Distractibility, Impulsivity, and Activation of Top-down Control Resources

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Boston College Electronic Thesis or Dissertation, 2011

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Abstract

Distractibility and impulsivity have long been thought of as two separate psychological processes; however, there is currently evidence that suggests otherwise. The aim of this study was to gain a better understanding on the behavioral level of the interaction between these two traits, and gain insight into the mechanisms that may cause them to be expressed behaviorally. I proposed a model for understanding this mechanism, in which some individuals have a higher than average threshold for activation of the top-down cognitive control resources that are important for directing and maintaining attention as well as for regulating impulsive behaviors. To test the strength of this model I used an experimental paradigm that combined two different types of tasks—a spatial working memory task and a delay discounting of a primary reward (juice) task. Participants were administered the Conners' Adult ADHD Rating Scale in order to be classified in terms of their trait distractibility and trait impulsivity subscale scores. Analyses revealed that individuals with high trait *distractibility* were more impulsive in the delay discounting task than the low distractibility group, especially when they were less engaged by the concurrent working memory task. Individuals with high trait *impulsivity* performed better on the working memory tasks in general, and the difference was larger during the easier versions of the tasks; these same individuals also made more impulsive choices than the low trait impulsivity individuals in general, particularly when they were less challenged by the concurrent working memory tasks. These results suggest that there is indeed an association between the traits of distractibility and impulsivity, and that they may be linked by a common mechanism involving a variable threshold of activation of top-down control resources to regulate these behaviors.

Introduction

Everyone has those moments when they find it difficult to concentrate on the task they are supposed to be doing, and instead find themselves impulsively searching for some kind of distraction to procrastinate from that overhanging but uninteresting task. Or perhaps you have began to “zone-out” during a boring lecture and mentally travel to more interesting or pleasing situations – sometimes maybe it even seems like you have little control over this slipping into a day-dream. Many people have also experienced the situation where you know you shouldn’t do something, but you just can’t stop thinking about it so you’re driven by impulse do it anyway.

These two traits just described, distractibility and impulsivity, have long been thought of as two separate psychological processes; however, there is currently evidence arising in the field that suggests otherwise – that possibly these two traits are both manifestations of the same underlying mechanism. Research focusing on attention often will study working memory processes, because actively attending to relevant information is mediated by working memory and is necessary for successful performance. Research focusing on impulsivity often will study response inhibition tasks or delay discounting of a reward, because impulsive behaviors are usually directed toward some sort of psychological or physical reward and thus involve the reinforcement pathway. The aim of this study was to gain a better understanding on the behavioral level of the interaction between these two traits, and possibly gain some insight into the mechanisms that may cause these traits to arise.

In order to engage attention during this study, I decided that working memory tasks would be used that required varying levels of attentional resources. A widely accepted theory of working memory is the Baddeley and Hitch tripartite model (1974). This model proposes that the three components that make up working memory are the phonological loop, the visuo-spatial sketchpad, and the central executive. The phonological loop is primarily responsible for processing verbal and auditory information, and is utilized in what is referred to as verbal working memory. The visuo-spatial sketchpad is mainly responsible for processing visual and spatial information, and is utilized in the process called spatial working memory. Verbal working memory and spatial working memory have been distinguished as two separate processes, such that a verbal task is easily disrupted by a similar verbal task but not by a visuo-spatial task, and a visuo-spatial task is disrupted easily another visuo-spatial task but not by a verbal task (Radvansky, 2006).

The central executive is the main control center of working memory in charge of allocation of attentional resources to each of the other two components. The central executive also integrates active information not directly handled by either component, such as from long-term memory (Radvansky, 2006). When a sensory stimulus is encountered, it conveys a signal that is perceived by the sensory centers of the brain. These sensory centers then relay the signal to working memory in the frontal region of the brain, specifically the pre-frontal cortex (PFC). The central executive controls what incoming information one will focus on, and this type of attentional regulation is known as top-down control. As opposed to bottom-up influences at the level of the sensory registers, top-down control integrates information from long-term memory (such as goal-oriented planning), from emotional processing, and from the motivation/reward circuit (Radvansky, 2006). If the central executive is not efficiently directing attention to the appropriate information, the result is distractibility and difficulty regulating cognitive and affective processes.

In studying the traits of distractibility and impulsivity, it would be helpful first to review research on a group of individuals who have consistent deficits in these areas and see how they differ from healthy individuals. A neuropsychiatric disorder that fits this purpose is Attention Deficit/Hyperactivity Disorder (ADHD), which is notorious for such symptoms of distractibility, impulsivity, and hyperactivity. The onset of ADHD is in preschool, and it affects 3-9% of children, many of whom will have symptoms persisting into adulthood as well (Emond et al., 2008). Some of the problems encountered by individuals with ADHD are poor academic performance, cognitive deficits, underachievement, poor behavioral inhibition, misconduct, poor social relationships, and higher incidences of anxiety and depression in adulthood.

The etiology of ADHD is still not completely understood, yet promising research has highlighted primarily the role of both the frontal-striatal networks (Valera et al., 2007; Emond et al., 2008; Tripp & Wickens, 2009) and, more recently, the reward circuit (Tripp & Wickens, 2009). Research with the ADHD clinical group has particularly provided insight into the neuropsychology of attention, behavioral control, and working memory. Impairment of these functions in ADHD varies in severity, such that individuals experience certain symptoms worse than others (Emond et al., 2008). Because of the established link between ADHD and deficits in both attention and impulse control, previous research on this clinical group will be discussed further to provide the basis for the direction of this study; in addition, as described further in the next section, the measures of trait distractibility and trait impulsivity that I used in this study were derived primarily from ADHD research and diagnosis tools.

There is a large body of research that suggests executive dysfunction in the pre-frontal cortex is the cause of inattention in ADHD. One fMRI study found more varied pre-frontal cortex (PFC) activation in adolescent girls with ADHD during a working memory task, and their brain-behavior relationship was less efficient than controls' – meaning that increased PFC activation did not strongly correlate with increased working memory performance in that group

(Sheridan et al., 2007). Another study analyzed the effects of the catecholamines dopamine and noradrenaline on the pre-frontal cortex, showing that PFC function is impaired when not enough of these neurotransmitters are released (Arnsten, 2009). Genetic linkage studies have suggested that these catecholamine pathways are altered in individuals with ADHD, and the authors propose that this is a critical element in the etiology of ADHD (Arnsten, 2009). A recent ADHD literature review supported this theory of dopamine deregulation in fronto-subcortical areas, providing evidence from animal models, pharmacology, imaging, and genetics studies (Genro et al., 2010).

Taking this research into consideration, it appears that executive function mediated by the pre-frontal cortex in ADHD individuals is impaired, or works differently from normal individuals. Thus, it would follow that there would also be behavioral differences in these individuals in attentional control and thus working memory performance. Because ADHD individuals share the same traits of distractibility and impulsivity that I intended to find a link between in my study, I decided to use a working memory task as a behavioral measure of attentional engagement in sub-clinical individuals as well. Cognitive control over attentional engagement is indirectly measured through the working memory task, because good performance on the task requires attention to be directed and maintained towards it.

