Exploring the Wandering Mind in ADHD

by

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Dedication

This dissertation is dedicated to my family (by blood, love, and friendship) – thank you for your unending support and guidance.

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is characterized by inattention, hyperactivity, and impulsivity. One important candidate factor underlying the inattention deficits is a failure of cognitive control, the voluntary goal-oriented control of behavior. Mind-wandering is an example of cognitive control failure, and is characterized by a decoupling of attention from the present task context toward unrelated concerns. Heightened ADHD symptomatology has been associated with increased mind-wandering, and both increased mind-wandering and increased ADHD symptomatology have been linked to increased errors in which participants fail to inhibit a response. However, these studies have important limitations of generalizability. Furthermore, there is a need to investigate compensatory strategies that may influence performance. This dissertation had two primary objectives: (1) to evaluate the relationship between mind-wandering, response inhibition, and ADHD; (2) to assess a potential compensatory strategy to reduce performance deficits in ADHD. We used modified versions of the continuous performance task (CPT) which requires subjects to respond to the majority of trials (90%) and creates a strong prepotent tendency to respond. For the first aim, we adapted the CPT to include embedded mind-wandering probes to measure mind-wandering and ADHD symptomatology in both non-clinical and clinical samples. Results indicated that inattention is linked to increased task-unrelated thoughts, and that task-unrelated thoughts can negatively influence overall task performance and performance on a trial-by-trial level. Based on research suggesting that rest breaks can ameliorate performance declines attributed to diminished attentional control resources, for the second aim we assessed the utility of breaks for individuals with ADHD. The first experiment allowed participants to choose if and when to take breaks in a standard CPT to evaluate if they were able to monitor their thoughts and/or performance and insert breaks to benefit their performance. The second experiment added experimenter-imposed breaks to test if the initiation of the break was a critical variable. Finally, we tested ADHD participants on and off of stimulant medication in the second experiment to measure the effects of medication on performance. Results indicated that stimulant medication and the incorporation of both types of rest breaks can normalize ADHD behavior to the level of control participants.

Chapter I

General Introduction

Attention-deficit/hyperactivity disorder

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common disorders of childhood with incidence of approximately 11% in youth aged 4-17 (American Psychiatric Association, 2013; Visser et al., 2014). In order to receive a diagnosis of ADHD, individuals must display a persistent pattern of symptoms that negatively interfere with functioning in more than one domain of life (e.g. work, school, interpersonal relationships). There are three ADHD subtypes based on symptomatology: predominantly inattentive, predominantly hyperactive/impulsive, and combined type (American Psychiatric Association, 2013). The predominantly inattentive subtype presents with at least six of nine symptoms including disorganization, forgetfulness, difficulties ignoring irrelevant information, and difficulties exerting mental effort. The predominantly hyperactive/impulsive subtype presents as at least six of nine symptoms (of which six relate to hyperactivity and three relate to impulsivity) including restlessness, the tendency to fidget, issues with interrupting and waiting one's turn, and impulsive decision-making. If individuals meet the criteria for both of these subtypes, then they are classified as the combined type. The diagnostic criteria also specify that symptoms need to be present before age 12 (previously age 7 in the DSM-IV-TR).

Given estimates suggesting that 30-60% of individuals continue to exhibit symptoms into adulthood, ADHD has recently been conceptualized as a lifespan disorder (Biederman, Mick

& Faraone, 2000; Faraone & Biederman, 2005). This shift in the understanding of ADHD was reflected in the updated Diagnostic and Statistical Manual (DSM-V) which was released 13 years after the previous version (DSM-IV-TR). The DSM-V criteria for ADHD include symptom descriptions that have been adapted to be relevant for older adolescents and adults; for example (emphasis given to information that was not in the DSM-IV-TR): "often has trouble keeping attention on tasks or play activities *(e.g. has difficulty remaining focused during lectures, conversations, or lengthy readings)*"; "often loses things needed for tasks and activities (e.g. toys, school assignments, pencils, books, tools, *wallets, keys, paperwork, eyeglasses, mobile telephones*); "is often easily distracted by extraneous stimuli (*for older adolescents and adults, may include unrelated thoughts*)" (American Psychiatric Association, 2013). Research suggests that over time, symptoms of inattention decline more slowly than those of hyperactivity and impulsivity (Biederman, Mick, & Faraone, 2000). Therefore, adult ADHD tends to manifest as a disorder of inattention more than as a disorder of hyperactivity. Cognitive deficits related to inattention symptoms suggest that cognitive control, the voluntary goal-oriented control of behavior, may be at the core of ADHD dysfunction.

There are significant negative consequences associated with ADHD, including lower academic and occupational attainment (Klein et al., 2012). A review estimated that incremental costs of $87 billion to $138 billion dollars can be attributed to the productivity and income losses related to adult ADHD which has a prevalence of 5% (Doshi, et al., 2012; Willcutt, 2012). Additionally, persistent symptoms of inattention in adulthood are related to decreased subjective well-being (Das, Cherbuin, Butterworth, Anstey, & Easteal, 2012). In spite of the very significant cost of ADHD in adults, the existing literature on cognitive control in ADHD is focused almost entirely on children, and there is consequently a dearth of adult-focused ADHD literature (Engelhardt, Nigg, Carr, & Ferriera, 2008; Nigg, 2006). Investigating cognitive control in adults with ADHD is important given the significant maturation of brain circuits of cognitive control and their corresponding functions during the transition from adolescence to adulthood (Tannock, 1998). Thus, findings which pertain to children with ADHD may not apply to adult populations and further research is necessary to better understand these processes in adults.

Cognitive control deficits in ADHD

Cognitive control processes function to facilitate goal-relevant thoughts and behaviors (Hasher, Lustig, & Zacks, 2007). Cognitive control is comprised of multiple components that work to detect and prevent interference from irrelevant and distracting information in the environment and in memory, as well as to suppress dominant or automatic responses when necessary (Barkley, 1997; Friedman & Miyake, 2004; Nigg, 2000; Miyake, et al., 2000; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Response inhibition, the ability to inhibit a prepotent response deliberately when the context deems such a response inappropriate, has been targeted as a key cognitive control deficit in ADHD (Barkley, 1997; Nigg, 2001; Nigg, 2005).

One line of experimental support for an ADHD-related deficit in response inhibition comes from studies using a Go/No-Go task (Bozorgpour, Klorman, & Gift, 2013; Trommer, Hoeppner, & Zecker, 1991). The Go/No-Go task establishes a dominant response by making most trials “go” trials, in which the participant is required to respond to a stimulus (e.g., any letter except X) (Nigg, 2006). This response must be withheld on the “no-go” trials, which occur infrequently and are signaled by some other stimulus (e.g., an X) (Nigg, 2006). Many studies using the Go/No-Go task indicate that individuals with ADHD make excessive errors of commission by responding more than healthy controls to the no-go trials (Epstein et al., 2003; Pennington & Ozeroff, 1996) For example, Bozorgpour and colleagues (2013) found that compared to matched controls, those with ADHD, particularly those with the combined type, were less accurate and had more variable reaction times. Additionally, failures of response inhibition have been related to ADHD symptomatology across all three of the ADHD symptom domains (Epstein et al., 2003).

The Go/No-Go task measures the ability to withhold a response. A similar task used to measure the ability to cancel an initiated response is the Stop-Signal Task (Logan, Van Zandt, Verbruggen, & Wagenmakers, 2014; Schachar et al., 2005). In this paradigm, participants respond to a speeded "go" trial as quickly as possible, but on other trials they must inhibit a response when they hear a signal (e.g., a tone) after the stimulus is presented but before they have executed a response (Logan, et al., 2014). The key measure for this task is the stop-signal reaction time, which is the time it takes for inhibition to be completed after a stop signal is presented (for calculation procedures, see Logan, 1994). In a large community sample of children and adolescents with ADHD, Crosbie et al. (2013) found that participants with more ADHD traits had longer stop-signal response times compared to controls. Additionally, participants with the most severe ADHD symptoms had substantially slower response times, indicating less efficient inhibition resolution.

In summary, there is evidence supporting deficits in response inhibition in ADHD. Researchers have claimed that this impairment is critical in ADHD because it is associated with broader self-regulation difficulties (Barkley, 1997; Nigg, 2006; Sonuga-Barke, 2002). Nigg (2006) stated that "the basic control function of quickly interrupting a behavior as the context changes is critical to self-regulation" which he defines as "the set of effortful and automatic abilities that collectively enable behavior to be adapted effectively to its context" (p. 127, p. 329). Similarly, Sonuga-Barke (2002) described ADHD as primarily a disorder of the regulation of thought and action that results from inhibitory dysfunction. Difficulties with regulating thought in accordance with task demands can lead to task-unrelated thoughts or mind-wandering.

Mind-wandering in ADHD

Mind-wandering is characterized by a decoupling of attention from the present task context toward unrelated concerns, and as such it can disrupt goal-directed behavior (Mooneyham & Schooler, 2013; Schooler et al., 2011). The thoughts associated with mind-wandering are task-unrelated and self-generated in that they arise from intrinsic changes within the individual instead of changes in the external environment (Smallwood & Schooler, 2015).There are primarily three ways to assess the effects of mind-wandering during a task: the probe-caught method, the self-caught method, or the retrospective report method (Smallwood & Schooler, 2015). The probe-caught method and the self-caught method measures mind-wandering while the task is ongoing by requiring participants to respond to intermittent probes regarding the contents of their thoughts or to report when they catch themselves mind-wandering. The retrospective method involves participants reporting on the frequency of their mind-wandering upon completion of the task. Mind-wandering has been related to impaired performance on a number of tasks including reading (Schooler, Reichle, & Halpern, 2004), sustained attention (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; McVay & Kane, 2009), and working memory (Mrazek et al., 2011).

The self-generative aspect of mind-wandering makes it distinct from external distraction (Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011; Stawarczyk, Majerus, Catale, & D'Argembeau, 2014; Unsworth & McMillan, 2014), but does not necessarily mean that individuals are in control of the contents of their thoughts. Researchers have made a distinction between task-unrelated thoughts that are generated intentionally/deliberately and those that are generated unintentionally/spontaneously (Franklin et al., 2014; Smallwood & Schooler, 2015; Seli, Carriere, & Smilek, 2015; Seli, Risko, & Smilek, 2016a,b; Seli, Risko, Smilek, & Schacter, 2016; Seli, Cheyne, Xu, Purdon, & Smilek, 2015). A related distinction has been made in regards to whether individuals are aware of their mind-wandering (Christoff et al., 2009; Schooler et al., 2011; Smallwood & Schooler, 2006). In general, performance deficits are greater when individuals mind-wander without intention and/or without awareness (Seli, Wammes, Risko, & Smilek, 2016; Smallwood, McSpadden, & Schooler, 2008; Smallwood, McSpadden, Luus, & Schooler, 2006; Smallwood, McSpadden, & Schooler, 2007).

Increased mind-wandering has been associated with ADHD. Franklin et al. (2014) found that heightened levels of ADHD symptomatology were related to the frequency of mind-wandering as measured both in the lab during a reading task and out of the lab via daily self-report. Additionally, individuals with ADHD tend to engage in spontaneous, but not deliberate, mind-wandering (Seli, Smallwood, Cheyne, & Smilek, 2015; Shaw & Giambra, 1993), and the link between ADHD symptoms and detrimental mind-wandering may be partially driven by the lack of awareness of mind-wandering (Franklin et al., 2014). Consequently, as Franklin and colleagues suggest, it may be possible to instruct individuals with ADHD in strategies that promote effective self-monitoring to “check in” about whether their minds are on task (Franklin et al., 2014).

To conclude, the research suggesting that ADHD is associated with mind-wandering without intention or awareness is consistent with the notion of ADHD as a disorder in the regulation of thought in addition to the regulation of behavior. However, there has not been an attempt to identify an explicit relationship between these two issues in ADHD. Despite the lack of a direct empirical connection, research has investigated ways to separately ameliorate the deficits associated with the dysregulation of thought and behavior.

Identifying potential interventions to address performance deficits in ADHD

The ability to maintain consistent task engagement can be affected by cognitive and neural factors. Cognitively, resource theory argues that executive processing resources are limited and can thus be depleted over the course of a task, negatively impacting performance (Davies and Parasuraman, 1982; Helton and Russell, 2012). Feelings of mental fatigue and exhaustion are also related to performance decreases during a task (Helton & Warm, 2008). Additionally, when an individual is performing a task, typically the brain regions involved with attention and effortful control are activated (the "task-positive" network) including the dorsolateral prefrontal cortex (Fox et al., 2005). The "task-negative" or "default-mode" network, which includes the medial prefrontal cortex and posterior cingulate, is activated during rest and is predominantly associated with internally focused tasks like thinking about the self. These networks are anti-correlated in that activation in one network is associated with a deactivation in the other. When the default-mode network is not appropriately deactivated to accompany an increase in task-positive network activity, this asynchrony can result in an imbalance between attention and effortful control and task-irrelevant cognitions, Consistent with this idea, prior research has documented that mind-wandering episodes, response-inhibition failures, and attentional lapses are associated with activation in regions of the default-mode network (Christoff et al., 2009; Weissman, Roberts, Visscher, & Woldorff, 2006). Abnormalities in the development, functional connectivity, and activity of the default-mode network has also been identified in ADHD (Cao, Shu, Cao, Wang, & He, 2014; Fassbender et al., 2009; Kessler, Angstadt, & Sripada, 2016; McCarthy et al., 2013; Posner, Park, & Wang, 2014). These results suggest that the over-activation of task-irrelevant mental activity may prohibit consistent task engagement and accurate performance.

Researchers have sought to address these issues with stimulant medication and with behavioral strategies. Stimulant medication is often prescribed to treat ADHD and works to increase extra-synaptic dopamine and norepinephrine levels by inhibiting their reuptake (Swanson, Baler, & Volkow, 2011). Medication has been shown to reduce ADHD symptoms and normalize activity within the default-mode network by improving the ability to sustain the suppression of the default-mode network when performing a task (Liddle et al., 2011; Peterson et al., 2009; Querne et al., 2014). Additionally, one study used methylphenidate (a commonly prescribed stimulant) to prevent the impairment of regulatory control resulting from prior effortful regulation (Sripada, Kessler, & Jonides 2014). Behaviorally, stopping the current task should "promote the replenishment of cognitive resources that were exhausted in the pursuit of the goal and…resume it later with renewed energy" (Adler & Benbunan-Fich, 2013, pg. 1447). Consistent with this idea, participants who are given rest breaks show improved accuracy and perceive a task as less demanding compared to participants who performed a task continuously and to those who performed a different task during the break (Arrabito, Ho, Aghaei, Burns & Hou, 2014; Helton & Russell, 2015; Ross, Russell, & Helton; 2014). Additionally, an EEG study showed that a rest break decreased theta, an EEG marker of fatigue, in frontal electrodes and that the reduction was significantly correlated with behavioral improvement following the break (Lim, Quevenco, & Kwok, 2013). Taken together, these results highlight the utility of using stimulant medication and/or breaks in ADHD.

Current research

This dissertation seeks to achieve two main objectives: (1) to evaluate the relationship between mind-wandering, response inhibition, and ADHD; (2) to assess a potential compensatory strategy to reduce performance deficits associated with ADHD.

