivity” accounts of impulsivity. As in confirmatory factor analysis, I employed R package *lavaan* (Rosseel, 2012).

“Core Impulsive Action” model. The “Core Impulsive Action” model is equivalent to the model proposed by Madole et al. (2020) (Figure 8, based on Madole et al., 2020 model shown in Figure 3A). This model places impulsive action (poor response inhibition) as the predictor for emotional impulsivity, which in turn predicts impulsive choice. If this model is sound, impulsive action should predict emotional impulsivity, and emotional impulsivity should predict impulsive choice (Figure 13).

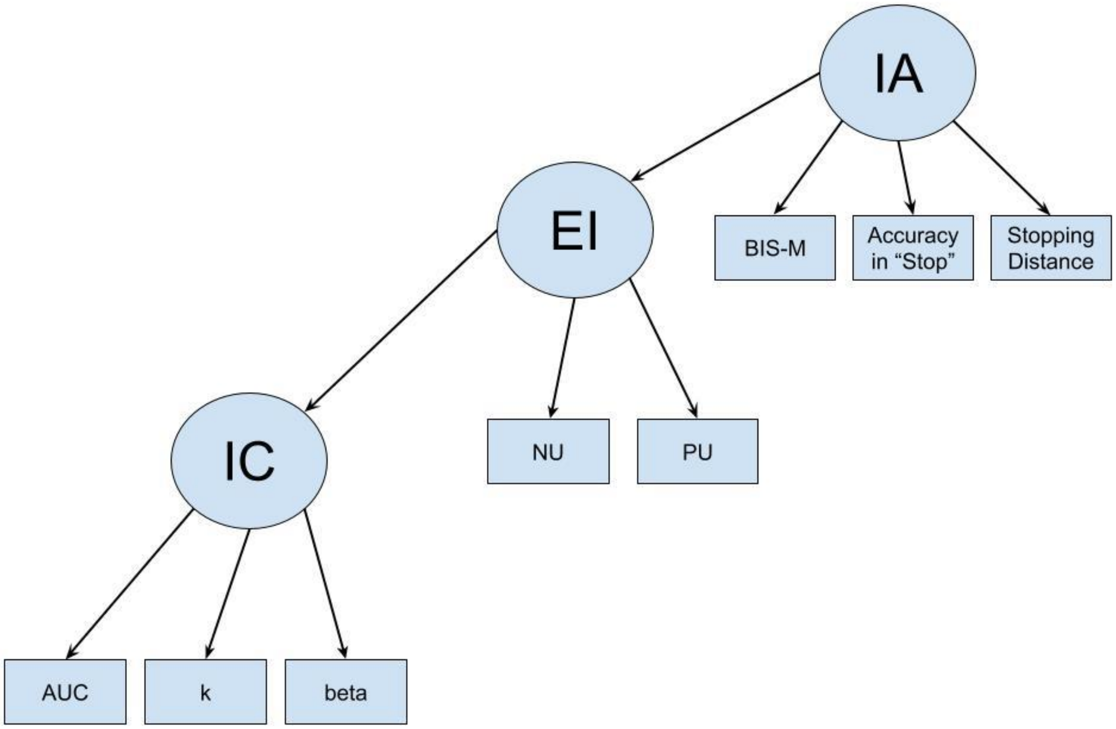

Figure 13. Hypothesized “Core Impulsive Action” model

The fit indices of the “Core Impulsive Action” model indicated an acceptable fit: $\chi 2(18) = 33.52$, $p < .05$; SRMR = .05; CFI = .96; RMSEA = .066, illustrated in Figure 14.

However, contrary to the predictions, the link between impulsive action and emotional impulsivity was not significant ($\beta = 2.42$, $p = .17$). Likewise, the link between emotional impulsivity and impulsive choice was not significant ($\beta = 0.18$, $p = .14$), suggesting that the “Core Impulsive Action” model fell short in accounting for the covariance structure of impulsive action, emotional impulsivity, and impulsive choice measures.

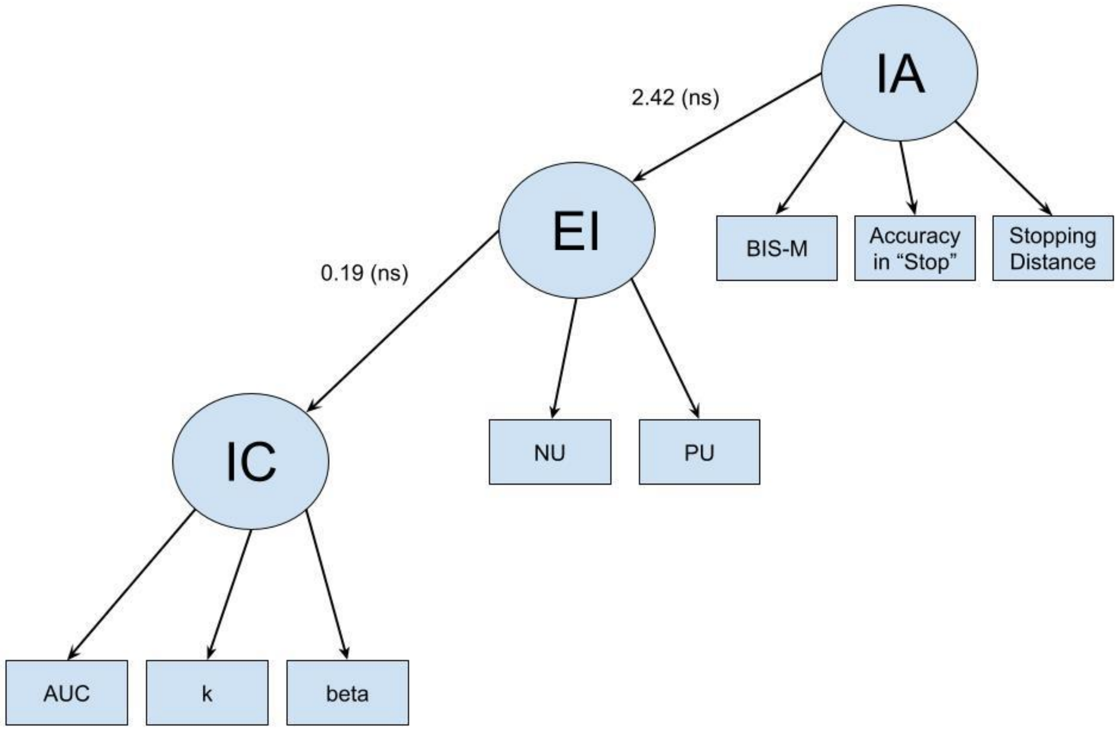

Figure 14. Final “Core Impulsive Action” model. ns = not significant.

<u>“Core Attentional Impulsivity” model</u>. The “Core Attentional Impulsivity” model, schematically illustrated in Figure 14, places attentional impulsivity as the predictor of emotional impulsivity and emotional impulsivity as the predictor of impulsive action and impulsive choice. This model is different from the "Core Impulsive Action" model in that attentional impulsivity plays a pivotal role for the general construct of impulsivity (emotional impulsivity, impulsive choice, and impulsive action). If this model is sound, impulsive attention should predict emotional impulsivity, and emotional impulsivity should predict both impulsive choice and impulsive action (Figure 15).

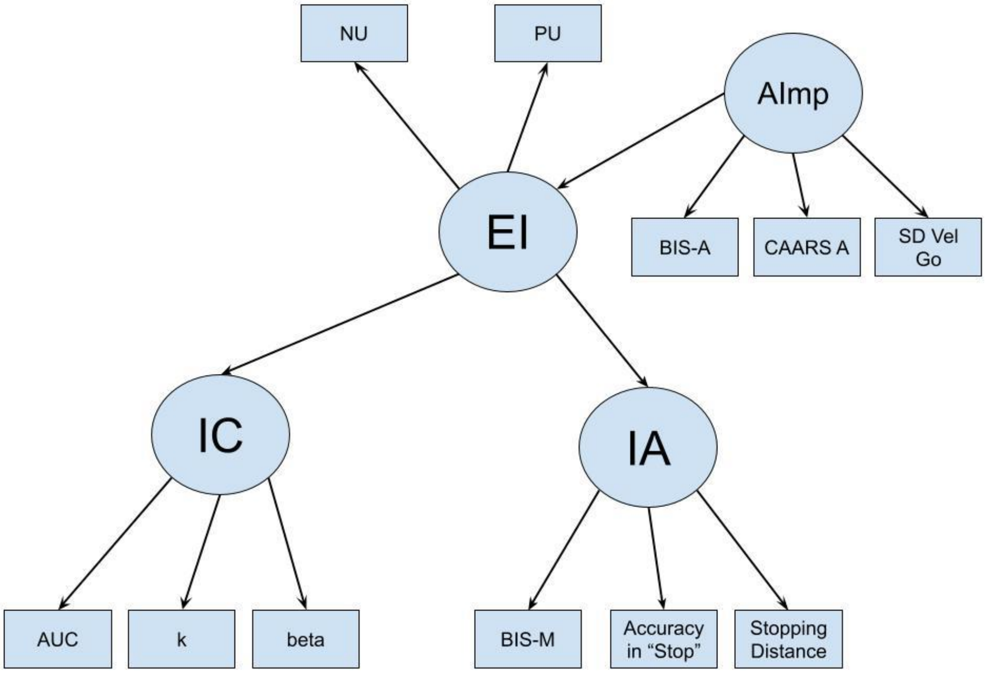

Figure 15. Hypothesized "Core Attentional Impulsivity" model

Consistent with the prediction, attentional impulsivity significantly predicted emotional impulsivity, which in turn predicted impulsive choice tendencies. However, emotional impulsivity did not significantly predict impulsive action (*β* = 1.15, *p* = .20). Instead, contrary to the initial hypothesis, impulsive action was correlated with emotional impulsivity and attentional impulsivity (illustrated in Figure 16).