Recently, there has been additional evidence that there may also be dopamine regulation differences in the reward circuit in individuals with ADHD. The role of this circuit in reinforcement learning in the ADHD spectrum has become increasingly significant in the past few years, especially in relation to symptoms of impulsivity. Phasic dopamine signaling, or the temporally-appropriate release of dopamine after a certain stimulus, has been shown to be required for reinforcement learning (Pizzagalli et al., 2007); in particular, Pizzagalli et al. found that learning was disrupted after a low dose of a dopamine agonist because constant autoreceptor stimulation prevented the effects of phasic release. In ADHD, activation of one key part of the reward circuit, the ventral striatum, has been shown to be reduced compared to healthy controls, both in adults and children (Ströhle et al., 2007; Scheres et al., 2007); these two studies also reported that reward circuit activation was negatively correlated with impulsivity and hyperactivity symptoms. Another study supported this finding by reporting volumetric reductions in the ventral striatum in ADHD children that also negatively correlated with symptoms of impulsivity and hyperactivity (Carmona et al., 2009).

Holroyd et al. (2008) recorded event-related brain potential (ERP) of children with and without ADHD as they navigated a virtual maze to find monetary rewards, and found that when physically given a reward halfway through the task, ADHD children showed an atypical increase in electrophysiological activity, compared to the controls who showed a decrease following payment. This indicated that the children with ADHD were more sensitive to the salience of the reward, and the authors suggest that this is likely a result of regulatory dysfunction of the midbrain dopamine system. A behavioral study by Kollins et al. (2010) found that monetary incentives promote smoking abstinence in adults with ADHD. Individuals with ADHD have significantly higher smoking rates than the general population and have more trouble quitting; however while participating in this study that offered monetary rewards for quitting smoking, more individuals with ADHD maintained abstinence than controls both during the study and after. The authors suggested that this result may be due to altered reinforcement processes in these individuals.

A review by Tripp & Wickens (2009) on the neurobiology of ADHD analyzed evidence that suggested that altered reinforcement mechanisms have a central role in symptoms, particularly delay sensitivity. The authors propose that a failure of dopamine transfer after a cell firing event during reinforcement may be the cause of increased impulsive behaviors. Shiels et al. (2009) found that stimulant medication reduces delay discounting in individuals with ADHD, supporting the dopamine-reward deregulation theory. Delay discounting refers to the change in the value of a reward as a function of temporal proximity (Green, Fry, & Myerson, 1994), such that smaller, immediate rewards are methodically preferred over larger, delayed rewards. Delay discounting tasks have been used previously to measure impulsive behavior in ADHD (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Scheres, Lee, & Sumiya, 2008). Steep temporal (delay) discounting has been shown in dimensional analyses to be associated with specifically the symptoms of impulsivity and hyperactivity, especially when reward magnitude at the trial level is small (Scheres et al., 2010). In addition, the association with impulsivity went beyond the cutoffs for ADHD severity. For this reason, I utilized a delay discounting task in this study with small rewards as a behavioral measure of impulsivity in all individuals, healthy or with ADHD. This task will also indirectly measure cognitive control over impulsive behaviors, because a lack of cognitive control over the decision is what would lead an individual to make an impulsive choice instead of the logical choice.

Perhaps the most intriguing research on the topic of ADHD etiology is the recent evidence that suggests that individual differences in both distractibility and impulsivity may be characterized as stemming from the same mechanism, as opposed to two separate deficits in executive functioning and reward processing. A recent study by Frank et al. (2007) found that in medicated individuals with ADHD, improvements in positive reinforcement learning were predictive of working memory improvements in distracting conditions. This suggests that a common dopamine mechanism underlies their behavioral improvements and that the attention and impulse control deficits may be linked together.

Another study by Clark et al. (2007) also linked the traits of distractibility and impulsivity as possibly stemming from the same mechanism. They analyzed performance on a stop-signal reaction time task and a spatial working memory task, and found an association between the two task performances in both ADHD and frontal lesion patients. This suggested that impulsivity and inattention may stem from a common pathological process. Paloyelis et al. (2009) provide further evidence towards this theory in their study on delay discounting in ADHD. Their results correlated with symptom ratings of ADHD, and reported a unique association between inattention symptoms and behavioral measures of impulsivity from the task. Specifically, the authors emphasized the potential role of impulsivity processes in the cause of behavioral inattention. However, their results could also potentially be explained by the theory that both traits are manifestation of the same process, as opposed to one trait's process causing the other trait to reveal itself.

A positron emission tomography (PET) imaging study by Volkow et al. (2009) reported a similar association between the traits of distractibility and impulsivity. They found a reduction in dopamine synaptic markers in the reward pathway – specifically the nucleus accumbens – in individuals with ADHD that were also correlated with the dimension of attention, which implicates the dopamine reward pathway in the symptoms of inattention. The authors explain that this could provide an explanation of why attentional problems in ADHD individuals are most evident in tasks that are considered boring or repetitive, or essentially unrewarding. Another recent study by Groom et al. (2010) analyzed both ADHD and healthy children's brains while playing a challenging computer game. The researchers found that when ADHD children were given their usual dose of methylphenidate (a stimulant), performance improved and their brain activity appeared to normalize and look similar to the controls. The interesting finding was that a similar result was observed when monetary rewards for good performance were introduced into the game, causing improved attention and reduced impulsivity in the children with ADHD.

In a study on time discounting for primary rewards in healthy subjects, McClure, Ericson, Laibson, Loewenstein, and Cohen (2007) found that limbic activation was greater for choices between an immediate and a delayed reward than for choices between two delayed rewards, whereas prefrontal cortex activation was nearly equal for both conditions. In addition, they found that the relative activation of both sets of brain regions predicted actual choice behavior. They concluded that the immediacy value of primary rewards is not subject to contextual effects, but rather is a more absolute function of time discounting that has likely been shaped by evolutionary forces. Because of this intrinsic value in a primary reward, and the prior research that has suggested the significance of intrinsic rewards in ADHD, I employed a delay discounting task with primary rewards in my study, similar to the paradigm in McClure et al. (2007).

The evidence that has recently accumulated on ADHD etiology is highly suggestive of a common link between the symptoms of inattention and impulsivity that were once thought to be of separate pathologies. From a neurophysiological standpoint, the dopamine dysfunction hypothesis seems to be the most promising, yet the exact mechanism by which it interacts with both pathways is still relatively unclear. In a study by Friedman-Hill et al. (2010), an attentional filtering paradigm that parametrically manipulated discrimination difficulty and distractor salience was used to analyze the mechanisms of top-down (cognitive) control. Their surprising finding was that for difficult discriminations, ADHD children filtered distractors as efficiently as healthy children, but for easy discriminations there were large group differences – ADHD children were slower to respond to trials with low salience distractors than with high salience distractors, which was the opposite of what was observed in healthy controls. This is contradictory to the idea that attentional problems stem from a diminished capacity of cognitive function, but instead it suggests that attention deficits in ADHD may stem from failure to efficiently engage top-down control, especially in low task demands. In other words, the distractibility seen in ADHD may be due to insufficient stimulation during a "boring" or repetitive task, which does not activate top-down control resources to efficiently control allocation of attention.