There have been limitations in the previous research on mind-wandering in ADHD including relying on non-clinical populations and the inconsistencies in probes and tasks used to measure mind-wandering. In order to evaluate the relationship between mind-wandering and response inhibition in ADHD, we used a continuous performance task (CPT). This task involves presentation of individual letters to the participant with the instructions to respond by pressing the spacebar if any letter that is not “X” is presented and not to press the spacebar when the letter is an “X”. The majority of trials (90%) required a response; this creates a strong prepotent tendency to respond. The validity of using the CPT to study ADHD has been established based on its ability to discriminate between ADHD and typical control groups and its sensitivity to treatment (Nichols & Waschbusch, 2004). This task requires participants to “continually supervise their performance to override the tendency to engage in mindless stimulus-press behavior” (Smallwood, McSpadden, & Schooler, 2007, pg. 528) and is conducive to mind-wandering because of its low attentional demands and repetitive response (Jackson & Balota, 2012). The first experiment used a non-clinical population which enabled us to refine the task parameters for use in a clinical population in the second experiment. This procedure also allowed us to compare the behavioral profile of individuals with heightened ADHD symptomatology to individuals clinically diagnosed with ADHD. We measured mind-wandering using embedded thought probes that required participants to report on their thoughts immediately prior to the presentation of the probe. This technique permitted a close examination of the relationship between mind-wandering and performance and how both changed over the course of the task.

The purpose of understanding this relationship is to develop interventions to ameliorate the negative consequences associated with ADHD. Incorporating rest breaks into tasks is one potential way to help individuals with ADHD. To assess the efficacy of this strategy, we adapted the continuous performance task (CPT) to include breaks. Breaks are theorized to be beneficial because they allow for the replenishment of limited cognitive control resources. Consequently, breaks should be most helpful when these cognitive resources are low. However, individuals with ADHD tend to mind-wander without awareness or intention, so it is unclear whether their ability to monitor and evaluate their thoughts is compromised. The first experiment allowed participants to choose if and when to take breaks to determine if ADHD participants are able to self-monitor and take action to improve their behavior. The second experiment included both subject-initiated and experimenter-imposed breaks in order to test whether the beneficial effects of the breaks are related to the ability to choose if/when to take them or if the break itself is critical. Because stimulant medication has been shown to normalize abnormal brain activity and performance deficits in ADHD, we also tested ADHD participants on and off medication in the second experiment to see whether medication status influenced their response inhibition, ability to self-monitor, and/or the usefulness of breaks.

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Chapter II

Evaluating the Relationship between Mind-Wandering and Response Inhibition in ADHD

Introduction

Attention-deficit/hyperactivity disorder (ADHD) manifests in adults as a disorder of inattention more than a disorder of hyperactivity and is characterized by symptoms such as disorganization, forgetfulness, and difficulties ignoring irrelevant information and exerting mental effort (American Psychiatric Association, 2013; Biederman, Mick & Faraone, 2000). Cognitive deficits related to these symptoms suggest that cognitive control, the voluntary goal-oriented control of behavior, may be at the core of ADHD dysfunction.

Mind-wandering is an example of cognitive control failure and is characterized by a decoupling of attention from the present task context toward unrelated concerns (Mooneyham & Schooler, 2013; Schooler et al., 2011). Some researchers have noted that mind-wandering itself is "reminiscent of certain ADHD symptoms" in that it involves internal thoughts distracting from external-task goals (Seli, Smallwood, Cheyne, & Smilek, 2015, p.629). As such, mind-wandering can disrupt goal-directed behavior and impair performance on a number of tasks including reading (Schooler, Reichle, & Halpern, 2004), sustained attention (McVay & Kane, 2009), and working memory (Mrazek et al., 2011).

Previous research has linked both increased mind-wandering and increased ADHD symptomatology to failures in response inhibition, which occur when participants fail to interrupt an ongoing behavior when conditions demand it (Barkley, 1997; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Epstein et al., 2003; Shaw & Giambra, 1993). Shaw and Giambra's seminal paper documented greater task-unrelated thoughts in college students who had been previously diagnosed with ADHD, and those individuals also had more frequent failures of response inhibition (1993). The association between ADHD symptomatology and mind-wandering has been measured with the probe-caught method in laboratory tasks and daily life as well as with questionnaires about overall occurrences of mind-wandering and attentional lapses (Franklin et al., 2014; Seli et al., 2015).

These studies, however, have important limitations concerning the generalizability of their results to other participants and to other tasks. Some studies have exclusively relied on non-clinical populations (e.g. Franklin et al., 2014) and have argued that characterizing ADHD as a continuum instead of a category is useful as many negative consequences associated with ADHD are also found in subclinical ADHD populations (Overbey, Snell, & Callis, 2011; Whalen, Jamner, Henker, Gehricke, & King, 2003, as cited in Franklin et al, 2014). Although this type of research may be beneficial for those with heightened levels of inattention, it may not necessarily capture the consequences of clinically significant inattention. For example, Seli and colleagues measured trait levels of deliberate and spontaneous mind-wandering in both clinical and non-clinical samples (2015). They found that although non-clinical individuals with greater ADHD symptoms experienced higher levels of both categories of mind-wandering than those with lesser ADHD symptoms, the individuals with a clinical diagnosis of ADHD showed more spontaneous, but not deliberate, mind-wandering than the non-clinical high-symptom participants. If only non-clinical individuals were examined, then the conclusions regarding the association between symptomatology and intentional mind-wandering would be incomplete. Further, there has been a focus on symptoms of hyperactivity (Shaw & Giambra, 1993) or on combined symptoms

(Franklin et al., 2014; Seli et al., 2015), despite the fact that symptoms of inattention generally persist into adulthood longer than symptoms of hyperactivity or impulsivity (Biederman, Mick, & Faraone, 2000). Consequently, it is critical to assess symptoms of inattention to draw conclusions about adult ADHD and task-unrelated thoughts, and it is important to utilize both non-clinical and clinical populations to understand what deficits characterize ADHD specifically compared to general inattention.

Although studies have often employed the probe-caught method to assess mind-wandering, the tasks in which these probes are used and the nature of those probes vary from one study to another. The specific task in which individuals are engaged has substantial implications for the frequency of task-unrelated thoughts, as those who are completing more difficult tasks or tasks that require deeper levels of engagement (e.g. reading) are less likely to experience mind-wandering (Smallwood, Fishman, & Schooler, 2007; Stawarcyzk, Majerus, Catale, & D'Argembeau, 2014). Additionally, the rate of probe presentation influences mind-wandering, with more frequent probes leading to fewer reports of mind-wandering (Seli, Carriere, Levene & Smilek, 2013). To further complicate matters, the instructions regarding the probes are not identical from one study to another: some ask participants to report on any task-unrelated thoughts that occurred since the previous probe (e.g. Shaw & Giambra, 1993) but others ask participants to report on their thoughts just immediately prior to the probe (e.g. Christoff et al., 2009).

Our approach was to use a non-clinical population to then refine our task parameters (e.g. trial number, probe frequency, probe options) to best study mind-wandering in individuals with a clinical diagnosis of ADHD. In addition to general task-level effects, we also examined time-on-task effects. Prior studies have shown both performance decrements (Epstein et al., 2003;

Smallwood et al., 2004) and increases in task-unrelated thoughts (Cunningham, Scerbo, & Freeman, 2000; McVay & Kane, 2012; Smallwood, Obonsawin, & Reid, 2002) over time, plus fluctuations in mind-wandering from block to block predict performance from block to block (Thomson, Seli, Besner, & Smilek, 2014), but these effects have not been explicitly studied in individuals with ADHD. By including both No-go and Go trials before the probe and asking participants to report on their thoughts in the time immediately preceding the probe, we were able to examine the link between performance and task-unrelated thoughts more closely.

Experiment 1: Non-clinical sample

Methods

These data were collected as part of a larger protocol to assess possible creativity differences as a function of mind-wandering. This protocol included creativity questionnaires (Creative Personality Scales; Creative Achievement Questionnaire) and creativity tasks that measured verbal fluency (Controlled Oral Word Association Task; Theme Task), non-verbal fluency (Five Point Test), divergent thinking (Unusual Uses Task; Abbreviated Torrance Test for Adults), and convergent thinking (Remote Associates Test). The results of this investigation of creativity were largely null and unrelated to the present focus on mind-wandering, and so these data will not be reported here. This paper will focus only on the Connor's Adult ADHD Rating Scale and the Connor's Continuous Performance Test, which were used to assess inattention and mind-wandering, respectively.

Participants

A total of 161 participants from the University of Michigan-Ann Arbor participated in this study. All participants were enrolled in the Introduction to Psychology course and received course credit for their participation. Due to data collection errors (failure to collect gender and age information necessary for CAARS scoring) and technical issues (experimental program crashing), only 92 participants (60 females, mean age = 18 years, range = 17-23) had complete data to include in the analyses.

Materials

Connor's Adult ADHD Rating Scales Self-Report Screening Version (CAARS-S:SV). The CAARS screening form is a self-report measure that assesses ADHD symptoms according to the criteria outlined in the DSM-IV (test-retest correlation= .88-.91) (Connors, Erhardt, & Sparrow, 1999). It consists of 30 questions with responses ranging from 0 ("not at all, never") to 3 ("very much, very frequently"). There are four subscales: Inattentive Symptoms, Hyperactive-Impulsive Symptoms, Total ADHD Symptoms, and an ADHD Index. The final score on each subscale is reported as a *t*-score which takes both age and gender into account. Although the sample was not clinically diagnosed with ADHD, there were 21 participants who had inattention scores that were greater than or equal to 61 which would be considered above the 86th percentile of scores and in the range typically consistent with clinically significant ADHD. Those participants were categorized as "above average inattention" and the remaining 71 participants were categorized as "average inattention".

Connor's Continuous Performance Test (CPT) – modified. The CPT is a computerized task used to measure response inhibition (Connors, Epstein, Angold, & Klaric, 2003). Single letters are presented to participants, and they are instructed to respond by depressing the spacebar to every letter except "X". Each letter was presented for 250 ms with an interstimulus interval (ISI) of 1000, 2000, or 4000ms. 90% of trials required a response, and 10% of trials required withholding a response. The task consisted of 576 trials presenting continuously, with no breaks during the presentation. There were six blocks of trials, with each

ISI randomly occurring for 32 consecutive trials in each block. This version of the CPT was modified to include mind-wandering probes. On 10% of the trials (randomly determined), participants were probed with, “What were you thinking about just now?”. There were 7 response options which were explained in advance: 1) the task: thinking about the letters or the appropriate response; 2) your task performance: evaluating your own performance; 3) everyday stuff: thinking about recent or impending life events or tasks; 4) current state of being: thinking about conditions such as hunger or sleepiness; 5) personal worries: thinking about concerns, troubles, or fears; 6) daydreams: having fantasies disconnected from reality; 7) other: other thought types. During the task, the thought probes presented the italicized seven options and participants indicated their response by pressing the corresponding number key. Separating the two probe options relating to the task did not reveal any significant differences between thinking about the task and thinking about task performance: both were negatively associated with false alarms (r_{task}=-.23, p<.05; $r_{performance}$=-.14, p=.19) and were reported at similar levels between the average and above-average inattention group. Consequently, the first two response options were combined into a “task-related thoughts” (TRTs) category, and the other five response options were combined into a “task-unrelated thoughts” (TUTs) category.

Procedure

The study duration was approximately 1.5 hours, and testing was conducted in groups ranging from 5 to 15 participants. The first portion of the study consisted of the timed administration of the creativity tasks. The second portion included the untimed questionnaires and the computerized CPT. Following the CPT, participants were debriefed.

Results

Overall performance

There was a main effect of ISI on false alarms, $F(2,180)=6.20$, $p<.01$ with false alarms increasing with longer ISIs, but there was no interaction between group and ISI. There was a main effect of ISI on TUTs, $F(2,180)=62.72$, $p<.001$, with TUTs increasing with longer ISIs. There was an interaction between group and ISI for TUTs, $F(2,180)=3.06$, $p<.05$ in that participants with average inattention showed a greater increase in TUTs at longer ISIs than participants with above average inattention, but this was primarily driven by the average inattention group's low TUTs in the shortest ISI (see Appendix A for summary of descriptive statistics and ANOVA results). The ISIs were collapsed for the following analyses. Overall performance on the task is summarized in Table 1.1.

Table 1.1. *Summary of ADHD Symptoms and CPT Performance for Full Sample*

	M (SD)
CAARS-Inattention	53.05 (9.21)
CAARS-Hyperactivity	51.13 (10.76)
Hits (%)	97.75 (5.61)
False alarms (%)	48.70 (21.95)
d'	2.45 (.97)
Go reaction time (ms)	350.48 (49.20)
Task unrelated thoughts (%)	45.91 (25.42)

Consistent with our hypothesis, TUTs were significantly positively associated with poor response inhibition as measured by false alarms, $r=.303$, $p<.01$ (Figure 1.1).

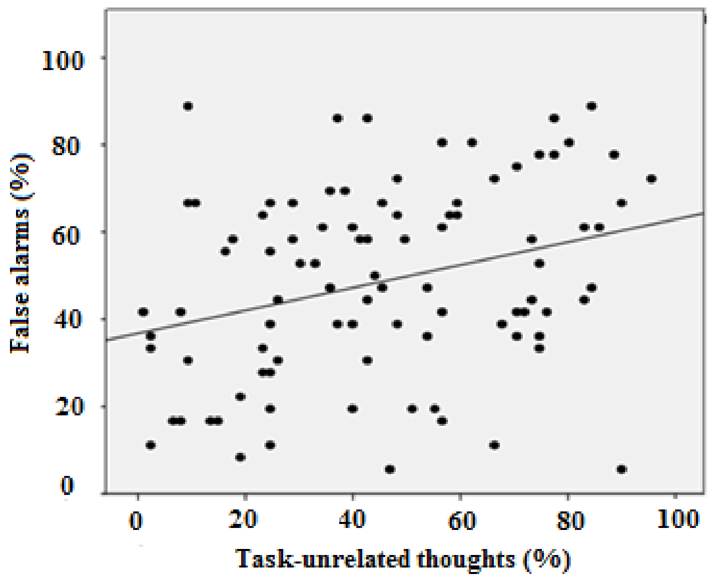

Figure 1.1. Relationship Between TUTs and False Alarms

Time-on-task effects

In order to assess performance and mind-wandering over time, we compared the first half of the task to the second half. Both false alarms, $t(91)=3.94$, $p<.001$, and TUTs, $t(91)=7.232$, $p<.001$, increased in the second half of the task suggesting that participants were not able to maintain their performance or focus over the length of the task (Figures 1.2 and 1.3). False alarms and TUTs were significantly correlated in the first half of the task, $r=.28$, $p<.01$, and in the second half of the task, $r=.23$, $p<.05$.