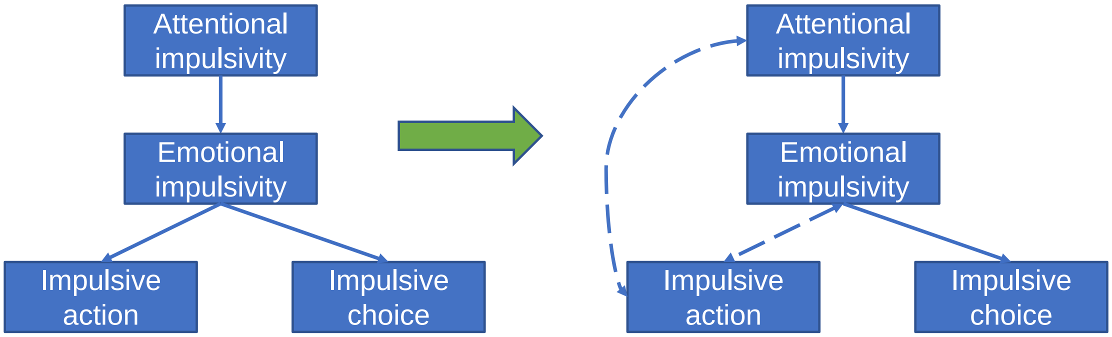

Figure 16. Revision of the "Core Attentional Impulsivity" model.
Note: Solid arrows indicate regressions. Dashed arrows indicate correlations.

Fit indices of the final "Core Attentional Impulsivity" model showed an acceptable fit: $\chi2(40) = 67.39$, $p < .05$; SRMR = .056; CFI = .96; RMSEA = .059. The final (revised) model is illustrated in Figure 16. In sum, structural equation modeling confirmed the predictions of the "Core Attentional Impulsivity" model. Altogether, our data favors the "Core Attentional Impulsivity " model.

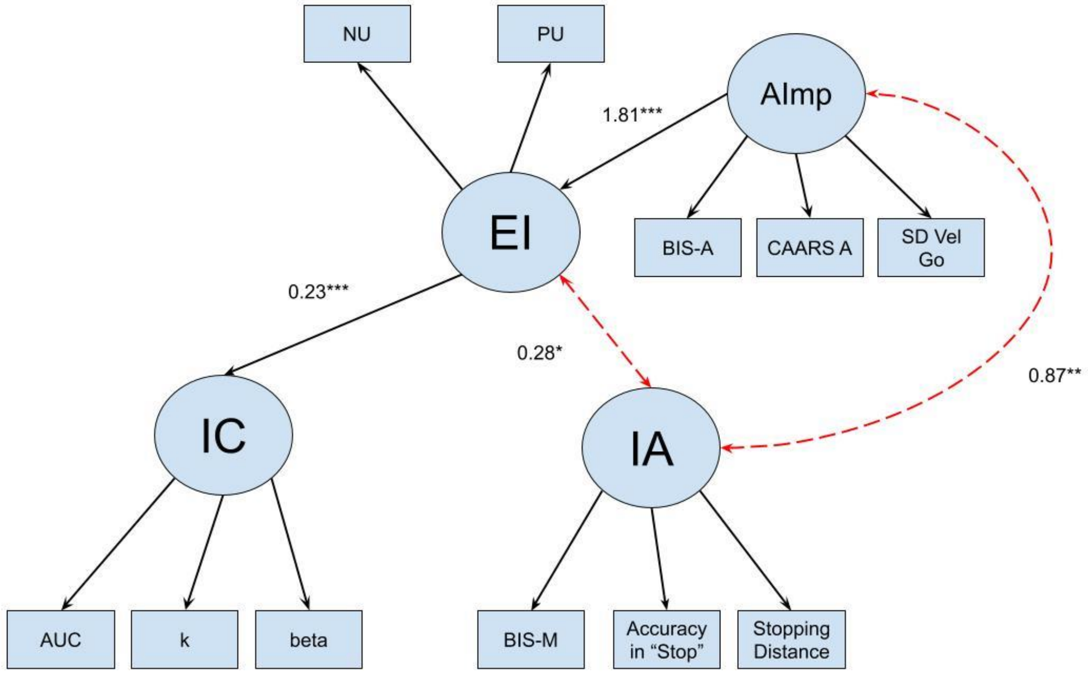

Figure 17. Final "Core Attentional Impulsivity" model.
Note: *p <.05, ** p<.01, ***p <.001. Red dashed lines indicate paths that were changed or added to the original "Core Attentional Impulsivity" model.

2.3. Discussion

In both the keypress and mouse movement conditions, I observed strong correlations between SST performance and delay discounting rates, although the mouse movement condition had the edge over the keypress condition. Specifically, mouse movement measures have more significant correlations with DDT performance after the false discovery correction; moreover, these correlations are stronger than in the keypress condition. This finding is consistent with our previous studies (Leontyev and Yamauchi, 2019; Leontyev et al., 2018; Leontyev et al., 2019), highlighting the advantages that mouse movement design has over traditional keypress design.

Interestingly, these advantages are apparent in response time and accuracy-based measures. One possible explanation is that because responding by moving a mouse takes a longer time, participants hesitate more and reassess their decision to respond. In other words, the mouse tracking design allows participants to show their individual differences in perseverance in responding. Perseverance is frequently highlighted as one of the facets of impulsivity; future research should explore perseverance as a possible contributor to impulsive choices, impulsive action, and inattention.

Structural equation modeling showed the clear advantage of the Attentional Impulsivity model (“Core Attentional Impulsivity”) over the Response Inhibition (“Core Impulsive Action”) model. As the results show, the predictor of emotional impulsivity is the inability to sustain attention, evidenced by significant relationships between attentional impulsivity, emotional impulsivity, and impulsive choice. Parallel to Madole et al. (2020), these results also suggest that deficits in response inhibition (impulsive action) are not a predictor of emotional impulsivity but rather are a correlate of emotional impulsivity (Figure 18).

In Study 2, I further contrasted the adequacy of “Core Impulsive Action” and “Core Impulsive Attention” models experimentally. As in Study 1, participants carried out SST and DDT. Unlike Study 1, however, I elicited positive and negative emotions while subjects were completing SST and DDT.

Figure 18. Changes in the "Core Attentional Impulsivity" model.

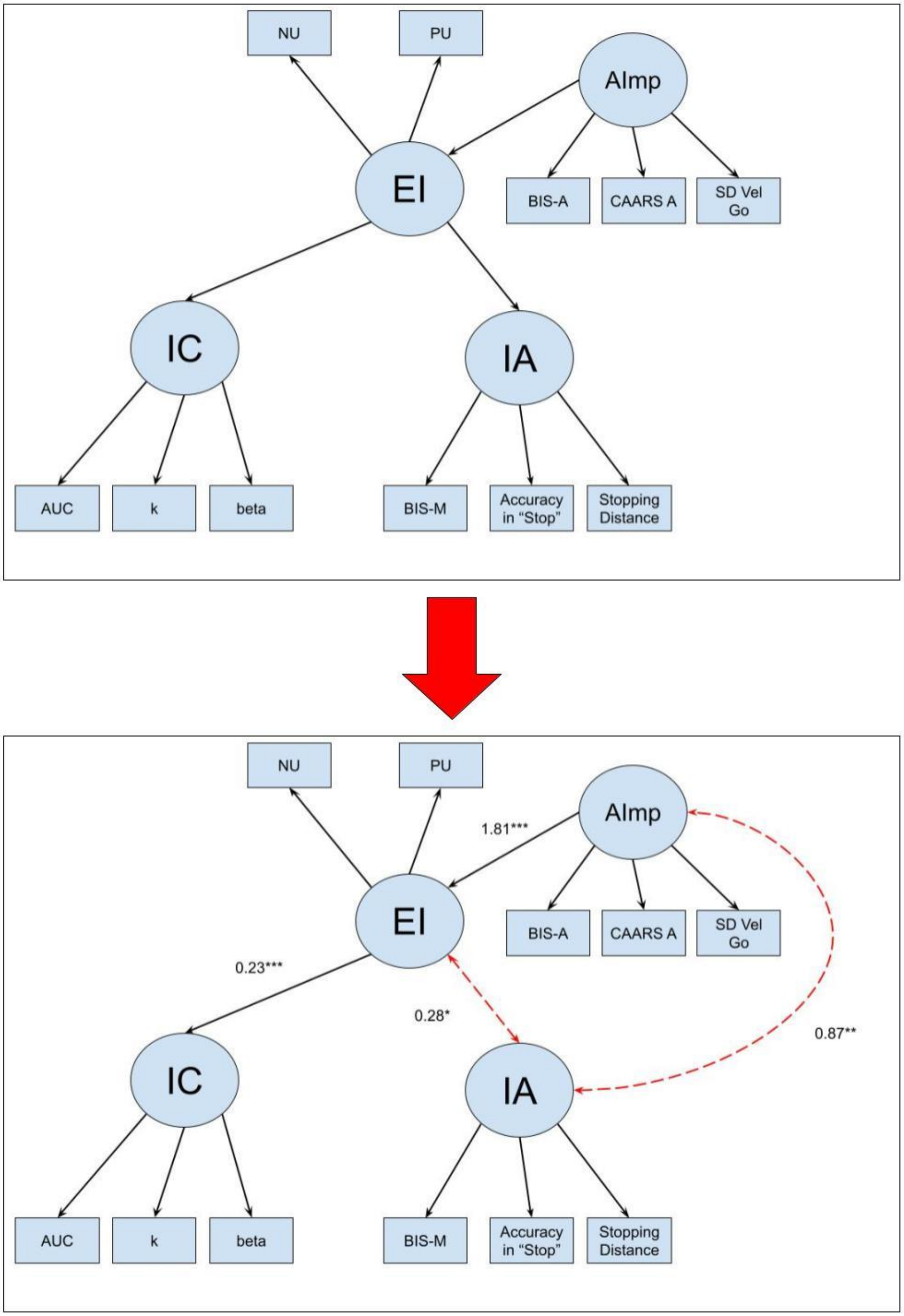

Figure 18. Changes in the "Core Attentional Impulsivity" model.

3. STUDY 2: TESTING ATTENTIONAL IMPULSIVITY EXPERIMENTALLY

The purpose of Study 2 was to experimentally test the “Core Impulsive Action” and “Core Attentional Impulsivity” models. I used nearly the same SST and DDT, as in Study 1, with minor changes: the participants had emotions elicited using standardized emotional pictures (the International Affective Picture System, IAPS, and Open Affective Standardized Image Set, OASIS; Bradley and Lang, 2017; Kurdi et al., 2017). Participants viewed pleasant (high-valence), unpleasant (low-valence), or neutral emotional pictures during the stop-signal and delay discounting tasks (Figure 19). As indicators of attentional impulsivity, impulsive action, and impulsive choice, I used the behavioral measures confirmed by Study 1 to represent the aforementioned constructs. Specifically, I employed velocity in “go” trials as the primary measure of attentional impulsivity, stopping distance as the measure of impulsive action, and delay discounting rate as the measure of impulsive choice.