The authors of the previous study (Friedman-Hill et al., 2010) proposed that individuals with ADHD may actually have a higher threshold – or level of stimulation necessary – for activation of top-down control, thus making them more susceptible to inattention even during tasks that would normally be stimulating enough for the average healthy person. Based on the recent research on the reinforcement and reward circuit in ADHD, I proposed that this model of a threshold for activation of cognitive control resources could possibly be extended further to account for the symptoms of impulsivity as well. Particularly with the evidence suggesting dopamine irregularities, it would be reasonable to suggest that there may be a higher threshold at which top-down cognitive control resources are activated to regulate dopamine release in both the reward circuit and the working memory loop – which would account for both attentional and impulsivity control. Chronic low levels of phasic dopamine release would hinder appropriate refreshing of the working memory loop, and would also prevent positive reinforcement learning; however, when one circuit becomes highly excited – at a certain threshold level – the amount of dopamine increases for both circuits and both functional processes would improve. The threshold is the level of stimulation needed to activate top-down control resources and thus both maintain attention and inhibit impulsive task-switching behaviors.

The model I proposed is the following: one way this threshold for cognitive control activation could be reached is if the reinforcement pathway is highly excited by a reward that is highly stimulating or intrinsically rewarding (i.e. primary rewards, complex sensory stimuli, novelty, social reinforcement, motor activity). The anticipation and act of receiving a reward that is highly stimulating or intrinsically rewarding would excite the reinforcement circuit above the threshold for activation of top-down control resources. This would subsequently increase attention to specific reward information in order to keep refreshing it in the working memory loop. In addition, if the current task is associated with the reward in some way, then these increased attentional resources would also help to increase concentration and performance on that task. The other way this threshold for cognitive control activation could be reached is through a working memory or cognitive task that is very engaging or stimulating, which would require continually refreshing the working memory loop and attend to the changing stimuli. When the threshold is reached, top-down regulation would not only increase attention to and performance in the task, but it would also increase the reinforcing value of the task itself, by increasing inhibition of both sensory distractors and competing rewards. If this threshold is not reached with the current level of activity or stimulation, then top-down control will be weak and the individual will be more inclined to act on impulses, especially impulses that involve an intrinsic reward, such as juice. This would cause distraction from the current task to search for more rewarding but task-irrelevant distractors.

In order to test this theory on a behavioral level, a paradigm was used that combined a working memory task that increased in difficulty with a delay discounting task for immediate primary rewards. In addition, all subjects were administered a questionnaire for dimensional assessment of ADHD that revealed the degree of their character traits of inattention, impulsivity, and hyperactivity. These scores were used as a scale to calculate correlation of the traits with the behavioral measures from the working memory and delay discounting tasks. The scores were also used to split the participant pool into high and low trait distractibility groups for one analysis, and high and low trait impulsivity groups for another analysis. The scores were used even though most scores fell below the level for clinical severity in ADHD diagnosis, because I was interested in the interaction of top-down control thresholds and impulsive behaviors in a normal sub-clinical population.

Even though this was not tested, the neurobiology that was hypothesized to underlie the behavioral model being examined in this study was the following: the rush of dopamine into the reward system for positive reinforcement that follows threshold excitement of the reinforcement circuit would also increase the amount of dopamine available to attend to specific reward information in the working memory loop. In this case the attentional resources would likely be primarily directed to the reward and its associations, and this would occupy working memory. The other way the dopamine system could become highly excited is if a working memory task is very difficult or stimulating, which would require increased bursts of phasic dopamine to continually refresh the working memory loop and attend to the changing stimuli. This rush of dopamine into the system would not only increase attention to and performance in the task, but it would also increase the reinforcing value of the task itself because more dopamine will be available in the reward circuit. In this way, the highly stimulating task releases a threshold amount of dopamine that is significant enough to activate the regulatory mechanisms of higher cognitive processes–such as the central executive–thus increasing inhibition of sensory distractors or competing rewards. If this threshold is not reached with the current level of activity or stimulation, then top-down control will be weak and the individual will be more inclined to act on impulses, especially impulses that involve an intrinsic reward. This will cause distraction from the current task to search for more rewarding but task-irrelevant distractors.

For a practical example, if persons with ADHD have unusually high thresholds for top-down activation, then not only will performance on regular everyday tasks and monotonous work duties decrease due to inability to sustain attention, but impulsive behaviors favoring more highly stimulating intrinsic rewards will also increase. One long-term result of this type of functioning may be a decrease in dopamine transporters (reuptake proteins) to compensate for the lack of dopamine in the reward circuit. However, while this may increase circuit activation somewhat during low-stimulation tasks, the real problem would still be that there is not enough dopamine released to reach the threshold for top-down control. Instead, this compensatory mechanism would likely result in abnormal processing of rewards, such that distractors, particularly ones that provide an immediate intrinsic reward, activate the reinforcement pathway more easily and thus are also inserted into working memory more readily. This would lead to chronic problems with both inattentiveness and impulsive behaviors, especially during “boring” tasks such as tediously-detailed school assignments or studying for an exam. On the other hand, if a task is more intrinsically stimulating and provides the motivation for constant updating of working memory, the increase in mesolimbic and mesocortical dopamine will reinforce paying attention to that task, as well as activate neural connections in the pre-frontal cortex that help regulate impulsive behaviors and distractor interference.

The hypothesis was that during the less demanding working memory tasks, those individuals who are considered to be more distractible (higher trait inattention) would show more impulsivity in the delay discounting task, whereas during the more demanding working memory tasks they would behave similarly to the lower trait inattention participants because their cognitive control mechanisms would be sufficiently activated above threshold levels. More specifically, during the easy version of both working memory tasks, participants with higher trait inattention would make more choices for the immediate reward over the delayed reward when the delay discounting task interrupted. During the hard versions of both working memory tasks, the impulsive delay discounting choices should be relatively equivalent between groups. In addition, I predicted that those individuals who are considered to be more impulsive (higher trait impulsivity) would display a different pattern on working memory performance than those with low trait impulsivity, because these individuals would be more sensitive to the anticipation of a reward in the delay discounting task. Specifically, I predicted that this difference between groups would be greater during the easy versions of working memory tasks than during the more difficult versions of the working memory task.

Methods

Participants:

Recruitment of participants was primarily through the Boston College SONA system, which consists primarily of undergraduate Psychology students who wish to fulfill a research requirement. Participants were college students (aged 18-22) from Boston College or other local schools. A total of 44 participants, 22 male and 22 female, were tested. Data from participants were excluded who had indicated that they had eaten or drank within three hours prior to the study, or who had erratic data in the working memory tasks that suggested they had not understood the task. Ten participants were thus excluded, giving a total of 34 to be included in analysis. They had normal or corrected-to-normal vision, were native English speakers, and had no history of a neuropsychological or psychiatric disorder. In addition, no participants were currently taking medications that affected the central nervous system. The exceptions to those aforementioned requirements were persons who had been diagnosed with Attention Deficit/Hyperactivity Disorder (ADHD), and if they were prescribed psycho-stimulant medications for this disorder then these were allowed in some cases. Participants with ADHD who took medication consistently and on a regular schedule were be asked to continue taking their medication as usual; participants with ADHD who used medication on an irregular basis or not at all were asked to refrain from use of medication for at least 12 hours prior to study.