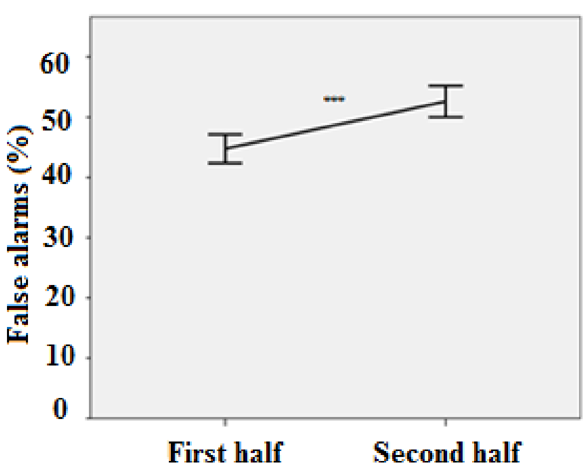

Figure 1.2. False Alarms by Half

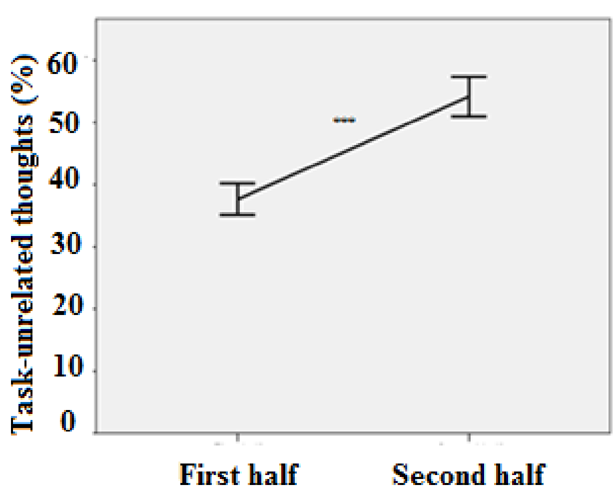

Figure 1.3. TUTs by Half

Probe analysis

These results indicate an overall association between TUTs and poor performance. The embedded probes allowed us to conduct a more detailed analysis of performance immediately before the probe: reports of TUTs were more often preceded by errors in the four trials pre-probe compared to TRTs, $t(91)=5.08$, $p<.001$ (Figure 1.4). This effect demonstrates the close relationship between errors and TUTs on a trial-by-trial level.

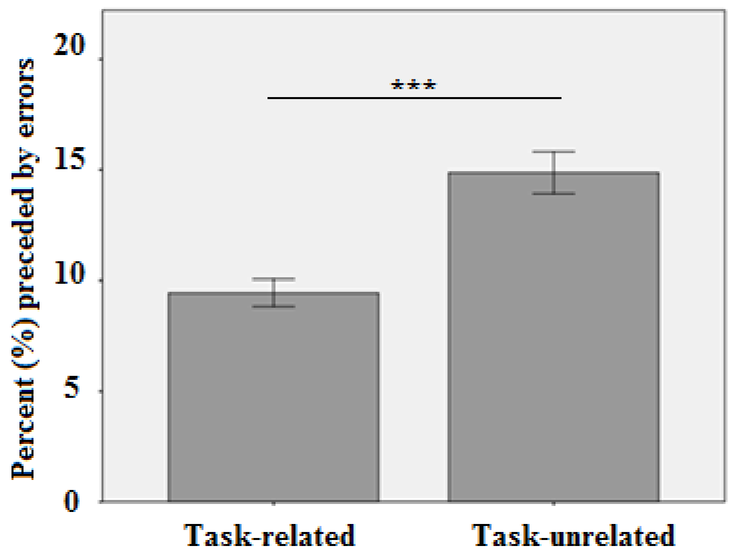

Figure 1.4. *Pre-Probe Errors as a Function of Thought Type*

Analyses of ADHD symptomatology

The performance of participants with above-average inattention was compared to the performance of participants with average inattention in order to determine if ADHD-like symptoms would moderate the results. Our hypotheses were supported as participants with above-average inattention had significantly higher false alarm rates, $t(90)=2.12$, $p<.05$, and marginally higher TUTs, $t(90)=1.63$, $p=.107$ (Figures 1.5 and 1.6). Additionally, ADHD symptomatology predicted false alarms, *ß*=8.10, $p=.09$, after controlling for the effect of TUTs, *ß*=.24, $p<.01$ (see Appendix A for summary of the regression analysis).

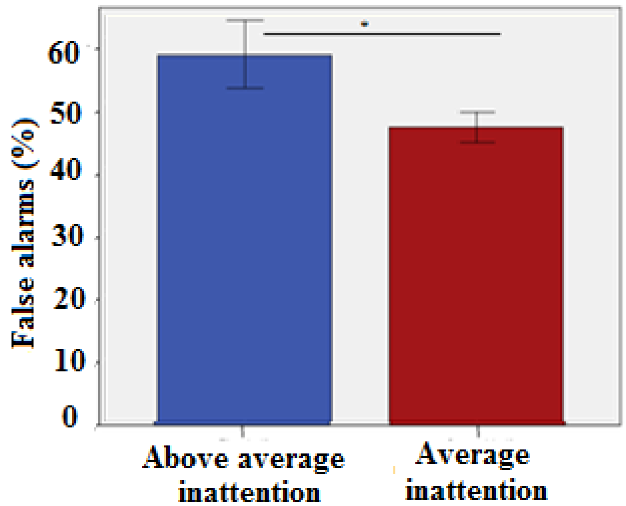

Figure 1.5. False Alarms by Inattention Group

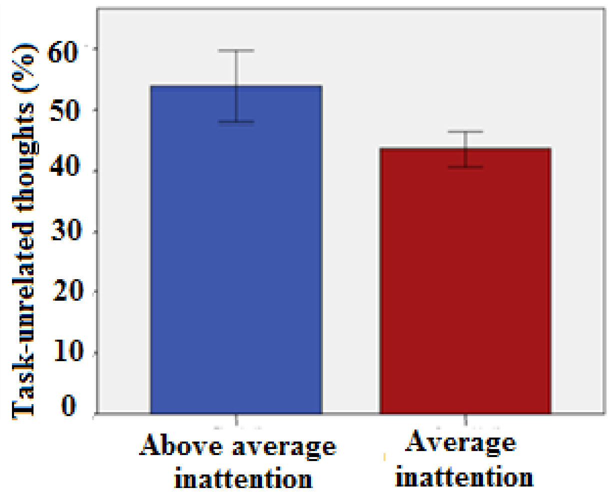

Figure 1.6. TUTs by Inattention Group

Contrary to predictions, there was not a significant interaction between group and half on false alarms, *F*(1,90)=1.77, *p*=.19 (Figure 1.7). However, the above-average inattention group showed a marginally significant increase in TUTs from the first half to the second half of the task compared to the average inattention group, *F*(1,90)=3.70, *p*=.06 (Figure 1.8).

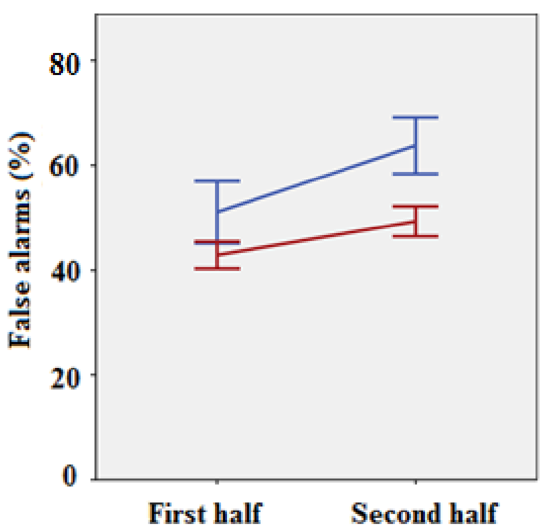

Figure 1.7: False Alarms by Half by Inattention Group

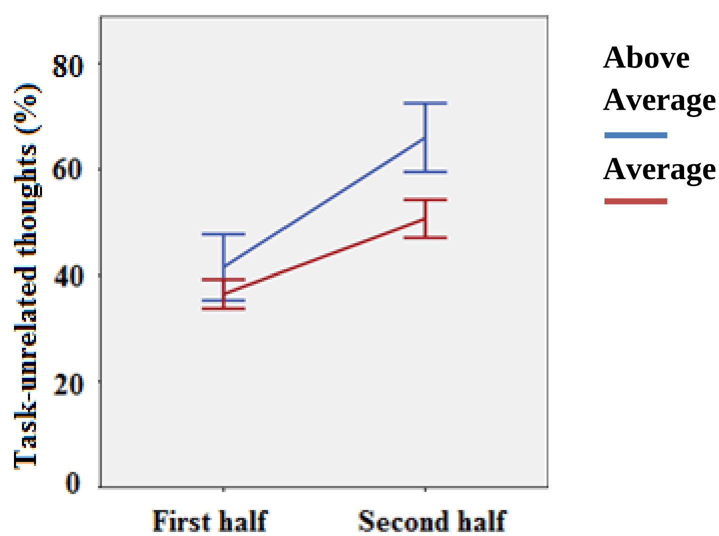

Figure 1.8: TUTs by Half by Inattention Group

In summary, greater TUTs are associated with increased false alarm rates and both TUTs and false alarms show an increase over time. Individuals with above average inattention have higher false alarm rates and a greater proportion of task-unrelated thoughts compared to individuals with average attention, and this difference is magnified in the second half of the task. Additionally, both ADHD symptomatology and the proportion of TUTs predicted false alarm rates, and reports of TUTs were more often preceded by errors than TRTs. After showing that inattention is linked to impaired response inhibition and increased TUTs in a non-clinical sample, we adapted the protocol to test our hypotheses in a clinical sample.

Experiment 2: Clinical sample

Methods

Participants

A total of 62 participants (31 ADHD, 31 control) from the University of Michigan-Ann Arbor participated in this study. All participants were enrolled in the Introduction to Psychology course and received course credit for their participation. Eligibility for the ADHD group included a current or past diagnosis of ADHD. Fifteen ADHD participants had one or more comorbid disorders (including anxiety and/or depression), and 23 ADHD participants had taken stimulant medication within 24 hours of the testing session. One ADHD participants declined to indicate medication status. Control participants were recruited to match the ADHD participants based on gender and age (+/- two years). Eligibility for the control group included no current or past diagnosis of ADHD, no use of stimulant medication, and no comorbid disorders.

Materials

ADHD Adult Self-Report Scale (ASRS). The ASRS consists of 18 questions based on the DSM-IV-TR criteria and has demonstrated test-retest reliability (.58-.77) and internal consistency (.63.-.72) (Kessler et al., 2007). Individuals report on the frequency of symptoms experienced in the past 6 months with the response options of “never”, “rarely”, “sometimes”, “often”, and “very often”. The final score is a symptom count of inattentive and hyperactive-impulsive symptoms.

Connor's Adult ADHD Rating Scales Self-Report Long Version (CAARS-S:LV). The CAARS long version includes six subscales: Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Problems with Self-Concept, DSM-IV: Inattentive Symptoms, DSM-IV: Hyperactive-Impulsive Symptoms, DSM-IV: Total ADHD Symptoms, and an ADHD Index (test-retest correlation= .88-.91) (Connors, Erhardt, & Sparrow, 1999). It consists of 66 questions with responses ranging from 0 ("not at all, never") to 3 ("very much, very frequently"). The final score of each subscale is reported as a *t*-score which takes both age and gender into account.

Daydreaming Frequency Scale (DDFS). The DDFS is a 12-item subscale of the Imaginal Process Inventory that has a test-retest reliability of .76 (Giambra, 1993; Singer and Antrobus, 1970). Participants respond based on the extent to which they experience daydreaming in their daily life on a 5-point Likert scale. The final score is an average of the responses with higher values indicating a greater tendency to daydream.

Cognitive Failures Questionnaire – Memory and Attention Lapses (CFQ-MAL). The CFQ-MAL is a 40-item questionnaire that evaluates memory and attention lapses (test-retest reliability=.71) (Bridger, Johnsen, & Brasher, 2013; McVay and Kane, 2009). Participants report the frequency of lapses on a 5-point scale ranging from 1 ("never") to 5 ("very often"). The final score is a sum of the responses with higher values indicating higher frequency of memory and attention lapses.

Intrinsic Motivation Index (IMI). The IMI is a 23-item scale that measures four dimensions of intrinsic motivation including interest-enjoyment, perceived competence, effort-importance, and tension-pressure (Cronbach's $\alpha = .85$) (McAuley, Duncan, & Tammen, 1989). Participants are instructed to indicate the extent to which the statements are true based on their experience during a specific task (e.g. “I felt relaxed while doing the task”; “I found the task very interesting”). The scale ranges from 1 (“not at all true”) to 7 (“very true”) with the midpoint representing “somewhat true”. Each dimension’s items are summed to produce final subscale scores.

Connor’s Continuous Performance Test (CPT) – modified. This version of the task was based on the previous version with a few important modifications to maximize the opportunity to measure task-unrelated thoughts. The number of trials was increased to 754 with probes occurring on fewer than 5% of trials. Because there were 2 task-related and 5 task-unrelated options in the previous version that were collapsed for analysis, we reduced the number of probe options from 7 to 3. The probe options were: 1) the task: thinking about the rules or your performance; 2) personal matters: thinking about upcoming or recent events/tasks, either emotional or non-emotional; and 3) other off-task thoughts: daydreaming zoning out, or other thought types. The latter two response options were collapsed into one task-unrelated thought category for analysis. Finally, due to the lack of interaction between ADHD symptomatology and ISI in Experiment 1, this version had a constant ISI of 2000ms.

Exit Questionnaire. This open-ended questionnaire was given to participants after they completed the CPT in order to qualitatively evaluate their experience. Questions included: “Do you think the mind-wandering questions during the task were able to accurately assess your thoughts? Why or why not”; “Did you think the mind-wandering questions during the task had an effect on your performance? If so, was it a positive effect or a negative effect? Please explain..” “Did you have a particular topic or idea you kept thinking about if/when you reported being off task?”.

Semi-Structured Clinical Interview. The ADHD semi-structured interview was administered by a lab manager or a senior research assistant who had been trained by the primary author under the guidance of a clinical psychiatrist. Training involved discussing the interview protocol, practicing with other research assistants, and observing interviews. First, any history of previous ADHD diagnosis and treatment was identified. Next, a checklist of symptoms was reviewed from the three symptom clusters of ADHD: inattention, hyperactivity, and impulsivity. Next, the person's symptoms from early schooling through high school, college, and up to the present time were assessed. The pervasiveness of symptoms was discussed in terms of how they manifested in the person's occupational and interpersonal relationships. The interview lasted 10-25 minutes depending on the complexity of the person's history and symptom severity. The interview was used to confirm group membership and was primarily used to exclude remitted individuals with ADHD and control subjects who showed ADHD-like symptoms despite never receiving a clinical diagnosis.

Procedure

The testing session lasted approximately 1 to 2 hours. After providing informed consent, participants filled out the ASRS and CAARS-S:LV questionnaires. Participants then completed the CPT, the exit questionnaire, the IMI, the DDFS and the CFQ-MAL. Following the written questionnaires, the trained research assistant would administer the semi-structured clinical interview and then debrief the participants.

Results

Individual differences

Individuals with ADHD scored significantly higher on both inattention and hyperactivity subscales of the ASRS and CAARS (Table 2.1). Importantly, scores were higher on inattention subscales than hyperactivity subscales (ASRS: $t(61)=5.94$, $p<.001$; CAARS: $t(61)=5.68$, *p*<.001), which supports the importance of focusing on inattention in young adult populations. There were no significant differences on measures of intrinsic motivation or daydreaming frequency, but the ADHD group reported more instances of attention and memory lapses as indexed by the CFQ, *t*(59)=4.39, *p*<.001.