If the core deficit in emotional impulsivity is impulsive action, participants’ SST performance (IA) should have deteriorated in trials that embed emotional stimuli compared to emotionally neutral stimuli. That is, participants should show longer stopping distance and less “stop” accuracy in the emotional condition. Alternatively, if the core deficit in emotional impulsivity is inattention, we expect to see significantly higher inattention measures (i.e., more variability in velocity in go trials) in the emotional condition but no difference in impulsive choice/action measures.

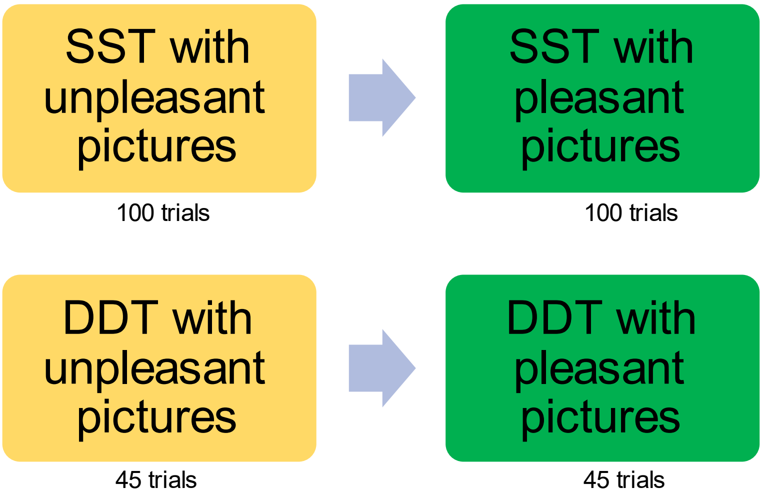

Figure 19. Order of tasks in Study 2.
Note: Participants completed SST and DDT in a fixed order. Within SST and DDT, the order of pleasant/unpleasant blocks was determined randomly for each participant.

3.1. Methods

3.1.1. Participants

A total of 78 individuals were recruited from the Texas A&M Psychology SONA subject pool for a course credit. Forty-eight of these individuals indicated their gender as female and 30 as male. Following my previous studies (Leontyev et al., 2019), I excluded the participants who failed to achieve at least 5% stop accuracy and 5% direction discrimination accuracy either in the emotional or neutral condition. The final sample included 61 individuals (35 females and 26 males). Table 11 describes participants' mean and standard deviation of ages.

Table 9. Mean and SD of participants' ages

	N	*Age*
Total	61	18.79 (1.17)
Female	35	18.8 (1.37)
Male	26	18.8 (0.85)

3.1.2. Procedure

The experiment consisted of two sessions (emotional and neutral), separated by one week. All participants took part in both sessions. Each participant experienced emotional and neutral conditions. Within the emotional condition, each participant was exposed to pleasant and unpleasant stimuli. The order of pleasant and unpleasant emotional picture blocks was determined randomly for each participant. The order of sessions was also randomized so that participants had an equal chance of being assigned to one of the conditions described in Table 10:

Table 10. Conditions for Study 2.

Conditions	**1st session**	**2nd session**
A	Emotional tasks	Neutral tasks
B	Neutral tasks	Emotional tasks

In the emotional session, participants first carried out the stop-signal task (200 trials total), presented in two blocks: one block (100 trials) contained pleasant pictures, while the other (100 trials) contained unpleasant pictures. The order of the blocks within the SST was determined randomly for each participant. Each block was followed by the

PANAS-X questionnaire. Then, participants completed the delay discounting task (90 trials, presented in two blocks of 45 trials). Likewise, each block was followed by the PANAS-X questionnaire. Figure 20 shows an example succession of SST, DDT, and PANAS-X blocks. After completing SST, DDT, and PANAS-X, participants also completed the UPPS questionnaire. The neutral condition was identical except that all stimuli were neutral.

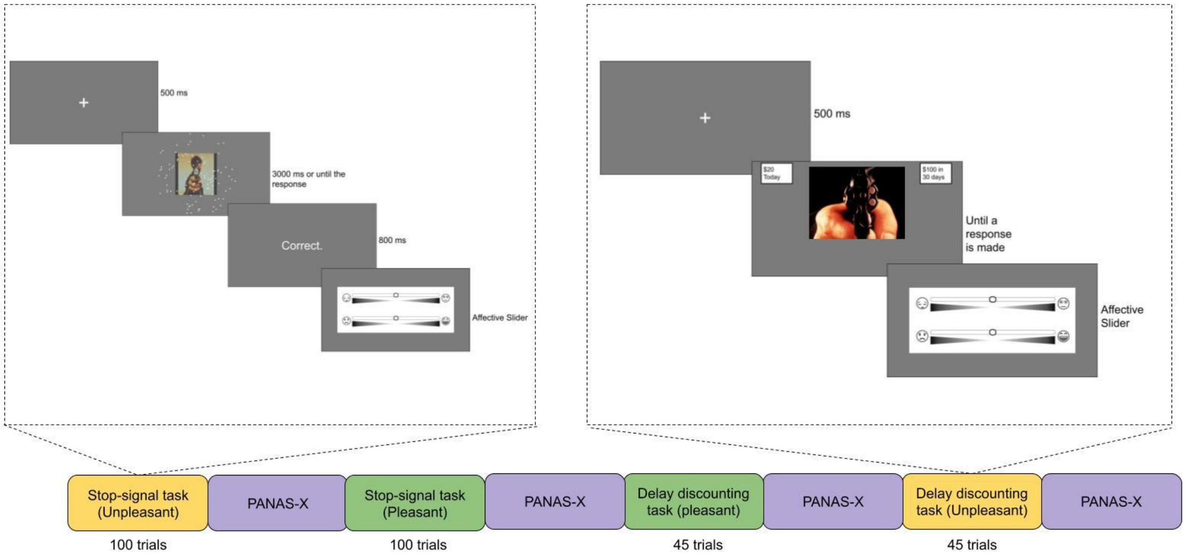

Figure 20. Example succession of SST and DDT task blocks and PANAS-X in the emotional condition.
Note: in this example, a participant first completed the SST block with unpleasant pictures, followed by the SST block with pleasant pictures. In the delay discounting task, the block with the pleasant pictures was delivered first, followed by the block with unpleasant pictures. All participants completed SST first, then DDT; the order of pleasant/unpleasant blocks was randomly determined for each participant.

Stop-signal task. The mouse movement version of the stop-signal task from Study 1 was used, except that the trials were presented in two blocks of 100 trials, 200 trials total; 80% of the trials were “go” trials and 20% “stop” trials. An emotional picture was shown in the background of each trial. In the emotional condition, each block contained either pleasant (high-valence) or unpleasant (low-valence) pictures. In the neutral condition, both blocks contained only neutral pictures. At the end of each trial, participants rated their arousal and valence using the Affective Slider (Figure 22). At the end of each 100-trial block, participants were asked to complete the Positive and Negative Affect Schedule questionnaire (PANAS-X; illustrated in Figure 21).

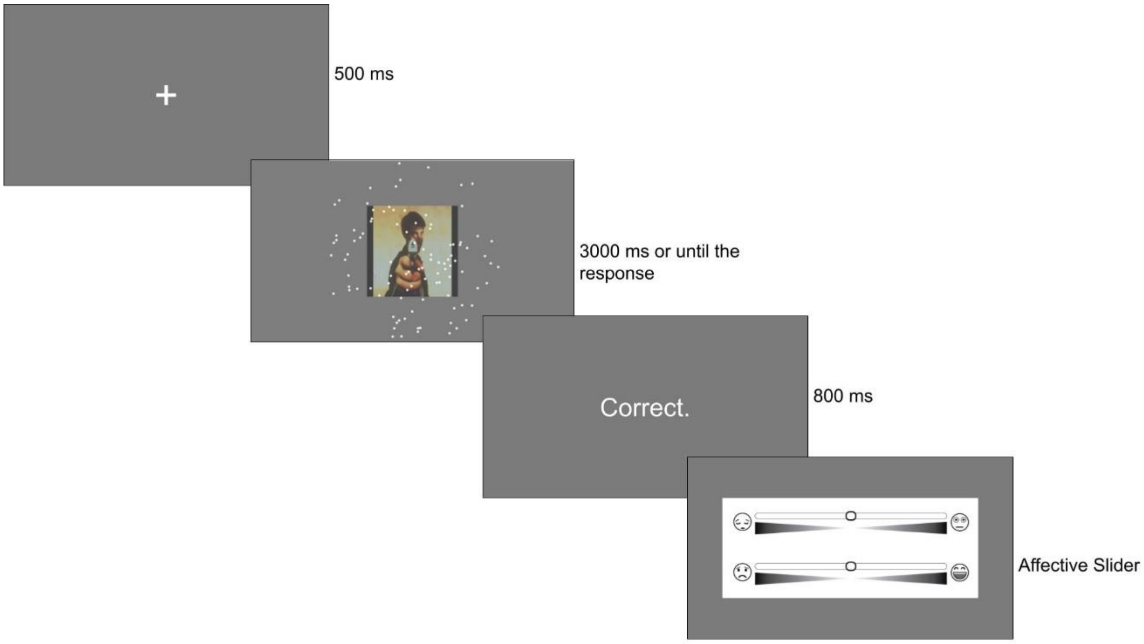

Figure 21. Example trial in the stop-signal task in the emotional condition.

Delay discounting task. The mouse movement version of the delay discounting task design from Study 1 was used with one modification: the task was presented in two blocks of 45 trials. In each trial, an emotional picture was shown in the background while completing the delay discounting task (Figure 22). In the emotional condition, these blocks contained either pleasant or unpleasant stimuli; in the neutral condition, the blocks contained only neutral pictures. At the end of each trial, participants indicated their arousal and valence using the Affective Slider; at the end of each 45-trial block, participants also completed the PANAS-X questionnaire (illustrated in figure 20).