Materials and Procedures:

The study consisted of a single testing session that involved both computer-based tasks and pen-and-paper surveys. Participants were asked not to eat or drink anything for three hours prior to study to ensure that there was a high value in receiving a primary reward. The testing phase was divided into two parts, with each part being identical except for the working memory task used. The two spatial working memory tasks, specialized computer versions of the Corsi Block-Tapping task and the visual N-back task, were balanced between participants. The Corsi Block-Tapping task has been shown to be effective in assessment of visuo-spatial working memory both in normal subjects and in patients with brain damage (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). The validity of the N-back task as a measure of individual differences in working memory has recently been questioned by some researchers (Kane et al., 2007; and Jaeggi et al., 2010), particularly because of its insufficient reliability and because it does not demonstrate convergent validity with any established working memory measures. However, for the purposes of this study the visual N-back task should have been a sufficient measure of visuo-spatial working memory and attentional control as a function of the central executive, because the task does well predict inter-individual differences in higher cognitive functions, such as fluid intelligence (Jaeggi et al., 2010). In addition, the N-back task is still used widely as a measure for working memory (i.e. Kunimi & Matsukawa, 2009; Schmiedek, Hildebrandt, Lövdén, Lindenberger, & Wilhelm, 2009; Costa, Peppe, Dell'Agnello, Caltagirone, & Carlesimo, 2009; and Cui, Gao, Chen, Zou, & Wang, 2010); the prefrontal cortex has also been shown to be differentially activated for varying levels of N-back task difficulty (Molteni et al., 2008; Rodriguez-Jimenez et al., 2009), which further supported the use of the task in this study to engage central executive functions.

At the beginning of each part of the testing phase, the participant performed several practice trials of the spatial working memory (SWM) tasks, both the N-back or the Corsi-block, and the delay discounting task on the computer. After the initial practice trials, each part of the testing phase consisted of three test blocks. The test blocks of the SWM tasks periodically increased in difficulty, with a corresponding "easy", "medium", and "hard" version of each task. See Table 1 for the specifications of each level of difficulty for each task. Each test block was approximately 9-10 minutes in length, and consisted of the following ten segments: an initial period of working memory trials (2.0 minutes); the first choice period (0.5 minutes);; the second choice period (0.5 minutes); a short break period (0.5 minutes); another trial period (2.0 minutes); the third choice period (0.5 minutes); a short trial period (0.5 minutes); the fourth choice period (0.5 minutes); and a short break period (0.5 minutes). See Table 2 for the full schedule of segments for each SWM task and the relative reward amounts.

Table 1. Task difficulties				
	Practice	**Easy**	**Medium**	**Hard**
Corsi-block	3 blocks	4 blocks	5 blocks	6 blocks
N-back	*N*=2	*N*=2	*N*=3	*N*=4

Table 2. Schedule of trial difficulties and choice events

Segment	**Task(s)**	**Task Difficulty**	**No. Trials: N-back / Corsi-block**	**Time**	**Immediate Reward (x=5mL)**	**Delayed Reward (x=5mL)**
zP	1 or 2	practice	20 / 4	1 min	-	-
1	1 or 2	easy	40 / 8	2.0 min	-	-
2	**choice**	-	-	0.5 min	5x	7x
3	1 or 2	easy	10 / 2	0.5 min	-	-
4	**choice**	-	-	0.5 min	5x	10x
5	break	-	-	0.5 min	-	-
6	1 or 2	easy	40 / 8	2.0 min	-	-
7	**choice**	-	-	0.5 min	7x	10x
8	1 or 2	easy	10 / 2	0.5 min	-	-
9	**choice**	-	-	0.5 min	5x	7x
10	break	-	-	0.5 min	-	-
11	1 or 2	medium	40 / 8	2.0 min	-	-
12	**choice**	-	-	0.5 min	5x	7x
13	1 or 2	medium	10 / 2	0.5 min	-	-
14	**choice**	-	-	0.5 min	5x	10x
15	break	-	-	0.5 min	-	-
16	1 or 2	medium	40 / 8	2.0 min	-	-
17	**choice**	-	-	0.5 min	7x	10x
18	1 or 2	medium	10 / 2	0.5 min	-	-
19	**choice**	-	-	0.5 min	5x	7x
20	break	-	-	0.5 min	-	-
21	1 or 2	hard	40 / 8	2.0 min	-	-
22	**choice**	-	-	0.5 min	5x	7x
23	1 or 2	hard	10 / 2	0.5 min	-	-
24	**choice**	-	-	0.5 min	5x	10x
25	break	-	-	0.5 min	-	-
26	1 or 2	hard	40 / 8	2.0 min	-	-
27	**choice**	-	-	0.5 min	7x	10x
28	1 or 2	hard	10 / 2	0.5 min	-	-
29	**choice**	-	-	0.5 min	5x	7x
30	break	-	-	0.5 min	-	-

For the N-back task, a battery of neutral pictures (no explicit emotional content) was used as the stimuli. Each picture was centered on a white background and took up about one quarter of the screen space. Pictures were displayed one at a time for duration of 1.5 seconds each (one picture equals one trial), with another 1.5 seconds of blank space between each picture. Participants were told to press the space bar if the current picture was the same as any of the previous *N* pictures (*N* ranged from 2 to 4, depending on task difficulty). For the Corsi-block task, an array of nine white blocks appeared on the screen at the beginning of each trial. In the first phase of the trial, one block at a time each became colored for duration of one second in a specific order, ranging from three to six blocks per trial depending on the difficulty. After a short pause of 2 seconds, the second phase of each trial either (a) repeated the exact same block-coloring pattern that just occurred, or (b) displayed a slight variation of the block-pattern that just occurred (differed by no more than one or two blocks). The participant was then asked to indicate with a button press whether the second pattern was the "same" or "different" as the first pattern.

During the choice segments, the participant was presented with a delay discounting choice and had 12 seconds to make a decision: he or she either chose to immediately receive a reward, or to wait to receive a relatively larger delayed reward in five minutes. The primary reward was juice, and there were three magnitude categories of [immediate option] vs. [delayed option]: 5x vs. 7x; 5x vs. 10x; and 7x vs. 10x. A single unit of magnitude (x) was one milliliter of juice – thus the magnitudes were 5mL juice, 7mL juice, and 10mL juice. If the participant chose the immediate reward, he or she received the reward and was provided with 20 seconds to consume it. The next trial segment continued 20 seconds after the decision period regardless of whether the immediate or the delayed reward was chosen. If the participant chose the delayed reward, they received it approximately five minutes later (plus or minus 30 seconds) during the break after the next test block. If more than one delayed reward was chosen during a test block, the participant received the compounded amount of juice during the reward period five minutes later. This first part of testing phase of the experiment took approximately thirty minutes.