Table 2.1. *Summary of Individual Difference Variables*

	ADHD		Control	
	M (SD)	*N*	*M (SD)*	*N*
ASRS-Inattention***	5.83 (2.27)	31	2.71 (2.02)	31
ASRS-Hyperactivity**	3.45 (2.08)	31	1.81 (2.02)	31
CAARS-Inattention***	62.74 (9.58)	31	52.84 (8.98)	31
CAARS-Hyperactivity**	56.10 (10.29)	31	47.19 (10.42)	31
IMI: Interest	11.61 (4.98)	31	12.10 (5.62)	31
IMI: Competence	15.68 (7.32)	31	16.90 (4.61)	31
IMI: Pressure	15.68 (6.62)	31	16.40 (5.92)	25
IMI: Choice	22.19 (7.36)	31	21.92 (6.48)	25
DDFS	39.81 (9.49)	31	36.73 (11.12)	30
CFQ***	126.16 (25.09)	31	101.17 (18.90)	30

Note: Uneven sample sizes are due to incomplete questionnaires and a protocol change
Significant group differences indicated by *p<.05, **p<.01, ***p<.001

As expected, the proportion of TUTs was positively associated with scores on both the DDFS, *r*=.20, *p*=.12, and the CFQ, *r*=.35, *p*<.01. However, scores on these measures were not predictive of false alarm rates. Interest in the task was not related to TUTs, *r*=-.10, *p*=.44, or false alarms, *r*=-.05, *p*=.70, which suggests that boredom was not a significant contributing factor to performance. Participants were typically correct in their assessment of their performance: perceived competence was negatively related to false alarm rates, *r*=-.25, *p*<.05. Perceived competence was not related to TUTs, *r*=-.16, *p*=.23.

ADHD subgroups

Performance was consistent across individuals with ADHD: there were no significant differences between those who only had an ADHD diagnosis (pure ADHD) and those who had one or more comorbid diagnoses, or between those who were un-medicated and medicated onfalse alarms, TUTs, or reaction time (Table 2.2). Similarly, there were no differences on any of the questionnaire measures between the ADHD subgroups. Consequently, we compared the ADHD group as a whole to the control group for the remaining analyses.

Table 2.2. *Summary of Individual Difference Variables and CPT Performance for ADHD Subgroups*

	Un-medicated ADHD (n=7)	Medicated ADHD (n=23)	Pure ADHD (n=16)	Comorbid ADHD (n=15)
	M(SD)			
ASRS-Inattention	6.00 (2.16)	5.87 (2.36)	5.56 (1.86)	6.13 (2.67)
ASRS-Hyperactivity	2.71 (1.98)	3.70 (2.14)	3.75 (2.18)	3.13 (2.00)
CAARS-Inattention	65.29 (9.03)	62.83 (9.12)	63.44 (8.25)	62.00 (11.08)
CAARS-Hyperactivity	55.86 (14.77)	56.65 (8.88)	57.38 (9.00)	54.73 (11.66)
IMI-Interest	10.14 (3.18)	12.26 (5.38)	11.31 (5.03)	11.93 (5.08)
IMI-Competence	16.00 (6.68)	15.13 (7.46)	19.00 (6.69)	12.13 (6.38)
IMI-Pressure	12.29 (6.42)	16.52 (6.58)	16.00 (4.84)	15.33 (8.28)
IMI-Choice	22.71 (6.21)	22.78 (7.03)	24.63 (6.08)	19.60 (7.91)
DDFS	38.86 (12.03)	40.00 (9.10)	41.88 (9.15)	37.60 (16.28)
CFQ	114.86 (25.46)	129.91 (24.98)	126.81 (24.40)	125.47 (26.64)
False alarms (%)	44.20 (22.57)	37.84 (18.86)	40.92 (22.18)	36.87 (16.28)
TUTs (%)	63.81 (20.13)	58.70 (18.28)	56.25 (20.69)	66.22 (16.99)
Go RT (ms)	341.85 (54.34)	385.76 (77.53)	357.84 (71.77)	395.07 (71.92)

Overall performance

Individuals with ADHD had marginally slower response times compared to control participants, $t(60)=1.65$, $p=.11$. Because reaction times were negatively correlated with false alarms, $r=-.505$, $p<.001$, reaction time was used as a covariate in analyses involving false alarms.

As expected, ADHD participants performed worse than control participants indicated by marginally higher false alarm rates after controlling for reaction time, $F(1,62)=3.10$, $p=.08$. Additionally, ADHD participants were more likely to report having TUTs compared to TRTs, $t(30)=3.19$, $p<.01$, and they reported a higher percentage of TUTs compared to control participants, $t(60)=3.09$, $p<.01$ (Figure 2.1). TUTs were significantly related to false alarms, $ß=.19$, $p<.05$, after controlling for reaction time, $ß=-.17$, $p<.001$.

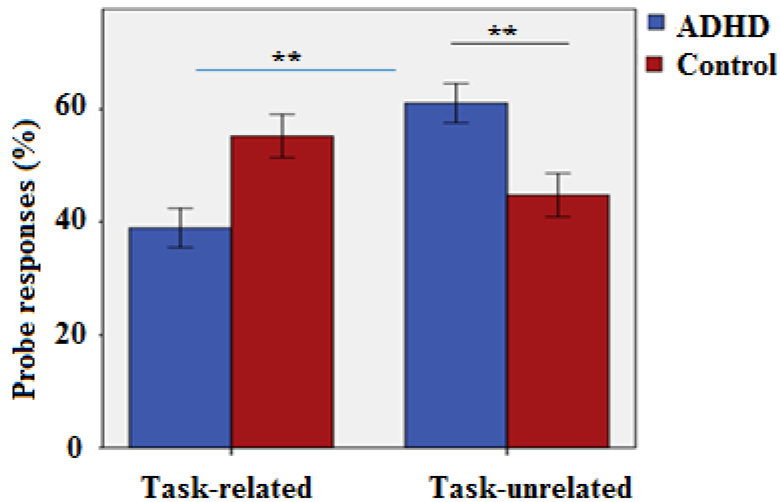

Figure 2.1. Probe Responses by Group

Time-on-task effects

To determine whether the groups showed different patterns of performance over time, the task was divided into halves. A group-by-half ANCOVA with reaction time as the covariate identified a marginally significant main effect of group, $F(1,59)=3.26$, $p=.07$ but no effect of half or interaction, suggesting that performance did not worsen over time (see Appendix B for summary of ANOVA results). There was a main effect of half on TUTs, $F(1,60)=35.94$, $p<.001$, with an increased proportion of TUTs in the second half compared to the first half of the task. Interestingly, the groups displayed different patterns of mind-wandering over time (Figure 2.2). Control participants began the task more likely to report TRTs compared to TUTs, $t(30)=3.52$, $p<.001$, but in the second half of the task they were equally likely to report TRTs and TUTs, *t*(30)=.873, *p*=.39. ADHD participants started the task reporting similar amounts of TRTs and TUTs, *t*(30)=1.174, *p*=.25, and the proportion of TUTs was significantly higher than TRTs in the second half of the task, *t*(30)=4.62, *p*<.001.

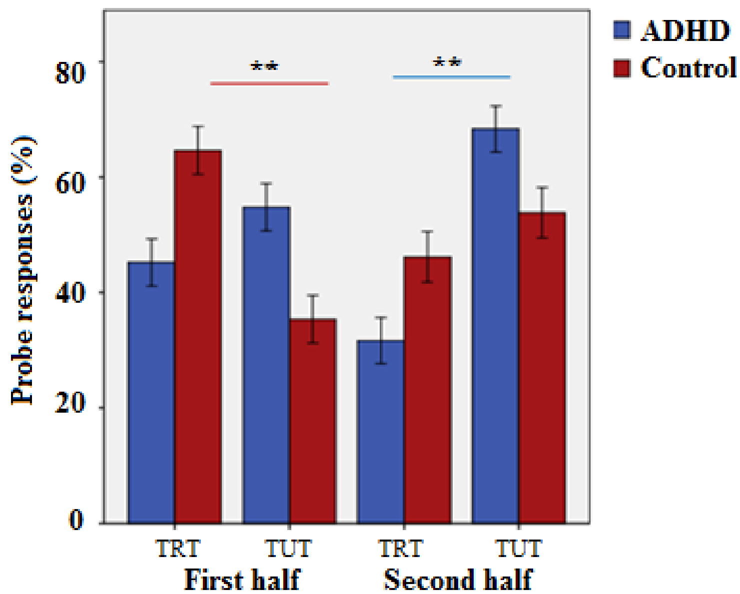

Figure 2.2. Probe Responses by Half by Group

Probe analyses

Consistent with the results from the previous experiment, TUTs were more often preceded by errors in the four pre-probe trials compared to TRTs, *F*(1,59)=27.93, *p*<.001, and this effect was consistent between groups (Figure 2.3).

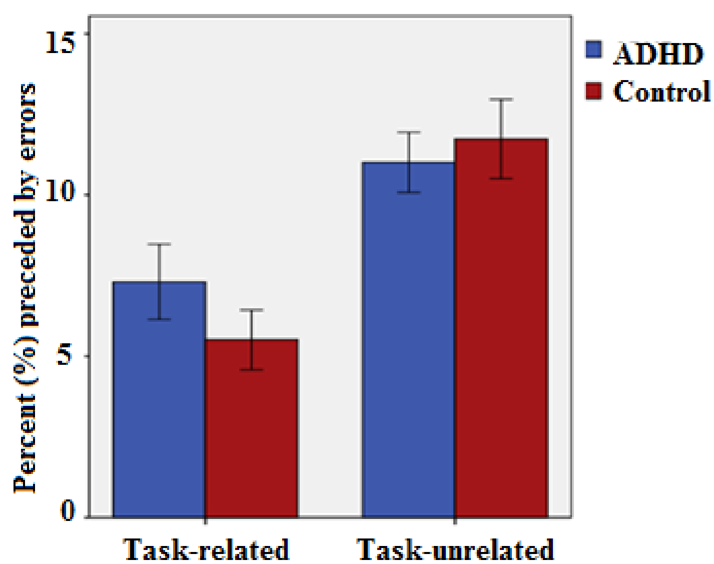

Figure 2.3. Pre-Probe Errors as a Function of Thought Type

To analyze the potential impact of the probes on performance, we utilized the responses to the exit questionnaire question: “Do you think the probes affected your performance? If so, was it a positive effect or a negative effect?” The majority of ADHD participants (n=20) indicated that the probes had a positive effect by providing short breaks and reminding them to focus on the task. However, there were some ADHD participants (n=5) who reported a negative effect of the probes because they were a source of distraction or they interrupted the flow of their responding. ADHD participants who reported a positive effect had a significantly higher d’ (an index of sensitivity), $t(23) = 1.84$, $p<.05$, compared to the ADHD participants who reported a negative effect (Figure 2.4).

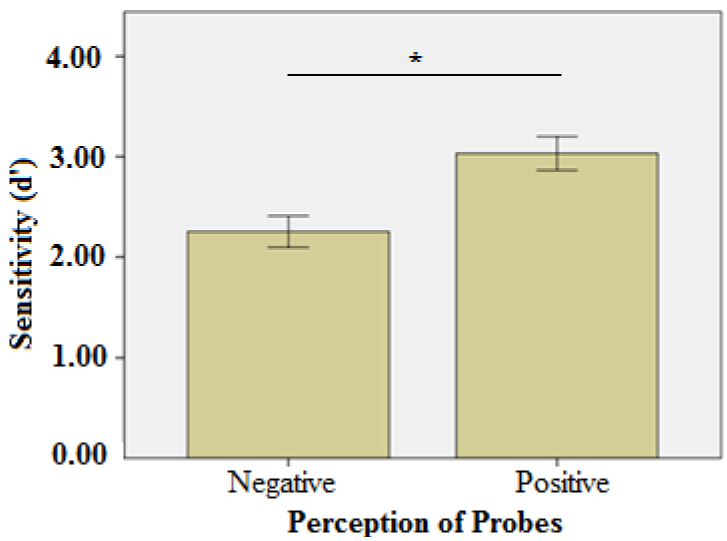

Figure 2.4. Sensitivity of ADHD Participants Based on Their Perception of the Probes

Discussion

Our goal was to assess the role of mind-wandering as part of cognitive control deficits in adult ADHD by exploring the relationship between task-unrelated thoughts and performance on a sustained attention task. Consistent with previous research, task-unrelated thoughts were associated with impaired response inhibition on a sustained attention task in both non-clinical and clinical samples (Christoff et al., 2009; Smallwood, McSpadden, & Schooler, 2007). We were also able to show that reports of task-unrelated thoughts were more often directly preceded by errors compared to reports of task-related thoughts. This type of analysis is not feasible in studies that use probes to inquire about the occurrence of any task-unrelated thoughts *between probes* instead of *immediately prior* to the probe (e.g. Shaw & Giambra, 1993), or in studies that require only go-trials before a probe which excludes the impact of mind-wandering on response inhibition (e.g. Stawarcyzk et al., 2014).

We utilized a non-clinical sample to establish the appropriate task parameters before testing the task with a clinical sample. In the non-clinical sample, we identified a sub-sample of participants with above average inattention scores who had higher false alarm rates and a higher proportion of task unrelated thoughts compared to participants with average inattention scores. Additionally, the severity of inattention as indexed by scores on the CAARS significantly predicted false alarms. The individuals with a clinical diagnosis of ADHD displayed a similar pattern, yet they responded significantly more slowly than control participants, necessitating the use of reaction time as a covariate. This difference emphasizes the importance of using clinical samples and highlights the distinction between above-average inattention and clinically significant inattention. One variable that needs to be investigated in this context is the use of stimulant medication (Swanson, Baler, & Volkow, 2011). Mind-wandering has been linked to activation in the default-mode network of the brain (Christoff et al., 2009; Mason et al., 2007) which has been shown to be atypical in individuals with ADHD (Fassbender et al., 2009; Sonuga-Barke & Castellanos, 2007). Stimulant medication can normalize default-mode activity (Liddle et al., 2011; Peterson et al., 2009) which could then decrease the instances of attentional lapses.

We replicated the time-on-task effects on mind-wandering, as the proportion of task-unrelated thoughts significantly increased from the first half to the second half of the task (Cunningham, Scerbo, & Freeman, 2000; Robertson, Manly, Andrade, Baddeley & Yiend, 1997; Thomson et al., 2014). This effect was greater for the above-average inattention group compared to the average inattention group. The ADHD and control groups displayed different patterns of mind-wandering over time: control participants reported task-unrelated thoughts to 38% of the probes in the first half, which then increased to 53%; ADHD participants reported task-unrelated thoughts to 55% of the probes in the first half, which then increased to 68%. These results indicate that although task-unrelated thoughts increased over time for both groups, ADHD participants began the task less focused and engaged than control participants and finished the task yet more disengaged.