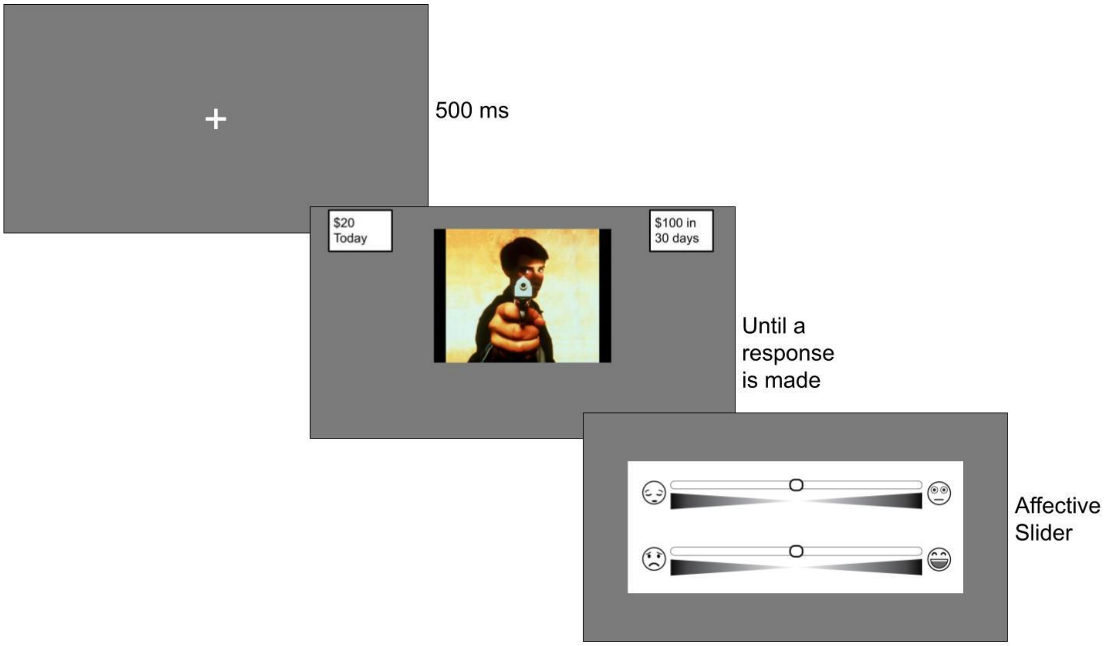

Figure 22. Example trial in the delay discounting task in emotional condition.

3.1.3. Materials

Emotional stimuli. During the stop-signal or delay discounting task blocks, participants also observed emotional images. Each picture was presented for the duration of the trial, followed by the Affective Slider (AS, discussed below). The emotional pictures were chosen from the International Affective Picture System (IAPS). The IAPS contains 1195 pictures (JPEG format) with varying emotional content; these pictures were confirmed to elicit emotions (Uhrig et al., 2016). Based on the reported arousal and valence, eighty pictures were selected for this study. Stimuli for high- and low-valence blocks were selected from upper-right and upper-left red dashed “squares,” respectively, as illustrated in Figure 23. For the neutral condition, 290 stimuli were chosen from the dark-colored middle square.

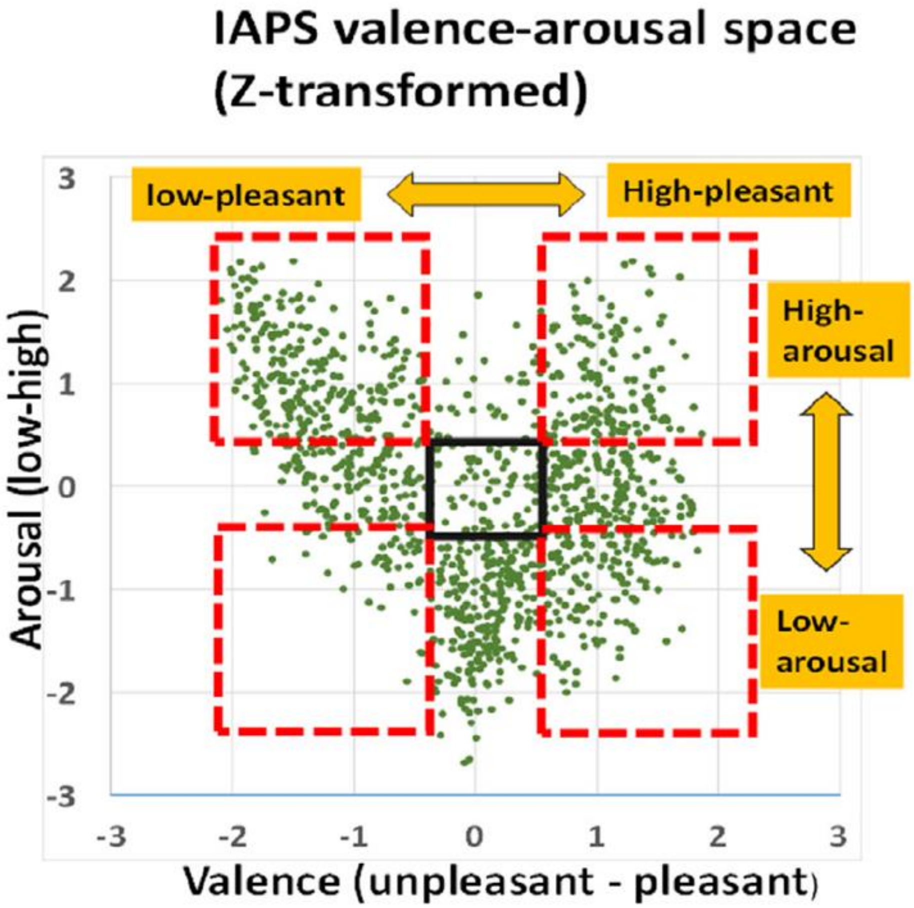

Figure 23. Distribution of IAPS pictures in arousal-valence space.
Note: Each dot represents an emotional stimulus. Reprinted from Yamauchi and Xiao, 2018

Because IAPS did not contain enough sufficiently arousing stimuli to be presented in each stop-signal task trial, I supplemented these stimuli with pictures from the Open Affective Standardized Image Set (OASIS; Kurdi et al., 2017), which contains 900 emotional images. These images are mapped on two dimensions: valence (pleasantness/unpleasantness of an image) and arousal (the intensity of emotional response that a given image evokes). 120 stimuli from the emotional condition were selected from the upper-right and upper-left dashed rectangles based on their arousal and valence; for the neutral condition, sixty stimuli were selected from the central area (Figure 24).

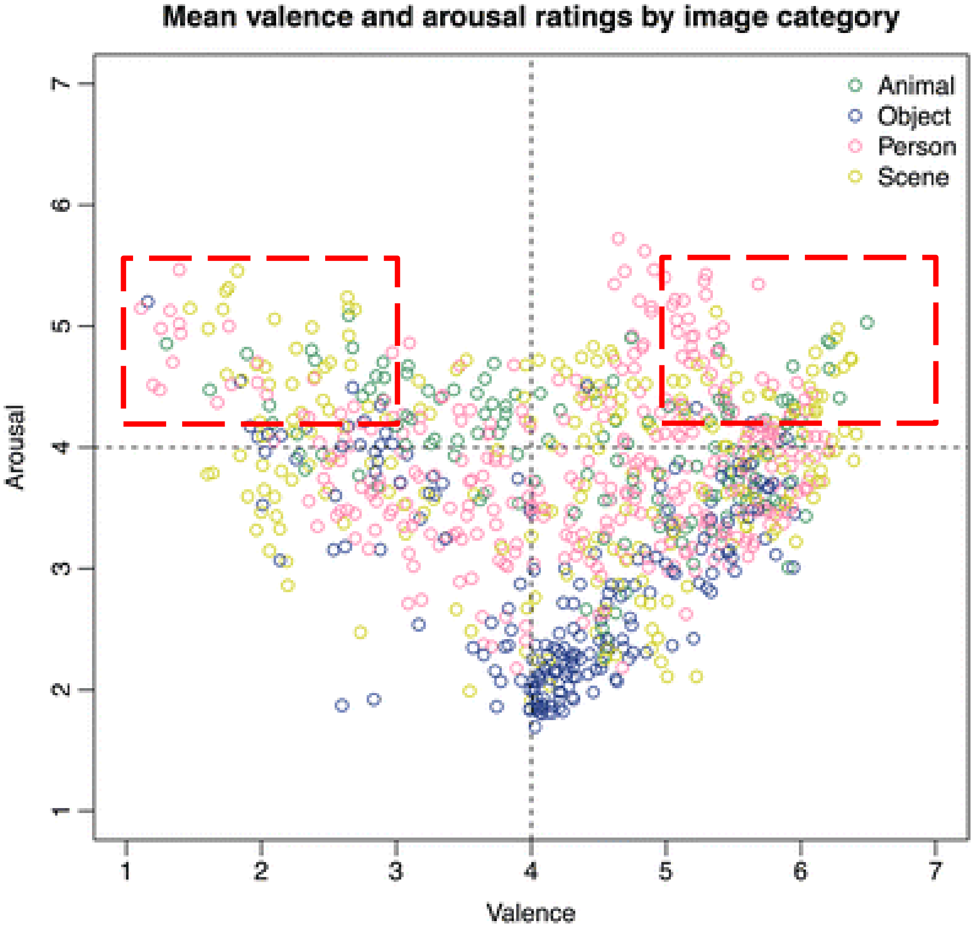

Figure 24. Distribution of OASIS pictures in arousal-valence space.
Note: Each dot represents an emotional stimulus. Reprinted from Kurdi et al., 2017.

In addition to UPPS, two self-report (PANAS-X and Affective Slider) measures were utilized to assess how emotional stimuli modulate arousal and affect.

Positive and Negative Affect Schedule – Extended Form (PANAS-X). Positive and Negative Affect Schedule – Extended Form (Watson and Clark, 1994) is a 60-item self-report questionnaire designed to measure positive and negative affect. The scales consist of different phrases and words (e.g., “dissatisfied with self”) that describe feelings and emotions that a participant might have experienced in the past few weeks. Participants rate how accurately a word or phrase describes their feeling from 1 (very slightly or not at all) to 5 (extremely). PANAS-X measures two higher-order scales (Positive and Negative Affect) and 11 specific affects: Fear, Sadness, Guilt, Hostility, Shyness, Fatigue, Surprise, Joviality, Self-Assurance, Attentiveness, and Serenity. Internal consistency coefficients range from .83 to .90 for the Positive Affect scale and from .84 to .91 for the Negative Affect scale.