Between the two parts of the testing phase, the participant was given the following questionnaires to complete: the SF-36 Health Form; the Beck Anxiety Index; and the Beck Depression Index (BDI-II). The second part of the testing phase began after completion of these forms, but no sooner than ten minutes and no longer than fifteen minutes. The second part of the test phase followed the same format as the first part of the test phase, except the other SWM task not used in the first part was used in this part. Thus the number of trials per segment was different, but the total time per segment remained the same. This second part of the test phase also took approximately thirty minutes.

There were eight different versions of the test phase that were balanced among participants. The order in which the three reward-magnitude categories were encountered in a test block were varied for each block, and four combinations were used. The pairing of orders to blocks was also balanced across participants so that each individual block was paired with each of the four magnitude-order combinations at least twelve times across participants. Thus there were eight different versions of the test phase: two orders in which the SWM tasks could be encountered, multiplied by four orders in which the magnitude-order combinations could be encountered.

After completion of the test phase of the experiment, the participants were administered the following cognitive tasks: the Digit/Symbol Copy task to measure performance IQ; the Stroop test to measure cognitive inhibition; and the Shipley Vocabulary Test to measure verbal

IQ. Finally, participants were asked to complete the following two surveys: a background questionnaire, which consisted of demographic questions; and the Conners' Adult ADHD Rating Scale (self-report, long version; see next paragraph). The cognitive tasks and surveys together took approximately 30 minutes. The study in total thus was about an hour and a half to two hours in length.

The Conners' Adult ADHD Rating Scale (CAARS) is a self-report measure of symptoms of ADHD as defined in the DSM-IV, including inattention/memory problems, hyperactivity/restlessness, and impulsivity/emotional instability. The report measures the levels of these symptoms through eight subscales, for which sound psychometric properties have been established, in addition to normative data for 2,000 adults (Conners, Erhardt, & Sparrow, 1999). Items on the questionnaire are rated on degree of severity using a Likert scale from 0 to 3, with 0 being "not at all, never" and 3 being "very much, very frequently." The entire CAARS questionnaire was completed by each participant, however only some of the subscales were used in data analysis (see Table 3).

Table 3. CAARS Subscale Descriptions [a]

Subscale	**Tendencies of High-Scorers**
Inattention/Memory Problems	Learn more slowly, have problems organizing and completing tasks, and have trouble concentrating
Impulsivity/Emotional Lability	Engage in more impulsive acts than others, moods change quickly and often, and are more easily angered and irritated by people
ADHD Index	Have clinically significant levels of ADHD symptoms compared to adults with a low score. High scores are useful for differentiating clinical ADHD individuals from non-clinical individuals.
DSM-IV Inattentive Symptoms	Have tendencies associated with the inattentive subtype of ADHD, as described in DSM-IV
DSM-IV Hyperactive-Impulsive	Have tendencies associated with the hyperactive-impulsive subtype of ADHD, as described in DSM-IV
DSM-IV Total ADHD Symptoms	Meet the criteria for ADHD, as described in the DSM-IV

[a] excerpt from table in Conners et al., 1999, p. 24

Data Analysis and Results

Performance on the working memory tasks (Corsi-block and N-back) and the number of impulsive choices (choosing immediate instead of delayed reward) were both recorded in the computer program E-Prime. For the working memory data from the Corsi-block task, the number of correct responses was computed for each task difficulty (easy, medium, hard). For the working memory data from the N-back task, false alarms (pictures that were incorrectly identified as recurring within *N* previous pictures) were subtracted from hits (pictures that were correctly identified as recurring within *N* previous pictures) in order to correct for any positive response bias. Like with the Corsi-block task, these corrected N-back scores were also computed for each task difficulty (easy, medium, hard). For the delay discounting task, impulsivity scores were computed by totaling the number of impulsive choices (choosing the immediate juice reward instead of the larger delayed reward), and were grouped by the level of difficulty (easy, medium, hard) of the working memory task (N-back, Corsi-block) during which the delay discounting task had interrupted[1].

Data analysis first consisted of a correlation of working memory performance for each task and difficulty level, ADHD rating scale (CAARS) sub-scores, and impulsivity scores for each task and difficulty. Pearson correlations revealed the several significant associations. High scores on the CAARS *Inattention/Memory Problems* subscale were positively associated with impulsive choices during the easy N-back task ($r^2 = .369$, $p<.05$), and also marginally had a marginally significant positive correlation with impulsive choices during the hard Corsi-block task ($r^2 = .305$, $p=.080$). This suggests that individuals with high trait inattention made more impulsive choices during some of the working memory tasks. High scores on the CAARS *Impulsivity/Emotional Labililty* subscale were also positively associated with impulsive choices during the easy N-back task ($r^2 = .348$, $p<.05$), as well as positively associated, with marginal significance, with impulsive choices during the N-back task for both the medium difficulty ($r^2 =$

[1] Recall that the delay discounting task (choice of juice reward) would periodically interrupt the working memory task. In the following text, this will be referred to as (for example) "impulsive choices *during* the easy N-back task", however it must be remembered that these two tasks are still mutually exclusive and not occurring at the same time. Thus the wording in the text is a simplified indication of the working memory task type and difficulty during which the delay discounting task interrupted.

.327, p=.059) and the hard difficulty (r^2 = .296, p=.089). This suggests that individuals with high trait impulsivity made more impulsive choices during some of the working memory tasks. High scores on the CAARS *ADHD Index* subscale were positively associated with impulsive choices during the hard Corsi-block task (r^2 = .402, p<.05), and there was a marginally significant positive association with impulsive choices during the easy N-back task (r^2 = .325, p=.061). This suggests that individuals who show more symptoms of ADHD were more impulsive during some of the working memory tasks. These correlations are suggestive of a relationship between the CAARS subscale traits (inattention and impulsivity) and the impulsivity scores in the delay discounting task.

Trait Distractibility

Before running analyses of variance, the participants were divided into two groups that differed in trait level of inattention (distractibility). The two subscales of the CAARS that were analyzed were *Inattention/Memory Problems* and *DSM-IV Inattentive Symptoms*. The cutoff score to place a participant in the "high" category was a standardized *T*-score[2] of 61, which placed the individual at least one standard deviation above the mean, in the 86th percentile or higher, and is considered "above average" (Conners et al., 1999, p.22). While all of the scores above this level are not necessarily high enough to be considered clinically significant, this cutoff level will support the goal of this study to analyze this trait in non-clinical as well as clinical individuals[3]. If participants met or exceeded the cutoff score on at least one of the two subscales mentioned above, then they were placed in the "high inattention" group, while

[2] The scoring worksheet for the CAARS response form results in a transformed *T*-score that compares individual responses to population norms. "High *T*-scores represent a problem; lower *T*-scores suggest that the individual does not present particular symptoms" (Conners et al., 1999, p.22).