These experiments contribute to the growing body of literature implicating mind-wandering as an important feature of ADHD (Franklin et al., 2014; Seli et al., 2014; Shaw & Giambra, 1993). Future work will need to continue to incorporate knowledge gained from other mind-wandering research, including the distinction between unintentional/spontaneous and intentional/deliberate mind-wandering (Franklin et al., 2014; Smallwood & Schooler, 2015; Seli, Carriere, & Smilek, 2015; Seli, Risko, & Smilek, 2016a,b; Seli, et al., 2014). Researchers have suggested that individuals with ADHD specifically engage in spontaneous, but not deliberate, mind-wandering (Seli et al., 2014; Shaw & Giambra, 1993), and that the awareness of mind-wandering may mediate the relationship between ADHD symptoms and mind-wandering that is detrimental to performance (Franklin et al., 2014). This distinction may prove to be important as the two types are differentially affected by extrinsic factors such as target probability (Smallwood, McSpadden, & Schooler, 2007) and task difficulty (Seli, Risko, & Smilek, 2016b), and intrinsic factors like motivation (Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Seli, Wammes, Risko, & Smilek, 2015) and mindfulness (Seli, Carriere, & Smilek, 2015). The impact of mind-wandering on performance may also be mediated by the specific type of task-unrelated thought including external distraction, task-related interference, and stimulus-independent thoughts (Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011; Stawarczyk, et al., 2014; Unsworth & McMillan, 2014). One recent neuroimaging study identified different patterns of default mode network activity depending on the stimulus-dependency of task-unrelated thoughts: the highest degree of activation was associated with mind-wandering, operationalized as stimulus-independent task-unrelated thoughts (e.g. "thoughts about what the participant did last evening, about what he/she needs to do this evening or about what significant others could be doing now"), and intermediate activity was associated with external distractions, operationalized as stimulus-dependent task-unrelated thoughts (e.g. "exteroceptive perceptions, such as noises, the luminance, the temperature, or other features of the current environment or interoceptive sensations, such as feeling thirsty, tired or other physical sensations") (Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011). The neural and behavioral consequences of stimulus-dependent task-unrelated thoughts might be different for adults with ADHD considering that they exhibit greater performance deficits resulting from external distractors compared to healthy adults (Forster, Robertson, Jennings, Asherson, & Lavie, 2014),

Understanding how and when mind-wandering occurs and is detrimental to performance will be critical to developing interventions. Our results suggest that, for some participants, the mind-wandering probes served as external cues that helped participants re-focus on the task. Pilot studies have employed similar external cues to improve attention, including a pager-like device that vibrated as a tactile prompt for students to check if they were paying attention

(Amato-Zech, Hoff, & Doepke, 2006; Moore, Anderson, Glassenbury, Lang, & Didden, 2013). Similarly, there has been success in reducing mind-wandering by increasing meta-awareness (Zedelius, Broadway, & Schooler, 2015), mindfulness (Jha et al., 2010) and self-monitoring (Clark, Prior, & Kinsella, 2000; Scheithauer & Kelley, 2014). For example, college students with ADHD who learned self-monitoring procedures (e.g. observing and recording behaviors with the goal of changing the behaviors in the future) had improved academic behavior and goal attainment compared to students who only learned study skills. Yet, some of the participants in our study reported a negative, distracting effect of the probes; other participants reported that they experienced no noticeable or long-term effects on their performance. Additional work is needed to clarify the extrinsic and/or intrinsic variables that differentiate between these subjective responses to the probes, as they may also relate to which intervention is likely to be efficacious for specific people in specific situations.

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Appendix A: Supplementary Tables for Chapter II, Experiment 1

Table 2.3. *Descriptive statistics for performance by ISI*

	Full sample (*n*=92)	Average inattention (*n*=21)	Above average inattention (*n*=71)
	M (SD)		
False alarms (%): 1000ms ISI	44.57 (24.60)	42.37 (24.91)	51.98 (22.50)
False alarms (%): 2000ms ISI	48.55 (25.06)	46.13 (23.98)	56.75 (27.46)
False alarms (%): 4000ms ISI	53.90 (25.99)	49.77 (24.48)	63.49 (28.68)
TUTs (%): 1000ms ISI	33.20 (26.84)	29.64 (25.49)	45.24 (28.39)
TUTs (%): 2000ms ISI	48.05 (27.28)	46.36 (26.89)	53.77 (28.56)
TUTs (%): 4000ms ISI	56.48 (26.70)	54.75 (26.52)	62.30 (27.11)

Table 2.4.*Summary of ISI by Group ANOVA Results*

	False Alarms			TUTs		
	df	*F*	*p*	*df*	*F*	*p*
ISI	2	6.20	.002	2	62.71	.00
Group	1	4.48	.04	1	2.65	.11
ISI*Group	2	.32	.73	2	3.06	.05
Error: ISI	180	(234.24)		180	(116.44)	
Error: Group	90	(1390.39)		90	(1904.64)	

Note: Values in parentheses represent mean square error

Table 2.5. *Summary of Multiple Regression Results with False Alarms as Dependent Variable*

	B	SE(B)	ß	*t*	*p*
Constant	35.44	4.53		7.90	.00
TUTs (%)	.24	.09	.28	2.72	.01
CAARS-Inattention	8.91	5.24	.17	1.70	.09

Note: CAARS-Inattention was dummy coded with “0” for average inattention and “1” for average inattention

Appendix B: Supplementary Table for Chapter II, Experiment 2

Table 2.6. *Summary of Half by Group ANOVA results*

	False Alarms		
	df	*F*	*p*
Half	1	16.36	.00
Group	1	4.48	.04
Half*Group	1	1.77	.19
Error: Half	90	(181.00)	
Error: Group	90	(926.92)	

Note: Values in parentheses represent mean square error

Chapter III

Assessing the Utility of Breaks to Improve Performance Deficits Associated with ADHD

Introduction

Attention-deficit/hyperactivity disorder (ADHD) has been described as a disorder of the regulation of thought and action in which deficits in inhibitory control result in both behavioral symptoms and poor task engagement (both in quality and in quantity) (Sonuga-Barke, 2002). Mind-wandering is one way that this dysregulation may affect task engagement in ADHD. Individuals with heightened ADHD symptomatology report more detrimental effects to their task performance as a result of mind-wandering (Franklin et al., 2014). Several studies have identified that mind-wandering in ADHD is characterized by more instances of "zone-outs", or mind-wandering episodes of which individuals are not aware, than "tune-outs", or off-task experiences that individuals know they are having (Smallwood, McSpadden, & Schooler, 2008). In addition to issues with recognizing when a mind-wandering episode is occurring, individuals with ADHD may have difficulties controlling the contents of their thoughts as studies have indicated that they also engage in more spontaneous/unintentional mind-wandering than deliberate/intentional mind-wandering (Seli et al., 2015). The link between ADHD symptoms and impaired performance due to mind-wandering may be partially driven by the lack of awareness, which suggests that enhancing the ability to detect off-task thoughts could reduce negative behavioral outcomes in individuals with ADHD (Franklin et al., 2014).

Indeed, previous studies have identified the utility of self-monitoring for individuals with ADHD. Adolescents with ADHD have difficulties with monitoring ongoing performance (Clark

Prior, & Kinsella, 2000). An intervention teaching self-monitoring behaviors to children with ADHD increased on-task behavior and improved academic performance more than an intervention solely focused on pharmacological treatment (Mathes & Bender, 1997 as cited in Harris, Friedlander, Saddler, Frizzelle, & Graham, 2005). Similarly, teaching college students self-monitoring procedures improved academic behavior and goal attainment more than just teaching study skills (Scheithauer & Kelley, 2014). Yet, regulating thought and behavior involves more than just monitoring one's thoughts: "maintaining adaptive behavior…[requires] an awareness of contextual demands, monitoring of one's behavior to evaluate whether it is appropriate for the context (i.e. self-monitoring) and adjusting behavior once a discrepancy is detected between the expected and actual outcomes (i.e. adaptive control)" (Shiels & Hawk Jr., 2010, p.952). In this way, failure to recognize off-task thoughts may be only part of the issue for individuals with ADHD; they could also have difficulties with adapting their behavior after they experience these attentional lapses.

One action that could help individuals maintain consistent performance is taking a break. Breaks are planned or spontaneous recesses from a task (Jett & George, 2003). Researchers have suggested that self-initiated breaks occur when there is an imbalance between the task demands and the individual's skills due to task difficulty, fatigue, and/or specific obstacles impeding the task goal, and the individual needs to engage in self-regulatory behavior to improve performance (Adler & Benbunan-Fich, 2013). The beneficial effects of breaks have been observed in sustained attention tasks which require participants to maintain attention for prolonged periods of time. Participants who were given rest breaks ranging from less than 2 minutes (Helton & Russell, 2015; Ross, Russell, & Helton, 2014); to 5 minutes (Arrabito, Ho, Aghaei, Burns & Hou, 2014) showed improved accuracy compared to participants who performed the task continuously (Arrabito, et al., 2014) and to those who performed a different task during the break (Helton & Russell, 2015; Ross, Russell, & Helton; 2014). The performance results are supported by self-report: Participants who were allowed rest breaks reported that the task was less effortful and demanding compared to participants who did not receive rest breaks (Ross, Russell, & Helton, 2014)

However, all of the aforementioned studies inserted breaks at specific points in the task which means that participants were not able to choose when to take a break. When given the choice to switch between multiple tasks, participants who experienced negative feelings about their current task (e.g. fatigue, frustration) tended to switch tasks more often (Adler & Benbunan-Fich, 2013). Individuals may benefit more from self-initiated breaks as a way to adjust their behavior when they experience negative feelings, attentional lapses, or performance difficulties. An experimenter-imposed break could be perceived by the participant as an interruption which would result in negative emotions like annoyance and anxiety (Bailey & Konstan, 2006; Zijlstra et al. 1999, as cited in Beeftink, van Eerde, & Rutte, 2008).

Additionally, despite the evidence that rest breaks can aid performance there are no studies that have investigated the utility of breaks in individuals with ADHD. If ADHD participants are unaware of their mind-wandering and not able to monitor their performance, then they may benefit from experimenter-imposed breaks because otherwise they would not be able to identify the best time(s) to take a break. Alternatively, breaks could hinder their performance by disrupting task momentum and encouraging task disengagement (Jett & George, 2003).

Our goal was to assess the efficacy of breaks during a sustained attention task in ADHD and control participants. The first study allowed participants to choose if and when to take breaks in order to determine whether individuals with ADHD are able to monitor their performance and/or task engagement and take breaks to maximize performance.. The second study included subject-initiated breaks and experimenter-imposed breaks to investigate if the value of the break is influenced by the decision of when to take a break. Because subject-initiated breaks have not been studied, we also wanted to identify what features of the break contribute to performance benefits and whether these features are different for ADHD and control participants or for subject-initiated and experimenter-imposed breaks. For the second study, ADHD participants were tested on and off of their medication to see if performance changed as a function of their medication status.

Experiment 1: Subject-initiated breaks

Methods

Participants

A total of 74 participants (37 ADHD, 37 control) participated in this study. Sixty-five University of Michigan participants (35 ADHD, 30 control) were enrolled in the Introduction to Psychology course and received course credit for their participation. Eight participants (2 ADHD, 6 control) recruited from the University of Michigan were paid $10 per hour for their participation. One control participants was recruited from Washtenaw Community College and was paid $17 per hour for her participation (the additional compensation was to accommodate any travel, assuming that non-UM participants would not be as close to campus as UM students). Eligibility for the ADHD group included a current or past diagnosis of ADHD. Twenty-two ADHD participants had one or more comorbid disorders (including anxiety and/or depression), and 26 ADHD participants had taken stimulant medication within 24 hours of the testing session. Control participants were recruited to match the ADHD participants based on gender and age

(+/- two years). Eligibility for the control group included no current or past diagnosis of ADHD, no use of stimulant medication, and no comorbid disorders.

Materials

ADHD Adult Self-Report Scale (ASRS). The ASRS consists of 18 questions based on the DSM-IV-TR criteria and has demonstrated test-retest reliability (.58-.77) and internal consistency (.63.-.72) (Kessler et al., 2007). Individuals report on the frequency of symptoms experienced in the past 6 months with the response options of "never", "rarely", "sometimes", "often", and "very often". The final score is a symptom count of inattentive and hyperactive-impulsive symptoms.

Connor's Adult ADHD Rating Scales Self-Report Long Version (CAARS-S:LV). The CAARS long version includes six subscales: Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Problems with Self-Concept, DSM-IV: Inattentive Symptoms, DSM-IV: Hyperactive-Impulsive Symptoms, DSM-IV: Total ADHD Symptoms, and an ADHD Index (test-retest correlation= .88-.91) (Connors, Erhardt, & Sparrow, 1999). It consists of 66 questions with responses ranging from 0 ("not at all, never") to 3 ("very much, very frequently"). The final score of each subscale is reported as a *t*-score which takes both age and gender into account.

Daydreaming Frequency Scale (DDFS). The DDFS is a 12-item subscale of the Imaginal Process Inventory that has a test-retest reliability of .76 (Giambra, 1993; Singer and Antrobus, 1970). Participants respond based on the extent to which they experience daydreaming in their daily life on a 5-point Likert scale. The final score is an average of the responses with higher values indicating a greater tendency to daydream.

Cognitive Failures Questionnaire – Memory and Attention Lapses (CFQ-MAL). The CFQ-MAL is a 40-item questionnaire that evaluates memory and attention lapses (test-retest reliability=.71) (Bridger, Johnsen, & Brasher, 2013; McVay and Kane, 2009). Participants report the frequency of lapses on a 5-point scale ranging from 1 ("never") to 5 ("very often"). The final score is a sum of the responses with higher values indicating higher frequency of memory and attention lapses.

Intrinsic Motivation Index (IMI). The IMI is a 23-item scale that measures four dimensions of intrinsic motivation including interest-enjoyment, perceived competence, effort-importance, and tension-pressure (Cronbach's α = .85) (McAuley, Duncan, & Tammen, 1989). Participants are instructed to indicate the extent to which the statements are true based on their experience during a specific task (e.g. "I felt relaxed while doing the task"; "I found the task very interesting"). The scale ranges from 1 ("not at all true") to 7 ("very true") with the midpoint representing "somewhat true". Each dimension's items are summed to produce final subscale scores.

Conscientiousness Questionnaire. The conscientiousness scale is composed of 32 questions assessing facets of conscientiousness including self-efficacy, achievement-striving, organization, and self-discipline (Goldberg et al., 2006). Participants reported how accurately each statement described them now (not as they wished to be in the future) on a scale from 1 ("very inaccurate") to 5 ("very accurate"). The final score is a sum of the responses.

Self-Reflection and Insight Scale (SRIS). The SRIS is a 20-item scale measuring the need for and engagement in self-reflection (the inspection and evaluation of one's thoughts and behavior) and insight (the clarity of understanding one's thoughts, feelings and behavior) (test-retest correlation = .77-.78) (Grant, Franklin, & Langford, 2002). Participants respond based on how much they agree that each statement describes them on a scale from 1 "(strongly disagree") to 5 ("strongly agree"). The items of each subscale are summed to produce final scores.

Connor's Continuous Performance Test (CPT) – modified. The CPT is a computerized task used to measure response inhibition (Connors, Epstein, Angold, & Klaric, 2003). Single letters are presented to participants, and they are instructed to respond by depressing the spacebar to every letter except "X". Each letter was presented for 250 ms with an interstimulus interval (ISI) of 1500ms. 90% of trials required a response, and 10% of trials required withholding a response. The task consisted of 800 trials presented continuously. Participants were told that the task would take approximately half an hour and that they could "take as many breaks as necessary to maximize [their] speed and accuracy". They were instructed to press "Q" in order to take a break, at which point the task would stop, and then they would press "Enter" in order to resume the task. In order to reinforce this point, a red key cover was placed on the "Q" key and a green key cover was placed on the "Enter" key. When participants resumed the task, a "get ready" slide was displayed for three seconds before the experimental trials continued. Participants did not have access to any of their personal belongings while in the testing room.