Affective slider (AS). Affective Slider (Betella and Verschure, 2016) is a computer-based self-report tool that allows one to quickly assess an individual’s subjective pleasure and arousal associated with an emotional stimulus via two digital sliders. Affective slider has been validated to produce results similar to the Self-Assessment Manikin (SAM; Betella and Verschure, 2016). AS’ reliability estimates range from 0.87 to 0.93 (Imbault et al., 2018).

3.1.4. Design

Study 2 employed a within-subjects design. To test the “Core Impulsive Action” theory, we applied paired t-tests comparing metrics of impulsive action (stopping distance and accuracy in “stop” trials) contrasted emotional and neural conditions obtained in the SST. To test the Core Attentional Impulsivity model, we applied paired t-test comparing metrics of attentional impulsivity (mean and SD of velocity in “go” trials). Further, in order to examine the impact of emotion on impulsive choice, we compared the delay discounting rate and choice consistency parameter (impulsive choice metrics) obtained in emotion and neutral conditions in DDT.

If the “Core Impulsive Action” view is valid, impulsive action measures (i.e., accuracy in “stop” trials and stopping distance) should be higher in the emotional condition compared to the neutral condition. In contrast, if the “Core Attentional Impulsivity” is valid, attentional impulsivity measures (i.e., SD velocity in “go” trials) should be higher in the emotional condition but not impulsive action measures.

Additionally, both “Core Impulsive Action” and “Core Attentional Impulsivity” models predict that emotion impact impulsive choice; that is, discounting rate (k) and choice consistency measure (β) should be higher in the emotional condition than in the neutral condition.

Further, to test “Core Impulsive Action” and “Core Attentional Impulsivity,” I employed moderation analysis. If the “Core Impulsive Action” theory is sound, emotional impulsivity is expected to moderate the relationship between impulsive action (i.e., stopping distance or accuracy in “stop” trials) and impulsive choice (i.e., discounting rate). Alternatively, if the “Core Attentional Impulsivity” theory is valid, emotional impulsivity should moderate the relationship between attentional impulsivity (SD velocity in “go” trials) and impulsive choice.

3.2. Results

3.2.1. Manipulation check

I first examined whether the emotion elicitation was effective. This analysis showed that 1) emotional stimuli produced an immediate change in affect; 2) this change was not limited to a given trial and persisted throughout SST and DDT.

Arousal. Repeated measures ANOVA indicated that, irrespective of a task, participants rated pleasant pictures as more arousing than neutral or unpleasant. There was a significant effect of stimulus type (pleasant/neutral/unpleasant) on participants' arousal ratings (F (2, 120) = 5.32, p =.007, MSE = 0.02, η^2 = 0.05). Post-hoc comparisons with Tukey correction, collapsing across tasks (SST/DDT), show significantly higher arousal in trials with pleasant pictures compared to neutral (t(60) = 3.58, p = .002) or to unpleasant pictures (t(60) = 3.64, p = .002). No significant difference in arousal was observed between trials with neutral and unpleasant stimuli (t (60) = 1.67, p = .22). There was no significant effect of task (F (1, 60) = 0.77, p =.39, MSE = 0.006, η^2 = 0.00), nor an interaction between task and stimulus type (F (2, 120) = 0.04, p =.95, MSE = 0.003, η^2 = 0.00) (Figure 25 and Table 11).

Table 11. Mean Affective Slider – Arousal scores

Task	Stimulus Type	Mean	SD
SST	Pleasant	0.42	0.18
	Unpleasant	0.31	0.24
	Neutral	0.35	0.20
DDT	Pleasant	0.43	0.20
	Unpleasant	0.31	0.28
	Neutral	0.35	0.21

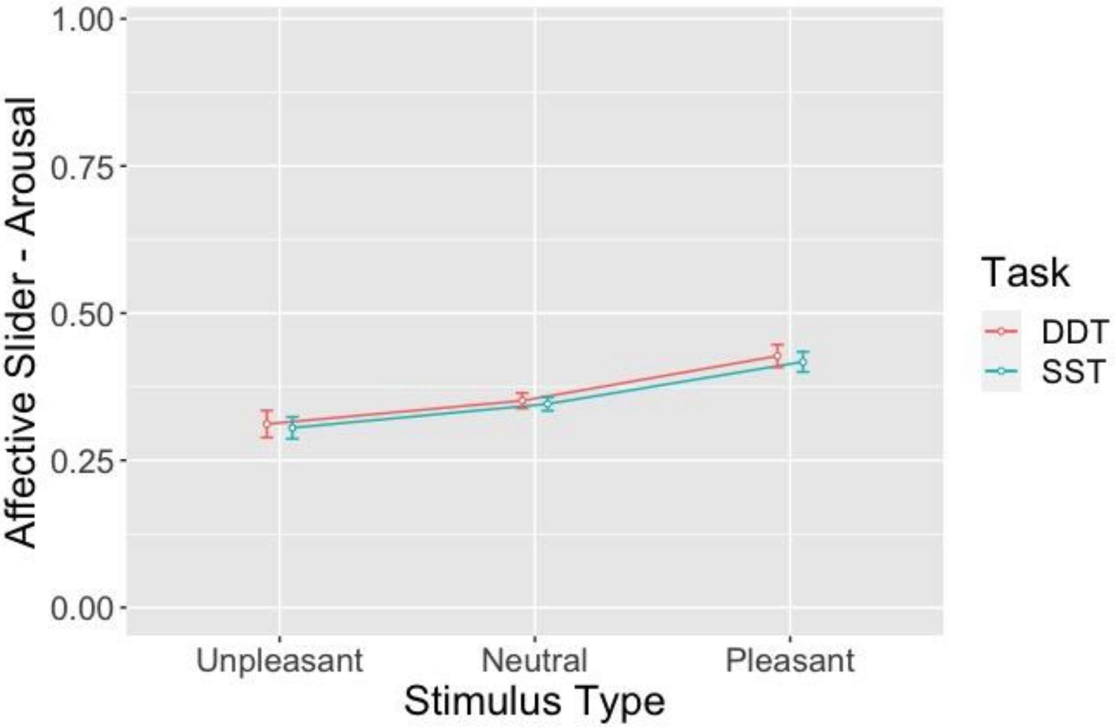

Figure 25. Affective Slider - Arousal scores.
Note: Error bars represent the standard error.

Valence. To ensure that participants' affect changed as a result of looking at pictures, a 2x2 (Task: SST/DDT vs. Valence: High/Low valence) repeated-measures ANOVA was run with valence ratings (PANAS and Affective Slider) as dependent measures. The results show that, as expected, participants experienced more positive affect after observing pleasant pictures and more negative affect after observing unpleasant pictures. Moreover, the impact of the pictures lasted throughout SST and DDT.

Affective Slider. As in Arousal measure, we find that, irrespective of a task, pleasant pictures were rated with higher valence than neutral or unpleasant. Likewise, participants indicated higher valence in trials with neutral stimuli than unpleasant stimuli. There was a significant effect of stimulus type (pleasant/neutral/unpleasant; F (2,120) = 193.25, MSE = 0.02, p <.001, η^2 = .57), but no effect of task (SST vs DDT; F (1,60) = 0.10, MSE = 0.003, p =.75, η^2 = .000). there was no interaction effect between task and stimulus type (1,60) = 0.59, MSE =0.003, p =.55, η^2 = .000) (Figure 26 and Table 12).

Table 12. Mean Affective Slider – Valence scores

Task	Stimulus Type	Mean	SD
SST	Pleasant	0.59	0.13
	Unpleasant	0.21	0.14
	Neutral	0.45	0.11
DDT	Pleasant	0.59	0.17
	Unpleasant	0.21	0.16
	Neutral	0.45	0.12

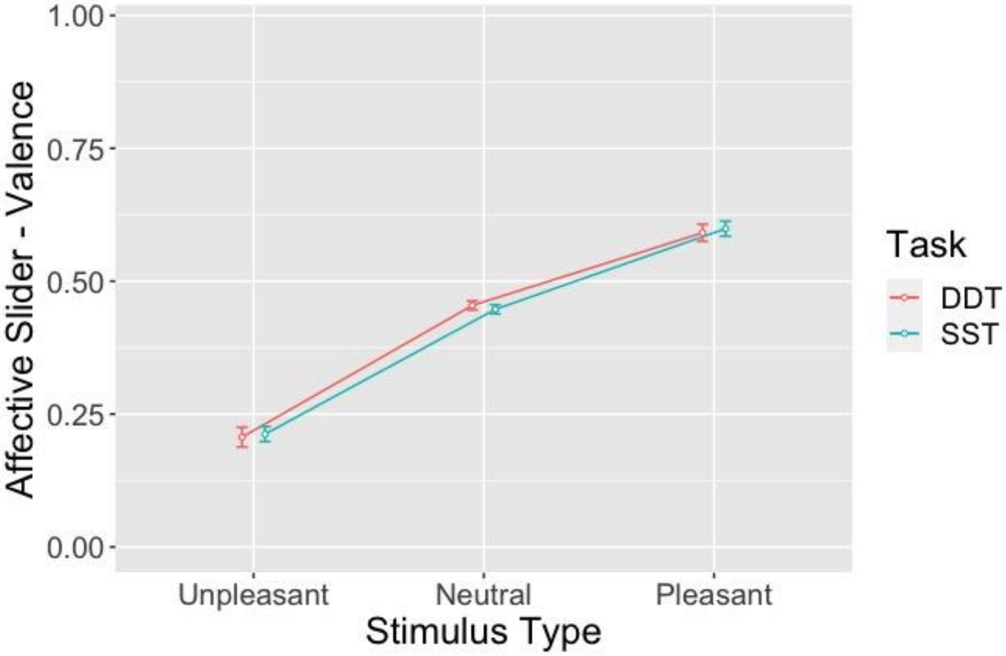

Figure 26. Mean Affective Slider - Valence scores.
Note: Error bars represent the standard error.

<u>*PANAS-X.*</u> Our manipulation was not limited to the trial level. We found that subjects experienced higher positive affect after SST/DDT blocks that contained pleasant stimuli and higher negative affect after SST/ DDT blocks that contained unpleasant stimuli.

Specifically, participants reported significantly higher Positive Affect after blocks with pleasant stimuli compared to neutral or unpleasant stimuli; *F* (2,120) = 18.11, *MSE* = 37.46, *p* <.001, η^2 = .05). We also found a significant effect of task (SST vs DDT; *F* (1,60) = 25.23, *MSE* =18.5, *p* <.001, η^2 = .02), but no interaction between task and stimulus type (*F* (2,120) = 0.04, *MSE* = 0.003, *p* = .95, η^2 = .000) (Figure 27 and Table 13).