[3] For use of this cutoff level in another study with a similar purpose for the CAARS report, see López-Arvizu et al. (2010).

participants who scored less than the cutoff on both subscales were placed in the "low inattention" group.

To determine if there were any covariates that would potentially affect the analyses, between group t-tests for the covariate measures were run, which revealed that scores on the Digit Symbol cognitive task were higher for the low inattention group than the high inattention group ($t\ (32) = 2.596$, $p<.05$), and thus the Digit Symbol score was run as a covariate in all ANCOVA.

To determine how the dependent variable of working memory performance differed by inattention group and task difficulty, an analysis of variance considered the within-subjects factors of task type (N-back, Corsi-block) and task difficulty (easy, medium, hard), and the between subjects factor of inattention group (high, low). The one-way ANCOVA revealed the following: a main effect of working memory task difficulty ($F\ (2,62) = 3.211$, $p<.05$, $\eta_P^2 = .094$); and an interaction of working memory task type and difficulty ($F\ (2,62) = 4.825$, $p<.05$, $\eta_P^2 = .135$). All other tests did not reach significance ($F<2.5$, $p>.05$).

Subsequent paired samples t-tests revealed the within subjects differences described by the main effect of working memory task difficulty. Scores on the easy N-back task were greater than scores on the medium N-back task ($t\ (33) = 10.899$, $p<.001$) as well as the hard N-back task ($t\ (33) = 11.286$, $p<.001$); however, scores on the medium and hard N-back tasks were not significantly different ($t<0.2$, $p>.8$). Scores on the easy Corsi-block task were greater than scores on the medium Corsi-block task ($t\ (33) = 3.865$, $p<.001$) as well as the hard Corsi-block task ($t\ (33) = 7.597$, $p<.001$); in addition, scores on the medium Corsi-block task were greater than scores on the hard Corsi-block task ($t\ (33) = 5.828$, $p<.001$). The interaction between working memory task type and task difficulty describes the differences in performance between the Corsi-block and N-back tasks, such that scores on the N-back got much worse when the difficulty level increased than scores on the Corsi-block did. Scores on the Corsi-block task were greater than scores on the N-back task for the easy difficulty ($t\ (33) = 3.945$, $p<.001$), the medium difficulty ($t\ (33) = 10.441$, $p<.001$), and the hard difficulty ($t\ (33) = 4.362$, $p<.001$). Independent samples t-tests revealed no significant differences between groups in working memory performance ($t<1.5$, $p>.15$). These results reveal that performance decreased as task difficulty increased, and that the Corsi-block task in general was not as difficult as the N-back task.

To determine how the dependent variable of impulsivity score from the delay discounting task differed by inattention group and by working memory task difficulty, an analysis of variance considered the within-subjects factors of task type (N-back, Corsi-block) and task difficulty (easy, medium, hard), and the between subjects factor of inattention group (high, low). The one-way ANCOVA revealed a marginally significant main effect of inattention group ($F\ (1,31) = 4.045$, $p=.053$, $\eta_P^2 = .115$). All other effects did not approach significance ($F<2.0$, $p>.165$).

Subsequent independent samples t-tests did not reveal significant differences between groups when the average impulsive choices for each task difficulty was collapsed across task type ($t<1.7$, $p>.11$). As the N-back test was more difficult and may be more likely to have a statistically significant main effect of group, a one-way ANCOVA was run considering the within subjects factor of working memory task difficulty for only the N-back task, and the between subjects factor of inattention group. This analysis indeed revealed a significant main effect of inattention group ($F\ (1,31) = 4.458$, $p<.05$, $\eta_P^2 = .126$), but no interaction with task difficulty ($F<1.7$, $p>.20$). Subsequent independent samples t-tests revealed that the high inattention group chose more impulsive rewards during the easy N-back task than the low inattention group (t (32) = 2.211, $p<.05$; see Figure 1). There were numerical group differences for the medium and hard difficulties, but the t-tests did not reach significance (t<1.6, $p>.13$).

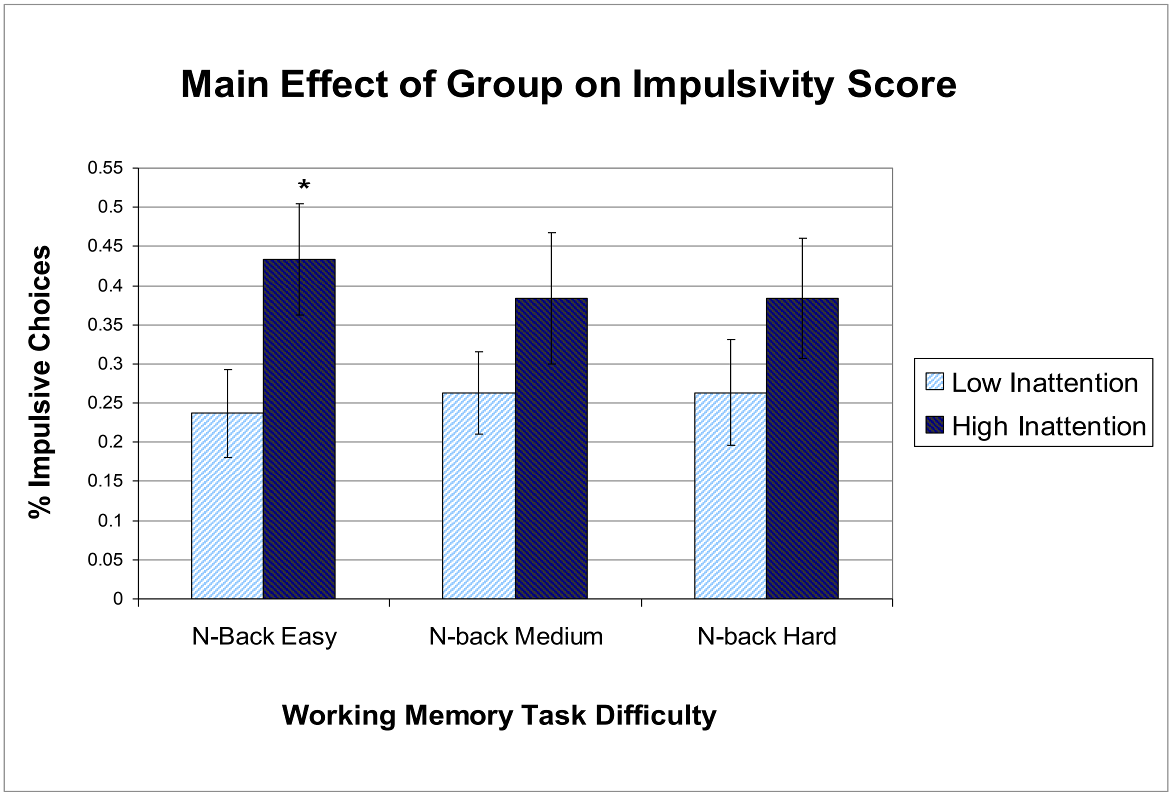

Figure 1. Main effect of inattention group (high, low) on mean percent impulsive choices in delay discounting task during different N-back task difficulties (easy, medium, hard). High inattention group (dark bars) chose significantly more immediate rewards during the easy N-back task than the low inattention group (light bars).