The specific instructions were as follows:

> "Because we want you to perform to the best of your ability, you will be able to pace yourself during the task by controlling the number and timing of the breaks. Any time you feel your performance is declining due to fatigue or mind-wandering, you should take a break to maximize your performance through the entire task.
> On any trial, you have the option of pressing the red "Q" key on the keyboard to take a break. Keep your left index finger on the "Q" key at all times so you can immediately take a break. You can take a break for as long as you feel is necessary. When you are ready to resume the task, press the green "Enter" key.
> …Take as many breaks as necessary to maximize your speed and accuracy. The entire task will last approximately 30 minutes."

Exit Questionnaire. This open-ended questionnaire was given to participants after they completed the CPT in order to qualitatively evaluate their experience. Questions included: “Did you have a plan or strategy for when you decided to take breaks?”; “Did you take breaks more often after some types of trials compared to others?”; “What did you do during the breaks? Did you have a particular topic or idea you kept thinking about?”; “Do you think that taking breaks helped your performance on the task? Why or why not?”

Semi-Structured Clinical Interview. The ADHD semi-structured interview was administered by a trained research assistant. First, any history of previous ADHD diagnosis and treatment was identified. Next, a checklist of symptoms was reviewed from the three symptom clusters of ADHD: inattention, hyperactivity, and impulsivity. Next, the person's symptoms from early schooling through high school, college, and up to the present time were assessed. The pervasiveness of symptoms was discussed in terms of how they manifested in the person’s occupational and interpersonal relationships. The interview lasted 10-25 minutes depending on the complexity of the person’s history and symptom severity.

Procedure

The testing session lasted approximately 1 to 1.5 hours. After providing informed consent, participants filled out the ASRS and CAARS-S:LV questionnaires. Participants then completed the CPT, the exit questionnaire, the IMI, the Conscientiousness Questionnaire, and the SRIS. The protocol was altered partway through testing such that 26 participants completed the DDFS and the CFQ-MAL in place of the Conscientiousness Questionnaire and the SRIS. Following the written questionnaires, a trained research assistant would administer the semi-structured clinical interview and then debrief the participant.

Results

Individual differences

Table 3.1 summarizes the questionnaire results by group. Consistent with expectations, individuals with ADHD had higher levels of inattention and hyperactivity and reported more instances of attention and memory failures compared to control participants. ADHD participants scored lower on conscientiousness compared to control participants, most likely because the items that indicated high conscientiousness (e.g. "I think ahead"; "I pay attention to details") often overlapped with issues that typically characterize ADHD such as procrastination (e.g. "I do things at the last minute") and inattention (e.g. "I don't pay attention"). There were no differences in the level of interest in or perceived competence at the task. ADHD participants scored lower on insight compared to control participants, but did not differ in the tendency or need to engage in self-reflection. This pattern may suggest that individuals with ADHD are capable of self-monitoring (e.g. "I frequently take time to reflect on my thoughts") but do not necessarily self-evaluate as effectively as controls (e.g. they are more likely to endorse "Thinking about my thoughts makes me more confused" than "I usually have a very clear idea about why I've behaved a certain way").

Table 3.1. *Summary of Individual Difference Variables*

	Control (n=37)		ADHD (n=37)	
	M (SD)	*N*	*M (SD)*	*N*
ASRS-Inattention***	2.11 (1.59)	37	5.41 (2.29)	37
ASRS_Hyperactivity***	1.32 (1.23)	37	3.30 (2.01)	37
CAARS-Inattention***	49.78 (8.86)	37	65.65 (11.61)	37
CAARS-Hyperactivity***	44.81 (9.34)	37	57.05 (8.95)	37
IMI: Interest	12.84 (7.01)	37	12.73 (5.19)	37
IMI: Competence	21.51 (6.87)	37	21.95 (7.33)	37
DDFS	35.00 (14.75)	12	41.43 (8.92)	14
CFQ***	83.25 (41.51)	12	135.07 (21.85)	14

Conscientiousness*	127.00 (17.68)	25	116.83 (10.54)	23
SRIS: Engage	23.20 (4.35)	25	22.00 (4.01)	23
SRIS: Need	23.56 (3.9)	25	21.87 (4.04)	23
SRIS: Insight*	29.08 (5.0)	25	25.52 (4.86)	23

Note: Uneven sample sizes are due to incomplete questionnaires and a protocol change
Significant group differences indicated by *p<.05, **p<.01, ***p<.001

When assessing the full sample, there were no significant correlations between number of breaks (including zero) and any of the questionnaire measures. However, within the ADHD group, there was a significant positive relationship between number of breaks and the CFQ, *r*=.58, p<.05, and the DDFS, *r*=.53, *p*=.05, suggesting that the individuals with ADHD who were more susceptible to attentional lapses and/or mind-wandering were more likely to need and take breaks (Figure 3.1). There were no trait individual difference variables that differentiated between participants who did or did not take any breaks, or between those who took more or fewer than 3 breaks (see Appendix C for summary of descriptive statistics).

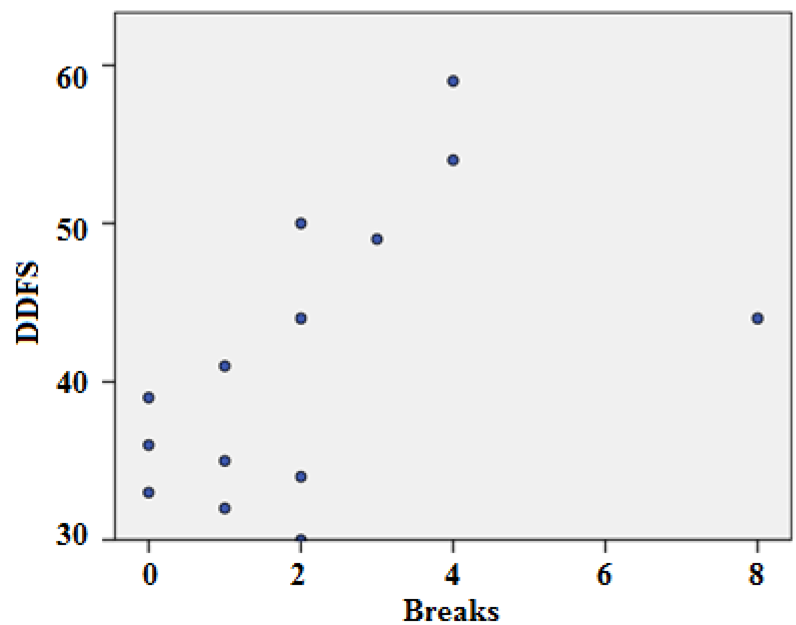

Figure 3.1. Relationship Between DDFS and Number of Breaks in Individuals with ADHD

ADHD subgroups

Individuals with ADHD who were un-medicated scored marginally higher than those who were medicated on the CFQ, $t(11)=1.83$, $p=.10$, and significantly higher on the DDFS, $t(11)=2.42$, $p<.05$. Although medicated ADHD participants reported similar levels of daydreaming compared to control participants, $t(21)=.93$, $p=.36$, they still experienced more frequent cognitive failures than control participants, $t(21)=3.71$, $p<.01$. There were no differences between the individuals with ADHD with and without comorbid diagnoses on any of the questionnaire measures.

Performance was consistent across ADHD participants. This pattern was true for the participants who did not take breaks (Table 3.2) and for those who did (Table 3.3). For the participants who did take breaks, the number of breaks did not vary between the sub-groups, but individuals with ADHD who were un-medicated took longer breaks than both those who were medicated, $t(27)=2.33$, $p<.05$, and control participants, $t(39)=2.27$, $p<.05$.

Table 3.2. *CPT performance for ADHD Subgroups With Zero Breaks*

	Un-medicated ADHD (n=1)	Medicated ADHD (n=6)	Pure ADHD (n=3)	Comorbid ADHD (n=5)
	M (SD)			
False alarms (%)	78.75	55.21 (23.52)	66.25 (3.31)	48.50 (28.65)
Go RT (ms)	262.47	295.10 (33.51)	273.62 (14.59)	305.03 (34.26)

Table 3.3. *CPT performance for ADHD Subgroups With Breaks*

	Un-medicated ADHD (n=9)	Medicated ADHD (n=20)	Pure ADHD (n=12)	Comorbid ADHD (n=17)	Control (n=32)
	M (SD)				
False alarms (%)	50.08 (21.24)	50.85 (18.57)	50.37 (17.75)	50.78 (20.46)	36.75 (18.64)
Go RT (ms)	311.05 (50.50)	329.11 (57.15)	315.47 (44.74)	329.17 (61.82)	341.29 (48.81)
Breaks	4.78 (3.35)	3.70 (2.74)	5.00 (3.33)	3.35 (2.47)	4.66 (3.28)
Break length (s)	63.53 (77.31)	22.66 (14.25)	40.57 (68.45)	31.65 (24.93)	28.54 (24.14)

Overall performance

Individuals with ADHD performed significantly worse than control participants, and this effect was magnified in the second half of the task. ADHD participants had higher false alarm rates than control participants, $t(72)=2.48$, $p<.05$ (Figure 3.2). A half by group mixed ANOVA identified an interaction, $F(1,72)=3.92$, $p=.052$, indicating that ADHD participants showed a significant increase in false alarms from the first half to the second half, but control participants did not (Figure 3.3).

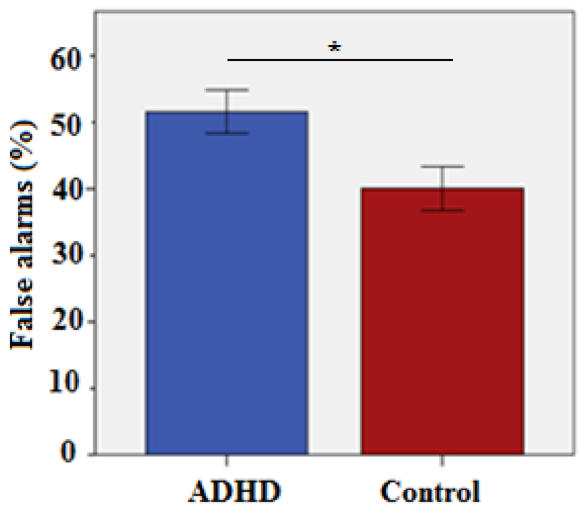

Figure 3.2. False Alarms by Group

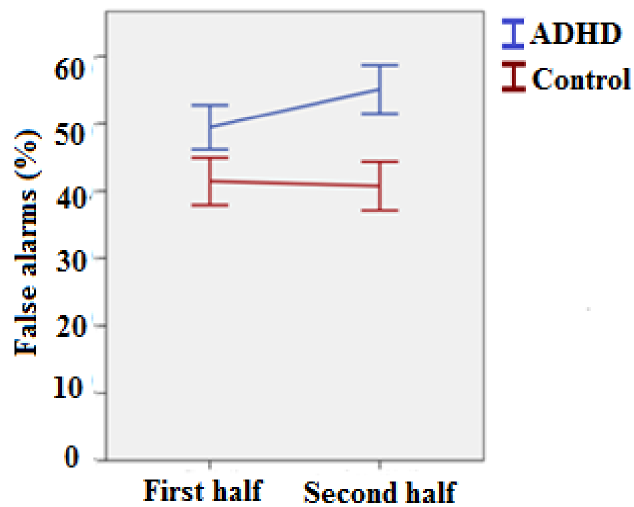

Figure 3.3. False Alarms by Half by Group

Break analyses

Thirteen participants (8 ADHD, 5 control) chose not to take any breaks, and those participants performed worse than the participants who did take breaks. A group (ADHD, control) by break (no breaks, breaks) ANOVA on false alarm rates identified a significant main effect of break, $F(1,70)=5.81$, $p<.05$, and a marginal interaction, $F(1,70)=2.74$, $p=.10$, in which control participants benefitted from taking breaks more than ADHD participants (Figure 3.4). Individuals who chose to take breaks did not differ from those who did not take breaks in terms of severity of ADHD symptomatology, frequency of attention lapses and daydreaming, or interest in the task.

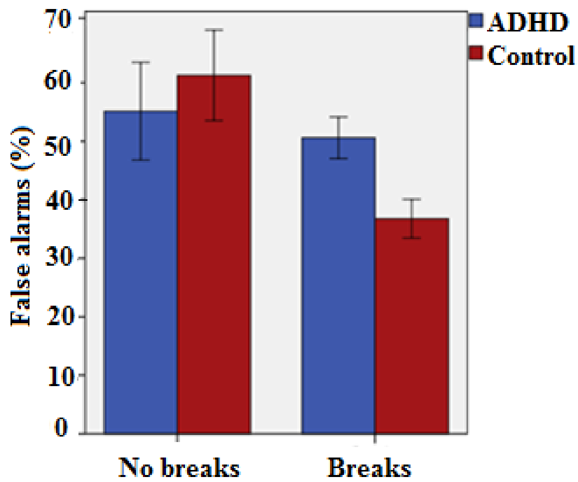

Figure 3.4. False Alarms by Group With and Without Breaks

The groups did not differ in the number of breaks which ranged from 1 to 13, $t(59)=.78$, $p=.44$. As the number of breaks increased, the false alarm rate decreased for both groups (Figure 3.5). A model predicting false alarm rates from group membership and number of breaks was significant, $F(2,73)=8.75$, $p<.001$, and accounted for 19.8% of the variance. Each break decreased the false alarm rate by 2.20% after controlling for group membership.

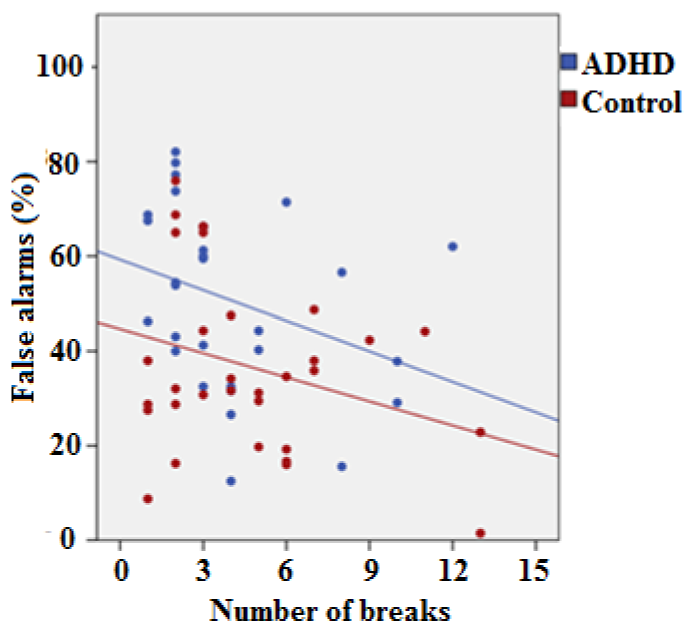

Figure 3.5. Relationship Between the Number of Breaks and False Alarms

Taking a break had an immediate positive impact on performance by reducing errors. We compared the error rate of the four trials prior to the break to the error rate of the four trials after the break (Figure 3.6). Individuals with ADHD tended to have higher error rates overall, $F(1,59)=3.05$, $p=.09$, but error rates were significantly reduced from pre-break to post-break, $F(1,59)=72.39$, $p<.001$. There was also evidence for post-break slowing in reaction time, F(1,59)=15.60, p<.001, which was marginally greater in the control group compared to the ADHD group, F(1,59)=2.74, p=.10.