Table 13. Mean PANAS-X Positive Affect scores

Task	Stimulus Type	Mean	SD
SST	Pleasant	25.2	9.44
	Unpleasant	20.5	8.54
	Neutral	21.6	7.97
DDT	Pleasant	22.6	8.87
	Unpleasant	18.2	6.95
	Neutral	19.6	8.17

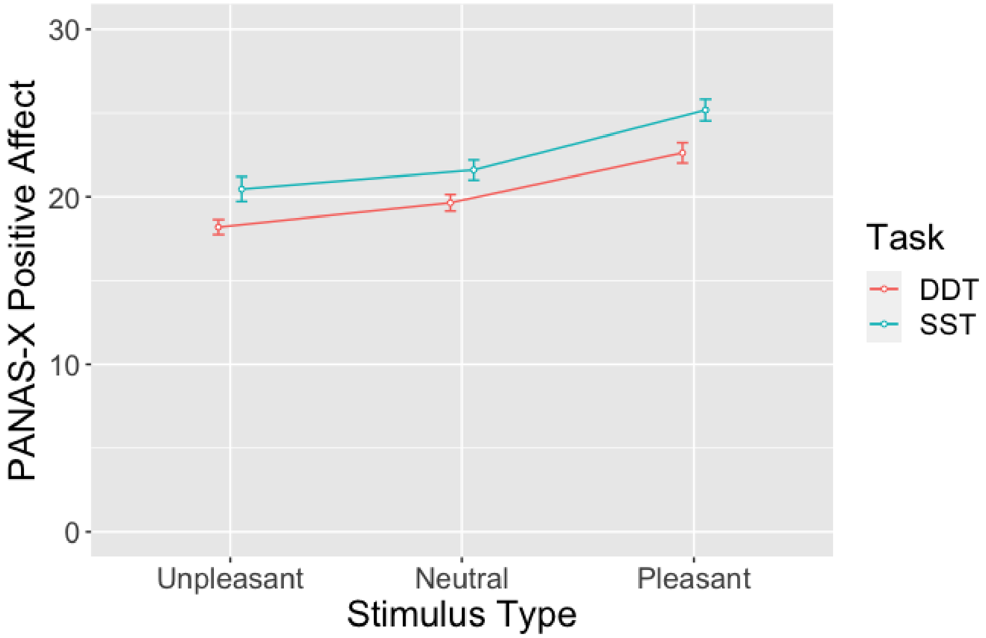

Figure 27. Mean PANAS-X Positive Affect scores.
Note: Error bars represent the standard error.

Likewise, negative affect was significantly higher after unpleasant than pleasant or neutral pictures, both in SST and DDT (F (2, 120) = 53.23, MSE = 25.04, p <.001, η^2 = .234). There was a significant effect of task (SST vs DDT; F (1, 60) = 7.27, MSE =

6.16, p =.009, η^2 =.004), but no significant interaction between task and stimulus type (F (2, 120) = 0.22, MSE = 3.74, p =.80, η^2 = .000) (Figure 28 and Table 14).

Table 14. Mean PANAS-X Negative Affect scores

Task	Stimulus Type	Mean	SD
SST	Pleasant	10.4	4.02
	Unpleasant	16.3	7.04
	Neutral	10.6	3.30
DDT	Pleasant	9.72	3.61
	Unpleasant	15.4	6.70
	Neutral	10	3.20

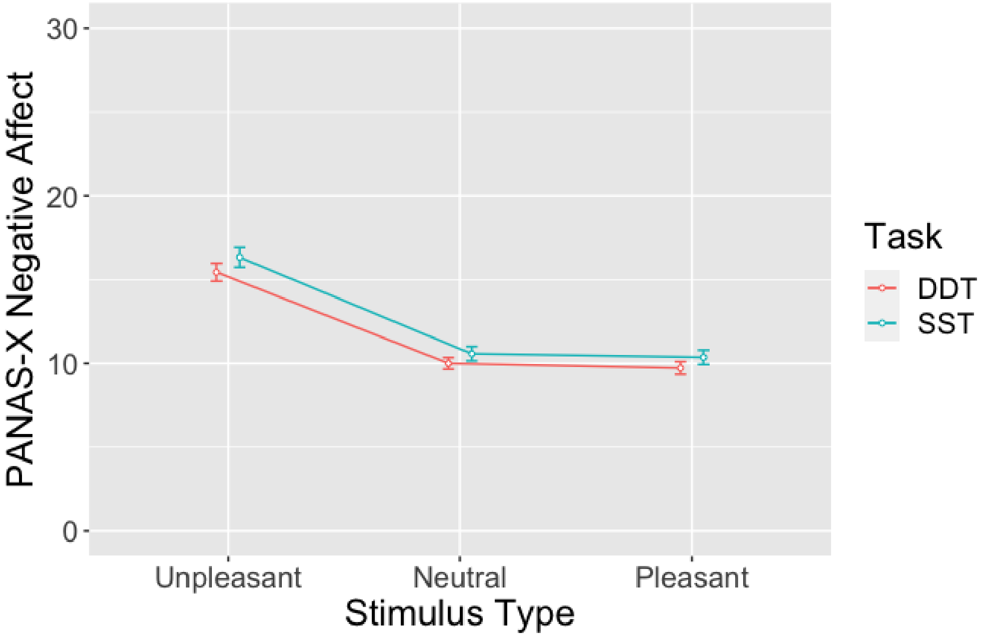

Figure 28. Mean PANAS-X Negative Affect scores.
Note: Error bars represent the standard error

In summary, the emotional pictures did induce a change in arousal and affect, evidenced by AS arousal and valence ratings. However, it is very important to note that participants rated unpleasant stimuli as less arousing. The emotional stimuli's effect lasted throughout both tasks, evidenced by higher PANAS-X Positive Affect scores after SST/DDT blocks with pleasant pictures, and higher PANAS-X Negative Affect scores after SST/DDT blocks with unpleasant pictures. Furthermore, Positive Affect was higher after SST than after DDT; because DDT was always delivered later in the experiment, it is likely that exhaustion lowered the participants' Positive Affect.

3.2.2. Main analyses

Did emotional stimuli affect impulsive action or attentional impulsivity? Overall, the results favored the "Core Attentional Impulsivity" theory. We found no difference in stopping distance or accuracy in "stop" trials (impulsive action measures). In contrast, the mean and SD of velocity in "go" trials (attentional impulsivity measures) were significantly higher in the emotional condition.

Specifically, contrary to the "Core Impulsive Action" model, no significant differences between emotional and neutral conditions were observed in accuracy in "stop" trials (*t* (60) = 0.14, *p* =.88) or stopping distance (*t* (60) = 1.45, *p* = .15) in the stop-signal task. For impulsive choice, no significant differences were found between emotional and neutral conditions in discounting rate (*t* (60) = -0.33, *p* =.74) or choice consistency (*t* (60) = 1.61, *p* = .11).

In contrast, consistent with Core attentional impulsivity model, significant differences were observed as predicted by the "Core Attentional Impulsivity" theory.

Mean maximum velocity in “go” trials was significantly higher in emotional condition compared to the neutral condition (M_{em} = 19.28, M_{neut} = 18.14; *t*(60) = 2.34, *p*=.02, illustrated in Figure 29, left panel). Likewise, SD of maximum velocity was higher in the emotional condition: M_{em} = 11.16, M_{neut} = 10.47; *t*(60) = 2.97, *p*=.004, Figure 29, right panel.

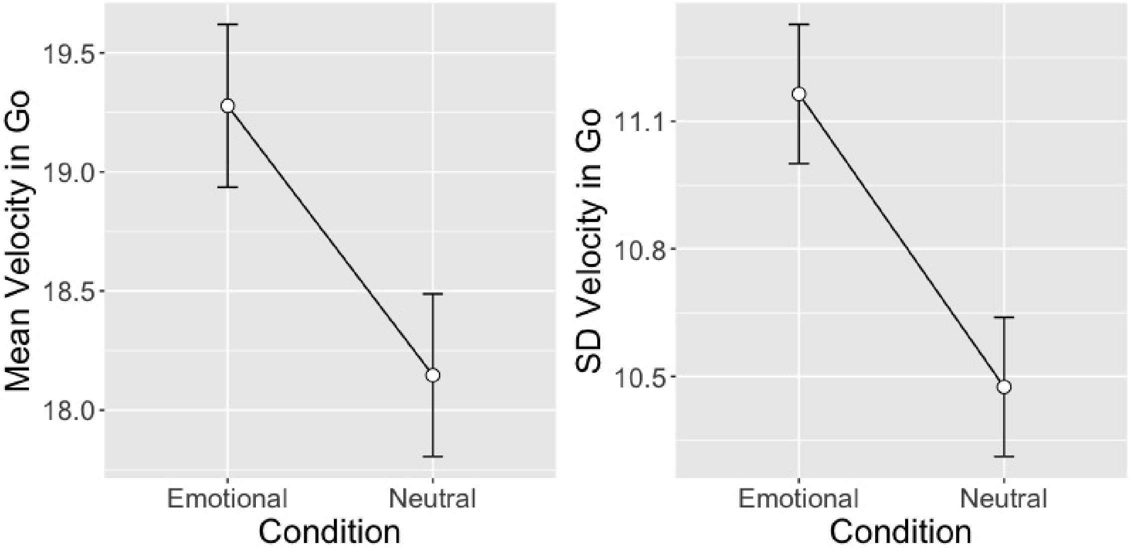

Figure 29. Velocity in "go" trials in neutral and emotional conditions.
Note: Error bars represent the standard error.

No significant differences, either in SST or DDT, were observed when compared trials with pleasant and unpleasant stimuli (i.e., within the emotional condition) in SST (accuracy in “stop” trials: *t* (60) = 0.38, *p* = .70; stopping distance *t*(60) = -1.91, *p* = .06; SD velocity in “go” trials: *t* (60) = 0.17, *p* = .86) or DDT (discounting rate: *t* (60) = 0.38, *p* = .70; choice consistency parameter: *t* (60) = 1.31, *p* = .19).