Trait Impulsivity

Before running analyses of variance for trait impulsivity, the participants were divided into two different groups—this time that differed in trait level of impulsivity. The two subscales of the CAARS that were analyzed for this trait were *Impulsivity/Emotional Lability* and *DSM-IV Hyperactive-Impulsive.* Because the participant median scores for these subscales were lower than the inattentive subscales, the cutoff score to place a participant in the "high" category for impulsivity was a standardized *T*-score of 50, which is the normalized mean and considered "average" (Conners et al., 1999, p.22). While all of the scores above this level are not necessarily high enough to be considered clinically significant, this cutoff level will support the goal of this study to analyze this trait in non-clinical as well as clinical individuals. If participants exceeded the cutoff score on at least one of the two subscales mentioned above, then they were placed in the "high impulsivity" group, while participants who scored less than or equal to the cutoff on both subscales were placed in the "low impulsivity" group.

To determine if there were any covariates that would potentially affect the analyses, between group t-tests for the covariate measures were run, which revealed that scores on the Beck Anxiety Inventory were marginally significantly higher for the high impulsivity group than the low impulsivity group ($t\ (32) = 1.911$, $p=.065$), and thus anxiety score was run as a covariate in all ANCOVA.

To determine how the dependent variable of impulsive choices in the delay discounting task differed by impulsivity group and working memory task difficulty, an analysis of variance considered the within-subjects factors of task type (N-back, Corsi-block) and task difficulty (easy, medium, hard), and the between subjects factor of impulsivity group (high, low). The one-way ANCOVA revealed an interaction of working memory task type, task difficulty, and impulsivity group ($F\ (2,62) = 4.965$, $p<.01$, $\eta_P^2 = .138$). All other tests did not reach significance ($F<2.7$, $p>.08$). Subsequent independent samples t-tests did not reveal any significant mean differences that would have indicated the nature of this interaction ($t<1.5$, $p>.16$), likely due to the effects of the covariate. However, numerical differences suggested that the high impulsivity group chose made more impulsive choices throughout most of the delay discounting task.

To determine how the dependent variable of working memory performance differed by impulsivity group and by working memory task difficulty, an analysis of variance considered the within-subjects factors of task type (N-back, Corsi-block) and task difficulty (easy, medium, hard), and the between subjects factor of impulsivity group (high, low). The one-way ANCOVA revealed a significant interaction between working memory task difficulty and impulsivity group ($F(2,62) = 4.005$, $p<.05$, $\eta_P^2 = .114$). All other effects did not approach significance ($F<2.2$, $p>.125$)[4].

Subsequent independent samples t-tests did not reveal significant differences between impulsivity groups when the average working memory performance for each task difficulty was collapsed across task type ($t<1.6$, $p>.12$). Independent samples t-tests that didn't collapse performance scores across task type revealed that the high impulsivity group scored marginally better on the easy N-back task ($t=1.802$, $p=.07$), and marginally worse on the hard Corsi-block task ($t=1.668$, $p=.098$). While the remaining task by difficulty cells did not reach significance ($t<0.7$, $p>.45$), numerical differences suggest that the high impulsivity group scored higher than the low impulsivity group on all working memory tasks, except the hard Corsi-block. This may help explain the interaction between working memory difficulty and impulsivity group seen in the ANCOVA, because the differences revealed from the t-tests were probably diminished by the covariate effects.

Discussion

The goal of this experiment was to gain a better understanding on the behavioral level of the interaction between the traits of distractibility and impulsivity, and also to gain further insight into the proposal that these two traits may both arise from the same pathology in top-down cognitive control. The investigations of this study revealed that individuals with high trait

[4] Note, however, that the task difficulty by task type interaction observed in the trait inattention analysis is still present in this analysis. Performance still decreased as tasks got harder, and the N-back task was more difficult in general than the Corsi-block task.

distractibility made more impulsive choices in general throughout the delay discounting task, and this distinction was especially apparent during the easy version of one of the two working memory tasks; however, these individuals showed no significant differences from the low trait distractibility group in performance on the working memory tasks. This experiment also revealed that individuals with high trait impulsivity performed better on the working memory tasks in general, and the difference was larger during the easier versions of the tasks; these same individuals also made more impulsive choices than the low trait impulsivity individuals in general, particularly in the easy version of one of the working memory tasks. These results suggest that there is indeed an association between the traits of distractibility and impulsivity, and that they may be linked by a common pathology involving activation of top-down control resources.

My hypothesis was that some people have a higher threshold for activation of the top-down control resources that are important for directing and maintaining attention as well as for regulating impulsive behaviors. Functionally, this model implies that a threshold amount of stimulation of either the reinforcement pathway or the attentional resources would activate some sort of feedback loop that leads higher cognitive processes to intervene and regulate the reinforcement and/or attentional process(es) that are being stimulated.

First, a particularly interesting finding from the correlation analyses is the association between high trait distractibility (HTD) and impulsive choices in the delay discounting tasks, such that HTD individuals were especially more impulsive when the delay discounting task occurred during the easy version of the N-back working memory task. In addition, individuals with high trait impulsivity (HTI) also made a greater amount of impulsive choices, especially during the easy N-back WM task, but the difference was also marginally significant during the medium and hard versions of this WM task as well. These correlations are suggestive of the link between distractibility and impulsivity, highlighting an enhanced association between the traits when the working memory (WM) task was easier, and presumably less stimulating.

To expand upon these findings for trait distractibility, an analysis of variance (ANCOVA) was considered for the dependent variable of impulsive choices in the delay discounting task, within-subjects factors of WM task type and WM task difficulty, and the between subjects factor of trait distractibility. This analysis revealed a marginally significant main effect of trait distractibility, such that individuals with HTD made more impulsive choices. When this same ANCOVA was run considering only the N-back task type, there was indeed a significant main effect of trait distractibility. Post-hoc t-tests revealed that HTD individuals made more impulsive choices than low trait distractibility (LTD) individuals, especially when the delay discounting task interrupted the easy WM task. These results can be interpreted as fitting with the model that there are higher top-down control activation thresholds for certain individuals. The less stimulating (easier) versions of the WM tasks were not sufficient to activate this higher threshold in the HTD individuals, and thus they had less resources regulating impulsive decision making, leading to more impulsive behavior. Essentially, this means that the more “boring” tasks did not tax these HTD individuals’ attentional resources enough to signal cognitive regulatory mechanisms that would have both increased their focus on the WM task and controlled their impulses.