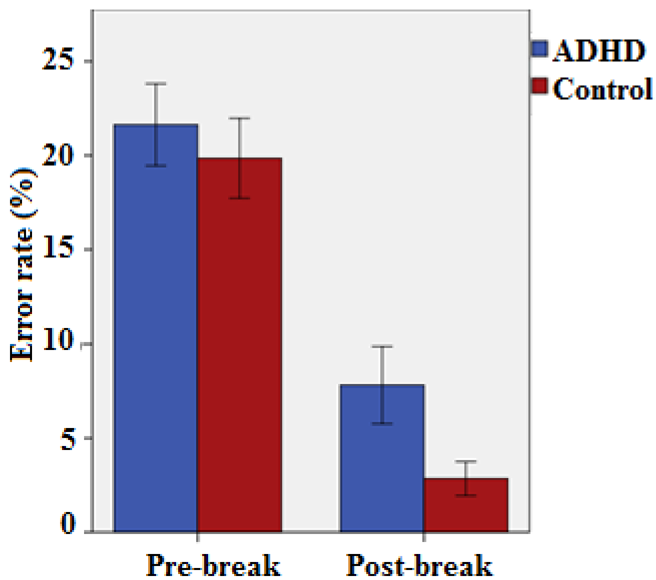

Figure 3.6. Error Rates Pre- and Post-Break by Group

Although breaks had a positive influence on performance by reducing the error rate immediately after the break, the majority of errors (93.72%) were not followed by a break. The majority of participants (n=47) took breaks after both inaccurate and accurate trials, but some participants chose to take breaks only after accurate trials (n=18) or only after inaccurate trials (n=9). There was no relationship between group and break-taking tendency, $\chi^2(2, N=73)=2.18$, $p=.20$.

To further explore the impact of the number of breaks on performance, we split participants into groups based on the median number of breaks, which was 3 (excluding those with zero breaks). Individuals who chose to take 3 or fewer breaks did not differ from those who chose to take more than 3 breaks in terms of severity of ADHD symptomatology, frequency of attentional lapses and daydreaming, or interest in the task. Consistent with the results using breaks as a continuous measures, a group (ADHD, control) by number of breaks (fewer than 3, more than 3) univariate ANOVA identified a main effect of break in that participants who took fewer than 3 breaks had more false alarms than those who took more than 3 breaks, $F(1,57)=15.84$, $p<.001$ (Figure 3.7). There was a main effect of group with individuals with ADHD participants performing worse than control participants, $F(1,57)=7.06$, $p<.05$, but taking more than 3 breaks helped ADHD participants reduce the gap. Individuals with ADHD who took fewer than 3 breaks had significantly higher false alarm rates compared to control participants who took fewer than 3 breaks, $t(30)=2.31$, $p<.05$, but individuals with ADHD who took more than 3 breaks did not significantly differ from control participants who took more than 3 breaks, $t(27)=1.44$, $p=.16$. Critically, both ADHD and control participants who took fewer than 3 breaks performed similarly to those who did not take breaks (AD: $t(23)=.53$, $p=.60$; C: $t(18)=1.59$, $p=.13$), which suggests that more than a few breaks are needed to positively affect behavior.

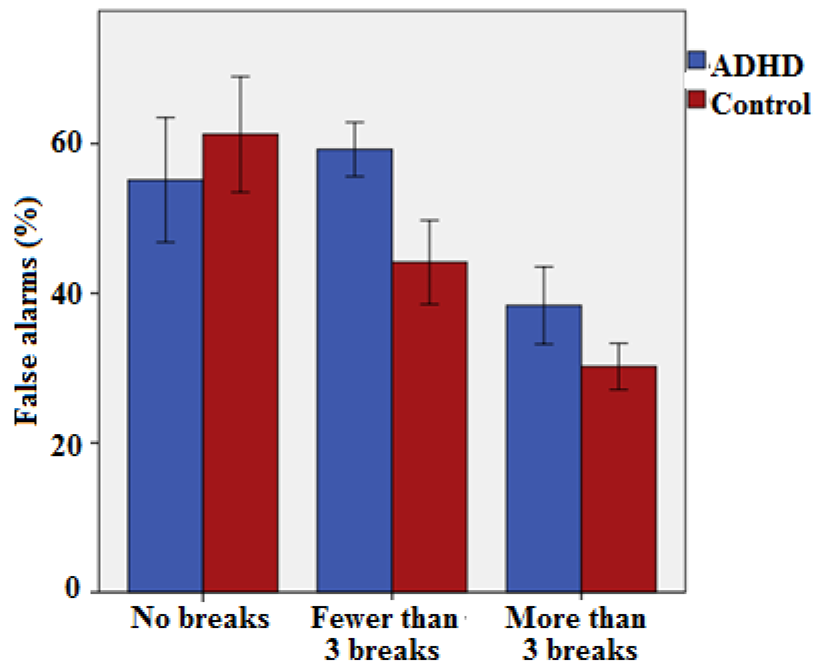

Figure 3.7. False Alarms by Group and Number of Breaks

As described previously, one way to assess the immediate impact of the break is to compare error rates before and after the break. To determine if the break had an enduring impact on performance, we measured the number of trials between the break and the first error. Of all of the breaks, 3.78% were not included in the analysis because no errors occurred after the break due to the break's proximity to either the end of the task or to the next break. ADHD participants made errors sooner than control participants, but this effect was eliminated in the participants who took more than 3 breaks (Figure 3.8). A group (ADHD, control) by median split (fewer than 3 breaks, more than 3 breaks) ANOVA identified a significant main effect of group, $F(1,56)=5.93$, $p<.05$, and a marginally significant interaction, $F(1,56)=3.63$, $p=.06$. Individuals with ADHD benefit from taking more breaks: ADHD participants who took less than 3 breaks made errors significantly sooner after a break than the ADHD participants who took more than 3 breaks, $t(27)=3.68$, $p<.001$. Further, ADHD participants who took more than 3 breaks performed similarly to both groups of control participants (fewer than 3 C: $t(24)=.60$, $p=.55$; more than 3 C:

t(27)=.45, *p*=.66). Importantly, for the participants who took more than 3 breaks, taking a break increased the amount of time before the next error by about ten seconds (approximately 6 trials) compared to making an error and not taking a break. A group (ADHD, control) by number of trials until next error (post-error, post-break) repeated measures ANOVA identified a main effect of the break, *F*(1,27)=2.92, *p*=.06. This effect was consistent for breaks occurring after inaccurate trials and after accurate trials.

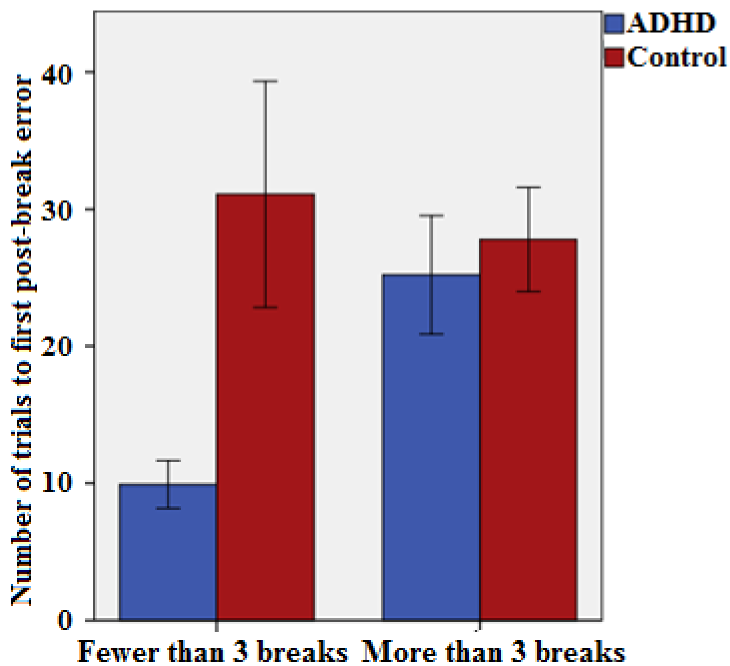

Figure 3.8. Trials to First Post-Break Error by Group and Number of Breaks

For participants who took more than 3 breaks, we separated the breaks into short breaks (*M*=16.42s) and long breaks (*M*=37.84s) based on each participant's median break length. The groups did not differ in the length of the long and short breaks. Longer breaks tended to be have a longer impact on performance, particularly for individuals with ADHD (Figure 3.9). A repeated measures ANOVA with break length (short, long) as the within-subjects variable and group (ADHD, control) as the between-subjects variable on the number of trials before the first post-break error indicated a marginally significant main effect of break length, *F*(1,27)= 3.48, *p*=.08, and interaction, *F*(1,27)=3.75, *p*=.06. For ADHD participants, shorter breaks resulted in fewer trials before the first error compared to longer breaks, *t*(11)=2.22, *p*<.05, but control participants were not impacted by the length of the break, *t*(16)=.06, *p*=.95.

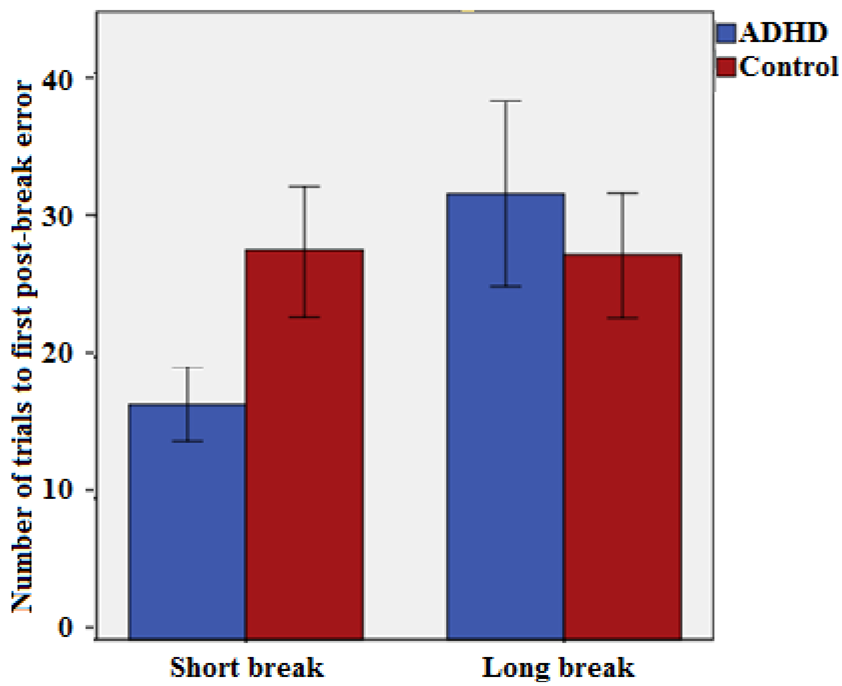

Figure 3.9. Number of Trials to First Post-Break Error by Group and Break Length

After the task, participants were asked to report on their break-taking strategy, their thoughts and/or activities during the break, and if the breaks helped their performance on the task. Strategies were categorized as "task-based" if they related exclusively to performance on the task (e.g. "I tended to take breaks after multiple errors" "I normally took breaks after long stretches without a mistake"; "I tried to take breaks after I messed up or after ~30 letters, whichever came first"); "self-based" if they were associated solely with intrinsic markers of fatigue (e.g. "when I lost focus"; "if I felt like my thoughts were drifting off"; "when I felt my attention span waning"), and "both" if they included task- and self-based strategies (e.g. "I took breaks when I felt my mind wandering or after I pressed the spacebar after I saw X"; "whenever

I hit the spacebar on an “X” twice in a row...Also, when I noticed I had zoned out”). Seven participants reported no strategy and were excluded for the purpose of this analysis. There was no association between group and break-taking strategy, $\chi^2(2, N=53)=.97$, $p=.62$. The majority of participants (45.3%) reported using strategies based only on the task, but participants tended to benefit more from breaks driven by both self- and task-based strategies. A group (ADHD, control) by strategy (self-based, task-based, both) ANCOVA including number of breaks as a covariate on number of trials to the first post-break error identified a marginal effect of break strategy, $F(1,44)=2.34$, $p=.11$. Breaks based on strategies incorporating both self- and task-based cues resulted in an average of 34 trials before the first post-break error which was about 10 trials more than task-based strategies ($M=24$) and about 20 trials more than self-based strategies ($M=15$). There was no interaction between group and strategy which suggests that individuals with and without ADHD would benefit from taking breaks based on monitoring both their performance and their attention.

Most subjects (74%) reported activity related to relieving physical fatigue during the breaks, such as closing eyes and stretching. Some subjects (27.9%) reported “task-related” thoughts involving their performance and the task goals (e.g. “The only thing I thought about was not to hit the spacebar when an x appeared”; “…thought about how many times I pushed the spacebar after x”; “I wasn’t thinking about anything except doing better when I started again”) while other subjects (18%) purposefully cleared their minds or tried not to think about the task (e.g. “…tried to forget about the task”; “…focus on something else to refresh my mind when I went back to the task”; “cleared my mind”; “zoned out”). There was no association between group and thought (task-related vs. no-thought), $\chi^2(1, N=28)=.74$, $p=.39$. The thoughts during the break did not significantly affect the efficacy of the break. A thought (task-thought, no-thought) by group (ADHD, control) univariate ANOVA on the number of trials to the first post-break error showed non-significant a effect of thought-type, $F(1,24)=1.70$, $p=.20$, and a non-significant interaction, $F(1,24)=1.93$, $p=.18$. These effects were not changed when the number of breaks was used as a covariate. These results suggest that the break itself is the critical variable, not necessarily what one thinks about during the break.

Most participants (64.4%) perceived the breaks as helpful and their perceptions were in line with their performance. Six participants did not explicitly classify their breaks as helpful or not helpful and were excluded from the following analysis. Group (ADHD, control) by break effect (helpful, not helpful) ANCOVAs with number of breaks as the covariate were conducted with false alarms and the number of trials to the first post-break as dependent variables. participants who perceived the break as helpful had reduced false alarms, $F(1,48)=3.99$, $p=.05$, and more trials to the first post-break error, $F(1,47)=4.03$, $p=.05$, compared to participants who did not perceive the break as helpful. Participants who took more than 3 breaks were more likely to report the breaks were helpful, $\chi^2(2, N=59)=5.57$, $p=.06$. Interestingly, two participants seemed to be aware that taking more breaks would have been better: "I didn't take too many but it probably would have helped"; "I did not take enough breaks to notice any difference".

In summary, participants who took breaks performed better than those who did not take breaks. Breaks benefitted performance in the short-term, as indexed by the decrease in error rate from pre- to post- break, and in the long-term, as indexed by the greater number of trials before the next error after a break compared to an error without a break. ADHD and control participants did not differ in the average number of breaks taken, but the number and length of the breaks had a significant impact on individuals with ADHD with the greatest benefit occurring with more than three breaks and longer breaks. After showing that individuals with ADHD were able to evaluate their thoughts and performance and that subject-initiated breaks improved their behavior, we incorporated experimenter-imposed breaks.