<u>Moderation analysis.</u> Study 1 yielded two models: “Core Impulsive Action” and “Core Attentional Impulsivity” (see Figures 14 and 17 above). According to these models, impulsive action and attentional impulsivity are the cognitive traits that, together with emotional impulsivity, predict impulsive choices. Here, I used moderation analysis to examine how introducing emotions changes the relationship between putative basic cognitive traits (impulsive action/attentional impulsivity) and impulsive choice.

If the "Core Impulsive Action" view is valid, then stopping distance or "stop" accuracy (IA) should predict discounting rate (IC), particularly at the high levels of emotional impulsivity (NU and PU). Because heightened emotion often accompanies impulsive behaviors, this relationship is expected to be stronger in the emotional condition compared to the neutral.

Alternatively, if the "Core Attentional Impulsivity" theory is correct, velocity in "go" trials (AImp) should predict discounting rate (IC), particularly at high levels of emotional impulsivity. Similarly, this association would be stronger in the emotional condition. To test these hypotheses, I performed a multiple parallel moderation analysis using PROCESS macro (Hayes, 2022).

"Core Impulsive Action" model. The predictions of the "Core Impulsive Action" theory were not confirmed. Emotional impulsivity did not moderate the relationship between impulsive action and impulsive choice in the neutral condition: neither stopping distance (IA measure), nor NU or PU scores (EI) accounted for a significant amount of variance in delay discounting rates (IC measure): F (5,55) = 0.58, p = .71, MSE = 1.04, R^2 = .05. No significant interactions between stopping distance and either PU or NU were recorded (PU x stopping distance: β = 0.16, p = .93; NU x stopping distance: β = 0.16, p = .91).

Likewise, in the emotional condition, stopping distance, NU, and PU scores did not account for a significant amount of variance in *k* values: *F* (5,53) = 1.22, *p* = .31, *MSE* = 0.98, R^2 = .10. No significant interactions between stopping distance and either PU or NU were detected (PU x stopping distance: β = 0.11, *p* = .51; NU x stopping distance: β = -0.001, *p* = .99).

Much like stopping distance, accuracy in "stop" trials showed poor performance. Neither accuracy in "stop" trials, nor NU or PU scores accounted for a significant amount of variance in the delay discounting rates in emotional (*F* (5,55) = 1.29, *p* = .28, *MSE* = 0.97, R^2 = .10) or neutral (*F* (5,55) = 0.61, *p* = .68, *MSE* = 1.03, R^2 = .05) conditions. No significant interactions, either in emotional (PU x "stop" accuracy: β = -0.04, *p* = .77; NU x "stop" accuracy: β = 0.17, *p* = .40) or neutral (PU x "stop" accuracy: β = 0.04, *p* = .78; NU x "stop" accuracy: β = -0.03, *p* = .84) conditions were detected.

"Core Attentional Impulsivity" model. In the neutral condition, no significant associations were found as predicted by the "Core Attentional Impulsivity" model. SD velocity in "go" trials (attentional impulsivity measure, $\mathrm{Vel}_{\mathrm{go}}$) and Negative/Positive urgency scores had no significant association with delay discounting rate estimated in the neutral condition: F (5,55) = 0.86, p = .51, MSE = 1.01, R^2 = .07. No significant interactions were observed between velocity in "go" trials and Negative (β = -0.04, p = .73) or Positive Urgency scores (β = 0.14, p = .36).

In contrast, in the emotional condition, consistent with the predictions of the "Core Attentional Impulsivity" model, PU and NU significantly moderated the relationship between attentional impulsivity and impulsive choice measures. $\mathrm{Vel}_{\mathrm{go}}$, NU, and PU scores accounted for a significant amount of variance in delay discounting rates, $F(5, 55) = 2.90$, $p = .02$, $MSE = 0.86$, $R^2 = .21$. An interaction term between PU and Vel_{go} scores significantly added to the amount of accounted variance in delay discounting rates: $\Delta R^2 = .06$, $\Delta F(1, 55) = 4.48$, $\beta = 0.33$, $t(55) = 2.12$, $p = .04$. On the other hand, interaction between NU and Vel_{go} did not significantly add to the amount of explained variance in discount rates: $\Delta R^2 = .005$, $\Delta F(1, 55) = 0.39$, $\beta = -0.08$, $t(55) =- 0.63$, $p = .53$. This relationship is summarized in Table 15 and Figure 30.

Table 15. Conditional effects of the Vel_{go} at values of NU and PU

NU value	PU value	β	95% CI	SE	*t*	*p*
Mean – 1SD	Mean – 1 SD	0.07	[-0.34,0.47]	0.20	0.34	0.73
Mean – 1SD	Mean	0.36	[-0.07, 0.78]	0.21	1.69	0.10
Mean – 1SD	**Mean + 1SD**	**0.76**	**[0.09, 1.41]**	**0.33**	**2.27**	**0.03**
Mean	Mean – 1SD	-0.04	[-0.38, 0.31]	0.17	-0.20	0.84
Mean	**Mean**	**0.25**	**[0.01, 0.50]**	**0.12**	**2.09**	**0.04**
Mean	**Mean + 1SD**	**0.64**	**[0.18, 1.10]**	**0.23**	**2.80**	**0.01**
Mean + 1SD	Mean – 1SD	-0.12	[-0.63, 0.38]	0.25	-0.49	0.63
Mean + 1SD	Mean	0.16	[-0.20, 0.53]	0.18	0.91	0.36
Mean + 1SD	**Mean + 1SD**	**0.55**	**[0.11, 0.99]**	**0.22**	**2.52**	**0.01**

Note: significant effects are in the boldface type

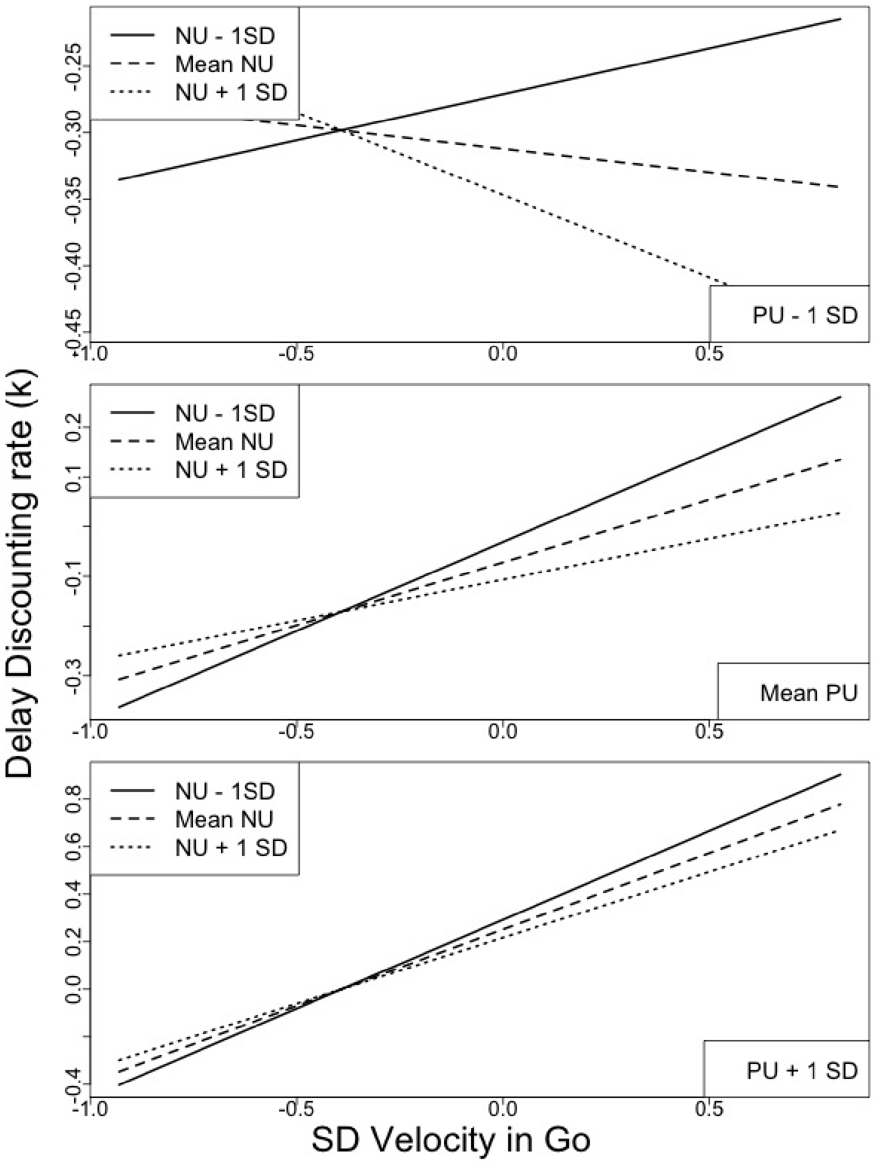

Figure 30. Probing the relationship between velocity in "go" trials and discounting rates.

Note: Upper panel: the relationship between velocity in "go" trials and the discounting rate at mean – 1SD Positive Urgency. Middle panel: the relationship between velocity in "go" trials and the discounting rate at mean Positive Urgency. Lower panel: the relationship between velocity in "go" trials and the discounting rate at mean + 1SD Positive Urgency. Solid line: the relationship between velocity in "go" trials and the discounting rate at mean – 1SD Negative Urgency; dashed line: the relationship between velocity in "go" trials and the discounting rate at mean Negative

Urgency; dotted line: the relationship between velocity in "go" trials and the discounting rate at mean + 1SD Negative Urgency.

In sum, the relationship between *k*, NU, PU, and Vel_{go} can be described as follows. Vel_{go} predicts delay discounting rates at moderate (mean) and high (mean + 1SD) levels of Positive Urgency. Negative Urgency does not play a major role in the relationship between Vel_{go} and delay discounting rates. Taken together, these results favor the "Core Attentional Impulsivity" theory.

Correlations. The "Core Impulsive Action" model (Figure 14) predicts no correlation between the impulsive action measures (e.g., accuracy in "stop" trials or stopping distance) and attentional impulsivity metrics (SD velocity in "go" trials). In contrast, the "Core Attentional Impulsivity" model predicts strong correlations between IA and AImp measures (Figure 17). The results favored the "Core Attentional Impulsivity" theory: as variability in velocity increased, so did the stopping distance (ρ = 0.54, p <. 001; Figure 31, left panel). Likewise, as variability increased, the accuracy in "stop" trials decreased (ρ = -0.40, p =. 001; Figure 31, right panel).