Similar analyses (ANCOVA) were considered in order to examine the dependent variables in relation to trait impulsivity. First, an ANCOVA with the dependent variable of impulsive choices in the delay discounting task, within-subjects factors of WM task type and WM task difficulty, and the between subjects factor of trait impulsivity was run. The results revealed an interaction among WM task difficulty, WM task type, and trait impulsivity group. The post-hoc *t*-tests didn't reveal the nature of this interaction, which was probably due to the effects of the covariate. However, this significant interaction observed in the ANCOVA, along with the positive correlation data between trait impulsivity and impulsive choices mentioned above, suggest that the nature of the interaction is that HTI individuals made more impulsive choices, especially during the N-back task, and that the distinction from low trait impulsivity (LTI) individuals was greatest in the easiest version of this task. As was the case with the HTD individuals, this result can be interpreted as fitting with the model of higher top-down control activation thresholds for certain individuals. The easier version of the N-back task may not have stimulated the HTI individuals as much as the harder version, and thus during these tasks their top-down control mechanisms were less active and led to more impulsive decision making.

This suggestion that HTI individuals are *more* impulsive during easier tasks than hard tasks is interesting because it is counterintuitive to what one would expect from these individuals if trait impulsivity was simply a symptom of decreased capacity of impulse control resources. Instead, a different explanation is necessary, such that trait impulsivity is a symptom of variable threshold levels of activation for top-down impulse control resources. It may be that HTI individuals indeed have the ability to control their impulses as well as LTI individuals, but they do not demonstrate that ability unless they are performing a task that is sufficiently engaging or rewarding. This concept is also a possible explanation for the observation that individuals with ADHD sometimes are completely distracted and can't pay attention, while at other times they become hyper-focused on their current task (Emond et al., 2008). The name "attention *deficit*" is a misnomer—if this was simply a deficit in attentional resources, how would individuals with ADHD have the ability to hyper-focus on some activities? The results from the trait distractibility and trait impulsivity analyses in this study align with the variability in engagement observed in individuals with ADHD, and provide support for the hypothesis that individuals differ in their threshold levels for activation of top-down regulatory mechanisms that monitor both attention maintenance and impulsive behavior.

Another ANCOVA was run with the dependent variable of working memory performance, within-subjects factors of WM task type and WM task difficulty, and the between subjects factor of trait impulsivity. The results revealed that individuals with HTI performed marginally better on each difficulty level of both WM tasks, except the hard Corsi-block task. The interaction between WM difficulty and trait impulsivity was significant in the ANCOVA; however the post-hoc t-tests did not reveal the true magnitude of this interaction, most likely due to covariate effects. Marginally significant numerical differences between the group means, however, indicated the nature of the interaction reported above in the ANCOVA. These results can be included in the threshold of top-down control activation interpretation as well.

Recall the ANCOVA discussed above that indicated that HTI individuals made more impulsive choices during the easy N-back task than during the medium and hard N-back tasks. Also keep in mind that anticipating and receiving an immediate reward will activate the reinforcement pathway to a high degree, as discussed previously. Because the HTI group chose more immediate rewards during the easier WM tasks, it could be assumed that anticipation of this reward was high during the easy WM task, which would mean greater stimulation of the reinforcement pathway. If the top-down control threshold model were true, then it would follow that this higher amount of stimulation (due the reward task that is occurring during the easy WM task) would be more likely to activate top-down control resources that would have the effect of increasing attention to the WM task at hand, thus increasing performance on this task for those individuals. In other words, the results from these two ANCOVA suggest that the HTI group was more *sensitive* to the receiving of a reward, such that the presence of this delay discounting task may have increased their performance on the WM task more so than the LTI group, with the largest distinction between groups being in the easy N-back WM task. The general trend for the HTI group observed from the ANCOVA data is that the more impulsive choices they made in the delay discounting task, the greater the positive difference was between their WM performance and the LTI group's WM performance.

Considering all of the results from this experiment in regards to the proposed cognitive model that has been discussed, there are potentially two modalities through which the threshold for top-down control could be activated. One modality is through a working memory or cognitive task that is very engaging or stimulating, which would require continually refreshing the working memory loop and attend to the changing stimuli. When the threshold for activation is reached, top-down regulation would not only increase attention to and performance in the task, but it would also increase the reinforcing value of the task itself, by increasing inhibition of both sensory distractors and competing rewards. If this threshold is not reached with the current level of activity or stimulation, then top-down control will be weak and the individual will be more inclined to act on impulses, especially impulses that involve an intrinsic reward, such as juice. This will cause distraction from the current task to search for more rewarding but task-irrelevant distractors, as suggested by the data from the HTD individuals in the delay discounting task.

The other modality through which the threshold could be activated is the reinforcement pathway. The anticipation and act of receiving a reward that is highly stimulating or intrinsically rewarding (in this study, the primary reward of juice) would excite the reinforcement circuit above the threshold for activation of top-down control resources. This would subsequently increase attention to specific reward information in order to keep refreshing it in the working memory loop. In addition, if the current task is associated with the reward in some way, then these increased attentional resources would also help to increase concentration and performance on that task, as suggested by the data from HTI individuals in the WM tasks.

A potential criticism of this model is that, supposing the traits of impulsivity and distractibility do arise from a common pathology as described, one would expect that these two traits would thus always occur together with almost equal severity within individuals. In response to this, it could instead be argued that the degree of reliance on each modality for stimulation differs among individuals. For example, some individuals are primarily inattentive, and require a task to be more engaging in order to maintain attention to it, but are not necessarily be impulsive because they may have developed a reliance on finding stimulating distractors when they are disengaged. The opposite would be individuals who are primarily impulsive and favor tasks that have a high reward value associated with it to remain engaged, but are not necessarily inattentive because they only disengage attention when there is a distracting task that has a higher intrinsic reward than the current task. However, the most common scenario is some manifestation of both traits to some degree, as seen in most individuals with ADHD (Emond et al., 2008).

While promising, the results discussed above can only be considered, at best, marginally supportive of the top-down control threshold activation model, because many assumptions (albeit reasonable) were made and there were limitations with this study design. Nevertheless, these behavioral observations are definitely suggestive of this model for the link between trait distractibility, trait impulsivity, and a threshold for activation of top-down cognitive control. Future research into the potential validity of this model should combine behavioral and imaging methods to measure the effect of task engagement on activation of top-down control resources and subsequent impulsive behavior and distractibility. While the current study focused on these traits in a mostly sub-clinical population, perhaps testing a larger clinical population of ADHD individuals to compare to healthy controls would provide more insight into the interactions of these two traits and the possibility of a variable threshold for top-down control activation.

In addition, future studies should consider the potential role of dopamine in this threshold activation model. As previously discussed, increased evidence of the role of dopamine in ADHD pathology—which is primarily defined by the traits of distractibility and impulsivity in adults—has been accumulating in recent years. To test the threshold activation model in relation to dopamine, neuroimaging studies should target dopamine activation in reward circuit brain regions–such as the ventral striatum, amygdala, and pre-frontal cortex–during a task paradigm that measures both impulsive and inattentive behaviors. Positive results would be able to confirm that the dopamine pathway is indeed behind the connection between distractibility and impulsivity. Comparing activation of these specific dopaminergic brain regions to behavioral results in ADHD individuals relative to controls could be also helpful in uncovering a more exact etiology of ADHD and could provide a direction for new types of treatments for the disorder.

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