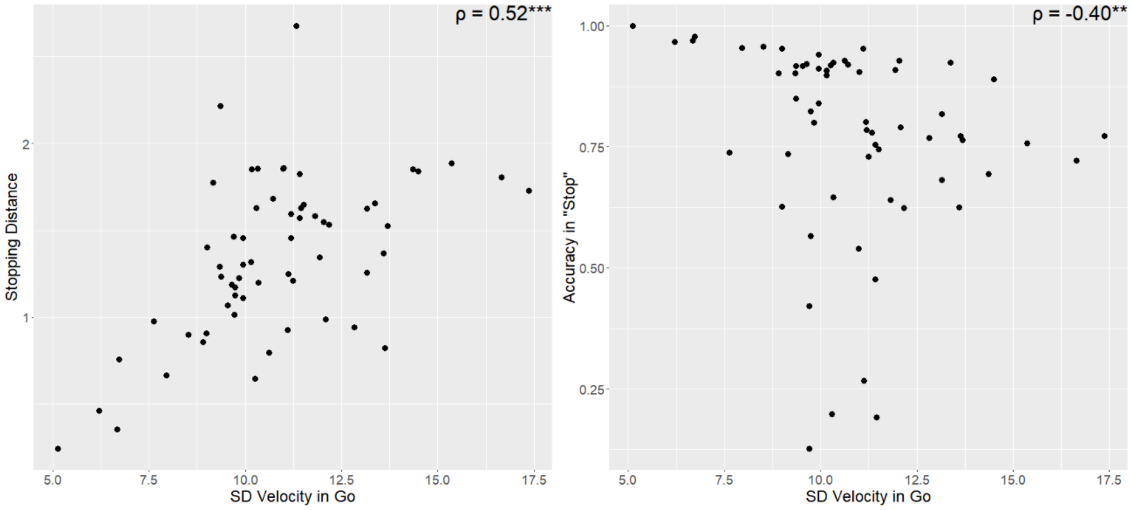

Figure 31. Correlation between attentional impulsivity and impulsive action measures.
Note: *p <.05, **p<.01, ***p <.001.

3.3. Discussion

In Study 2, I tested whether the core deficit in emotional impulsivity is the propensity to impulsive action or attentional impulsivity by comparing behaviors in SST and DDT with emotional and neutral pictures. Although the self-report measures of arousal give an inconclusive answer about the effectiveness of the emotional stimuli, it can still be argued that the emotional stimuli did work. The self-reported valence by affective slider, as well as positive and negative affect scores obtained from PANAS-X, suggest that participants experienced unpleasant emotions after observing unpleasant pictures and more pleasant emotions after observing pleasant pictures, compared to the emotional experiences after observing neutral pictures.

The results of Study 2 supported the attentional impulsivity account. Mean maximum velocity in go trials, as well as variability (SD) of maximum velocity, were higher in the emotional condition, suggesting higher inattention in the presence of emotional stimuli. Much like the “Core Attentional Impulsivity” theory predicted, emotional impulsivity also moderated the relationship between impulsive choice and inattention in the emotional condition.

Regarding the delay discounting task, the impulsive choice measures (k, β) showed no difference between emotional and neutral conditions. Likewise, no differences were observed in k or β between blocks with pleasant and unpleasant stimuli within the emotional condition.

The importance of variability in attention is in line with Hauser et al. (2016): variability of responses is a more important marker of inattention than average response. However, other measures of attentional impulsivity might yield different results. One possible venue for future studies is investigating how different measures of impulsive actions (e.g., SSRT, stopping distance, antisaccades) are related to individual differences in inattention measured by other tasks, for example, the Stroop task.

4. GENERAL DISCUSSION

4.1. Summary of the experiments

Contrary to the common view on impulsive choice and impulsive action as independent constructs, recent studies show that emotional impulsivity can influence both. To identify the main cognitive trait in emotional impulsivity, I investigated the relationship between emotional impulsivity (EI), impulsive choice (IC), impulsive action (IA), and attentional impulsivity (AImp) both on a trait level and in the presence of elicited emotions.

Study 1 examined the trait relationships between EI and IC/IA/AImp using correlation analysis and structural equation modeling. The “Core Attentional Impulsivity” model emerged as more informative, compared to the traditional model with impulsive action as the core deficit.

Study 2 experimentally tested the “Core Impulsive Action” and “Core Attentional Impulsivity” models. Inattention measures were higher in the emotional condition, pointing to the inattention as the most likely mechanism underlying emotional impulsivity. Importantly, emotional impulsivity moderated the relationship between inattention and impulsive choice, but not between impulsive action and impulsive choice.

4.2. Theoretical implications

The relationship between impulsive choice and impulsive action is complicated. Both IC and IA are considered parts of impulsivity; however, their relationship breaks when it comes to performance in behavioral tasks. Research on the IC/IA disagreement problem is essential because both impulsive choice and action are found in ADHD and substance addiction disorders. The lack of correlation between impulsive choice and impulsive action measures in the experimental paradigm still needs to be solved, particularly because understanding these disorders' pathophysiology is impossible without testing impulsive behaviors in a laboratory setting.

Although most direct comparisons of performance-based tasks and questionnaires point to the lack of association between impulsive choice and impulsive action, the question of their relationship is far from settled. The presence of impulsive choices and impulsive actions in various psychological disorders shows that although declaring IC and IA two completely unrelated constructs is appealing, demarcating them might obscure a common ground between both.

The reason why these two forms of impulsivity are not found together by the experimental paradigm might be the scope of behavioral experiments. While questionnaire-based approaches can study behaviors that span several days, weeks, or months, most experimental approaches to studying behavior are limited to the short term (i.e., to the span of an experimental session versus several weeks). Given the short span over which most experiments are conducted, perhaps behavioral experiments cannot detect the factors that affect impulsive behavior in the long term.

Emotional impulsivity is a promising avenue by which impulsive choice and impulsive action might be connected. However, to resolve this "grand question" —

whether emotional impulsivity influences both impulsive choice and impulsive action — we need to understand precisely how emotions give rise to impulsive behaviors.

The studies described in this dissertation point to attention as the primary mechanism by which emotions affect our inhibitory capacity. In Study 1, the attentional impulsivity model yielded significant results and an overall better fit than the Response Inhibition model. In Study 2, I observed significant differences between emotional and neutral conditions in velocity in "go" trials, which indicates poor attentional control. Moreover, the relationship observed in Study 1 was replicated: in line with the "Core Attentional Impulsivity" theory, inattention predicted impulsive choice together with emotional impulsivity.

These results suggest that the cognitive trait that underlies impulsive choice and impulsive action is not inadequate response inhibition ability but rather the inability to shield oneself from distractor interference. Results of Study 1 go against the traditional view that puts response inhibition problems at the core of emotional impulsivity. Together with Pearlestein et al. (2022), present studies suggest that other facets of executive function might be at play in impulsive behavior, particularly inattention.

Interestingly, it seems that inattention is more correlated with positive but not negative emotional urgency. This lack of relationship requires further investigation; perhaps, the difference between attentional impulsivity and response inhibition (which is known to be correlated with negative urgency more than positive; Johnson et al., 2020) lies in the specific facet of emotional impulsivity they are related to. That is, specific emotions might directly affect specific types of impulsive behaviors: negative emotions impacting primarily response inhibition and positive emotions impacting the ability to focus and maintain attention. Future studies should explore the specific effect of negative versus positive emotional stimuli, as well as their interaction with trait negative/positive emotional urgency.

Future studies should investigate the relationship between inattention and impulsive choice, for example, by employing more precise discounting rate estimation methods, e.g., adaptive delays (Mahalingham et al., 2018), or by offering real rewards. Another possibility for future studies is including in the current battery of tasks (SST and DDT) a task specifically designed to probe attention, for example, the Stroop task (Gronau et al., 2003).

Another avenue of future research is a specific facet of inattention that plays a role in promoting impulsive behaviors. The ability to suppress attention to irrelevant stimuli has at least two facets: resistance to distractor interference (i.e., the ability to ignore an immediately present distracting stimulus) and resistance to proactive interference (i.e., the ability to ignore traces of memory about a stimulus). Future studies should test both abilities in their relationship with emotional impulsivity, impulsive choice, and impulsive action.

Finally, these results raise interesting questions about the nature of ADHD. Presently, patients are usually diagnosed with one of the three subtypes of ADHD: ADHD-primarily inattentive subtype, ADHD-primarily hyperactive/impulsive subtype, and ADHD-combined subtype (Geurts et al., 2005). However, if attentional impulsivity is at the core of impulsive behavior, it should be present in the hyperactive/impulsive subtype as well. Future studies should further elaborate on the link between attentional impulsivity and hyperactivity.

4.3. Limitations

The present studies are limited in several different ways. First, it is possible that emotional influence cannot be captured fully in a laboratory setting. Although IAPS and OASIS are reliable and well-tested methods of eliciting emotional reactions, real-world emotional experiences are often complex and lasting. It might not be possible to replicate them within an experiment. Second, our samples are primarily drawn from the undergraduate subject pool. College students may be “screened” by the college admission process so that individuals who end up there are low on emotional impulsivity and exhibit less impulsive behaviors than individuals in the general population (Hanel and Vione, 2016).

Another limitation of the present studies is the validation of the emotional influence. Relying on the questionnaire measurements alone might not be sufficient. As the further breakdown of valence and arousal ratings suggests, participants might perceive arousal as something inextricably tied to the valence of the stimuli. That is, participants tend to perceive unpleasant stimuli as less arousing and, conversely, pleasant stimuli as more arousing (Kuppens et al., 2017).

Future studies can address this problem in several different ways. First, stronger and more immersive emotional stimuli might be used, such as emotional sounds (Gerdes et al., 2014). Second, a future inquiry might employ more sensitive equipment and pair it with other ways of validating the emotional influences, such as EEG. As Lee and Hsieh

(2014) show, distinct EEG patterns correspond to specific emotional states. Future experiments should make use of this discriminatory capability.

4.4. Conclusion

Emotional impulsivity plays an essential role in a variety of impulsive behaviors. However, its mechanism is not well-understood. The traditional view suggests that impulsive action is the core deficit in emotional impulsivity. Present studies tested this assumption and show that, instead, attentional impulsivity is the main cognitive trait that underlies emotional impulsivity.

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