Experiment 2: Subject-initiated and experimenter-imposed breaks

Methods

Participants

A total of 22 participants (11 ADHD, 11 control) participated in this study. Seven University of Michigan control participants were enrolled in the Introduction to Psychology course and received course credit for their participation. Fourteen participants (10ADHD, 4 control) recruited from the University of Michigan were paid $10 per hour for their participation, plus the ADHD participants received a $5 bonus for attending both study sessions. One ADHD participants was recruited from Eastern Michigan University and was paid $17 per hour for his participation.

Individuals were eligible to participate as ADHD participants if they had a current or past diagnosis of ADHD, if they were currently taking stimulant medication, and if they were willing to be off their medication for 24 hours prior to one of the study sessions. Five ADHD participants had one or more comorbid disorders (including anxiety and/or depression). Control participants were recruited to match the ADHD participants based on gender and age (+/- two years). Eligibility for the control group included no current or past diagnosis of ADHD and no use of stimulant medication.

Materials

Connor's Adult ADHD Rating Scales Self-Report Screening Form (CAARS-S:SV). The CAARS screening form is a self-report measure that assesses ADHD symptoms according to the criteria outlined in the DSM-IV (Connors, Erhardt, & Sparrow, 1999). It consists of 30 questions with responses ranging from 0 ("not at all, never") to 3 ("very much, very frequently").

There are four subscales: Inattentive Symptoms, Hyperactive-Impulsive Symptoms, Total ADHD Symptoms, and an ADHD Index. The final score on each subscale is reported as a *t*-score which takes both age and gender into account.

Cognitive Failures Questionnaire – Memory and Attention Lapses (CFQ-MAL). The CFQ-MAL is a 40-item questionnaire that evaluates memory and attention lapses (McKay and Vane, 2009). Individuals report the frequency of lapses on a 5-point scale ranging from 1 ("never") to 5 ("very often"). The final score is a sum of the responses with higher values indicating higher frequency of memory and attention lapses.

Intrinsic Motivation Index (IMI). The IMI is a 23-item scale that measures four dimensions of intrinsic motivation (McAuley, Duncan, & Tammen, 1989). We utilized an abbreviated version with 10 items that focused on interest-enjoyment and perceived competence. Participants are instructed to indicate the extent to which the statements are true based on their experience during a specific task (e.g. "I am satisfied with my performance at this task"; "I found the task very interesting"). The scale ranges from 1 ("not at all true") to 7 ("very true") with the midpoint representing "somewhat true". Each dimension's items are summed to produce final subscale scores. An additional question was added to assess overall motivation: "How motivated were you to perform well on this task?" with response options ranging from 1 ("not motivated at all") to 7 ("very motivated").

Change Detection Task. The change detection task is used to measure working memory capacity (Luck & Vogel, 1997). Participants were briefly presented with an array of randomly arranged colored squares, followed by a blank screen. After a short delay, the same square presentation was displayed with one square circled and participants had to determine if the circled square was the same color as the original presentation. This version of the task had 60 trials, half of which were change trials. The set size was 4, 6, or 8 squares. Accuracy and reaction time were measured.

Operation Span. The operation span task is a measure of working memory capacity (Unsworth, Heitz, Schrock, & Engle, 2005). Participants were presented with simple arithmetic equations (e.g. (3*3)-8=1) and indicated whether the solution is true or false. After each equation, a letter was presented for the participants to remember. At the end of each block, which contained 3 to 7 equations and letters, a screen with 12 letters was displayed. Participants used the mouse to select the letters that they saw in the order of presentation. The partial span score was calculated based on the total number of items recalled in the correct order. The absolute span score only included blocks in which all items were recalled in the correct order. For example, if a participant scored 2 of 3 letters correct, then the absolute span would be 0 and the partial span would be 3.

Connor's Continuous Performance Test (CPT) – modified. This CPT was a modified version of the CPT with subject-initiated breaks. The 800 trials were divided into 2 blocks of 400 trials, with each block maintaining the 90% go and 10% no-go parameter. Half of the participants completed the self-paced block first and the experimenter-imposed block second, and the other half completed the experimenter-imposed block first and the self-paced block second. The instructions for the self-paced block were the same as the previous study, except that participants were not informed about the duration of the task. For the experimenter-imposed block, participants were told that in order to perform to the best of their ability, they would be prompted to take breaks of at least 10 seconds. The exact instructions were as follows:

> "Because we want you to perform to the best of your ability, you will be prompted to take breaks. When you're given a break, you'll need to take a break of at least 10 seconds before you can begin the task again, but you'll also have the option of taking a longer break if desired. When you are ready to resume the task, press the green "Enter" key."

Participants were given a maximum of four breaks in the experimenter-imposed block. We chose to impose breaks based on performance instead of time because the exit questionnaire results from Experiment 1 indicated that the majority of participants used their task performance to cue themselves to take a break. Each sub-block of 100 trials was randomly assigned to be either a "good-break" block or a "poor-break" block. The two "good-break" sub-blocks imposed a break after the first successful hit (response on a go-trial). The two "poor-break" sub-blocks imposed a break after the first false alarm (response on a no-go trial).

Exit Questionnaire. This open-ended questionnaire was given to participants after they completed the CPT in order to qualitatively evaluate their experience. Questions included: "Did the breaks that you chose to take (i.e. when you decided to take a break, instead of being prompted to take one) help your performance on the task?"; "Did you have a plan or strategy for when you decided to take breaks?"; "Did the breaks given to you by the task (i.e. when you were prompted to take a break, instead of deciding to take one) help your performance?"; "Did you prefer one type of break over the other?"; "What did you do during the breaks? Did you have a particular topic or idea you kept thinking about?"

Semi-Structured Clinical Interview. The ADHD semi-structured interview was administered by a trained research assistant. First, any history of previous ADHD diagnosis and treatment was identified. Next, a checklist of symptoms was reviewed from the three symptom clusters of ADHD: inattention, hyperactivity, and impulsivity. Next, the person's symptoms from early schooling through high school, college, and up to the present time were assessed. The pervasiveness of symptoms was discussed in terms of how they manifested in the person's occupational and interpersonal relationships. The interview lasted 10-25 minutes depending on the complexity of the person's history and symptom severity.

Procedure

Control participants were tested in one 1-1.5 hour session. After providing informed consent, participants filled out the ASRS, the CAARS-S:SV, and the CFQ-MAL. After completing the CPT, they filled out the exit questionnaire and the abbreviated IMI. They then completed both working memory capacity tasks (Change Detection and OSPAN) and the order of these tasks was counterbalanced across participants. Following the tasks, the trained research assistant would administer the semi-structured clinical interview and then debrief the participant.

ADHD participants were tested in two 1-hour sessions that were spaced a minimum of two days apart. They were instructed to withhold their medication for at least 24 hours before one of the sessions (7 participants Session 1; 4 participants Session 2). In the first session, participants provided informed consent and then filled out the CAARS-S:SV. They completed the CPT, followed by the abbreviated IMI. The first session concluded with either the Change Detection task or the OSPAN, the order of which was counterbalanced across participants. In the second session, participants began by filling out the CFQ-MAL before completing the CPT. They then responded to the questions in the exit questionnaire and the abbreviated IMI, followed by the other working memory capacity measure (either OSPAN or Change Detection). Following the tasks, a trained research assistant would administer the semi-structured clinical interview and then debrief the participant.

Results

One ADHD participant was excluded due to poor task compliance, and one control participant was excluded after he reported difficulties initiating a break. After excluding these participants, 10 individuals with ADHD and 10 control participants were included in the analyses.

Because ADHD participants were tested twice but control participants were tested only once, we averaged across the two sessions for each ADHD participant in order to assess main effects.

There were no effects of session number within the ADHD group, nor were there any effects on performance between the two counterbalancing orders. Additionally, there were no interactions between group (ADHD vs. controls) and counterbalance (see Appendix D for summary of results by session and counterbalance). These results indicate that performance differences based on medication status or group membership are not due to order effects.

Individual differences

Consistent with expectations, individuals with ADHD were more inattentive and experienced more instances of memory and attention lapses. ADHD participants received higher scores on both the inattention, $t(18)=8.88$, $p<.001$, and hyperactivity subscales of the CAARS, $t(18)=3.96$, $p<.001$, than control participants (Table 4.1). Additionally, ADHD participants scored higher on the CFQ than control participants, $t(18)=4.46$, $p<.001$.

Medication status had an impact on how individuals with ADHD assessed their performance on the task. When they were on medication, they reported feeling more motivated to do well on the task than when they were off medication, $t(9)=2.37$, $p<.05$. They also perceived themselves as more competent at the task, $t(9)=2.25$, $p=.05$, but their interest in the task did not change, $t(9)=.45$, $p=.66$. Control participants did not significantly differ from ADHD participants (on and off medication) on the measures of motivation. Higher levels of motivation and perceived competence were associated with lower overall false alarm rates, $r_{\text{motivation}}=-.41$, $p<.05$, $r_{\text{competence}}=-.48$, p<.01, but interest did not significantly relate to performance on the task.

Table 4.1. *Summary of Individual Difference Variables*

	Group		ADHD	
	ADHD	Control	Off meds	On meds
	M (SD)			
CAARS: Inattention	79.50 (8.59)***	49.80 (6.16)		
CAARS: Hyperactivity	65.00 (13.55)***	45.50 (7.69)		
CFQ	144.30 (32.09)***	88.60 (22.97)		
Motivation		5.20 (1.40)	4.60 (.97)*	22.00 (4.01)
IMI: Interest		12.50 (3.44)	10.00 (6.06)*	21.87 (4.04)
IMI: Competence		15.00 (7.06)	11.20 (7.67)	25.52 (4.86)

Note: Significant differences indicated by *p<.05, **p<.01, ***p<.001

Three participants (1 ADHD, 2 control) were excluded from the OSPAN analysis due to their high error rate on the math component of the task. ADHD participants and control participants did not significantly differ in working memory capacity as assessed by the OSPAN and the change detection task.

Overall performance

Medication status had a significant impact on performance. Individuals with ADHD had more failures of response inhibition when they were off medication compared to when they were medicated, $t(9)=3.41$, $p<.01$ (Figure 4.1). Medication significantly reduced false alarm rates. ADHD participants tested off medication exhibited a performance deficit compared to control participants, $t(18)=2.02$, $p=.06$, but ADHD participants tested on medication did not show this deficit, $t(18)=.30$, $p=.77$. This pattern was present in both blocks (Table 4.2).

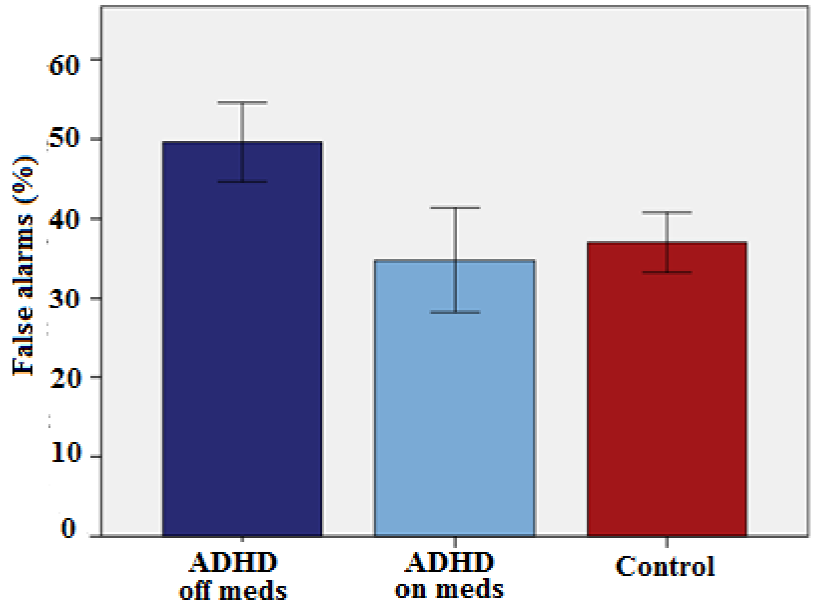

Figure 4.1. False Alarms by Medication Status

Table 4.2. *False Alarms by Medication Status and Block Type*

	ADHD off meds	ADHD on meds	Control
	M (SD)		
Subject-initiated break block	51.25 (15.51)	31.75 (21.92)	37.32 (13.81)
Experimenter-imposed break block	48.00 (17.04)	37.75 (21.42)	36.75 (13.64)

Subject-initiated break analyses

Three participants (2 ADHD, 1 control) did not initiate any breaks. The ADHD participants were consistent in their tendency to take breaks across both sessions (e.g. either they took zero breaks in both sessions or breaks in both sessions). Overall false alarm rates were comparable between participants who took breaks and participants who did not take breaks. The number of subject-initiated breaks ranged from 1 to 6 with a median of 2. On average, ADHD participants tested off medication took more breaks (*M*=3.00, SD=1.77) than ADHD participants tested on medication (*M*=2.00, *SD*=1.31) and control participants, (*M*=2.33, *SD*=1.66), but these differences were not significant.

To determine the immediate effect of the subject-initiated break, we calculated the error rate for the four trials immediately preceding the break and the four trials following the break. Error rates marginally decreased from pre-break to post-break, $t(16)=1.48$, $p=.16$ (Figure 4.2). Similarly, there was a significant post-break slowing of “go” reaction times, $t(16)=3.60$, $p<.01$ (Figure 4.3). These effects were predominantly consistent within each group, although ADHD participants did not differ in the error rates pre- and post-break when they were off medication (summarized in Table 4.3).

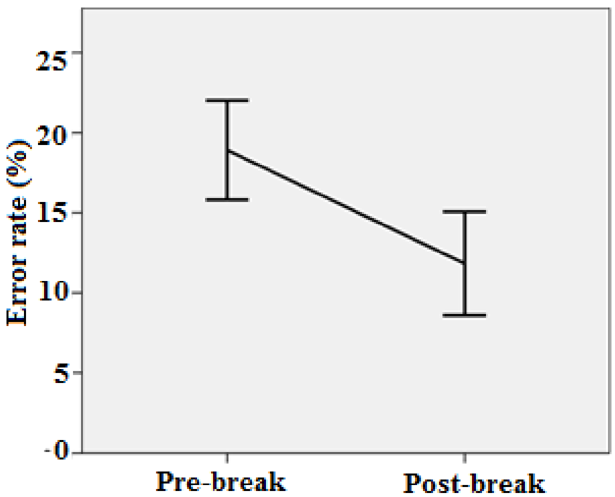

Figure 4.2. Error Rates Pre- and Post-Break

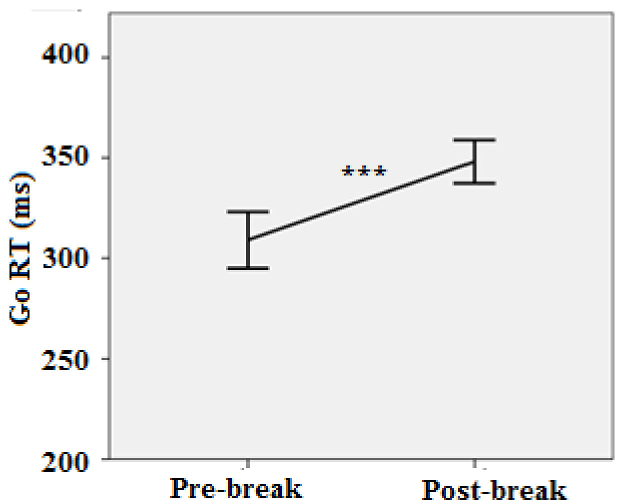

Figure 4.3. Reaction Time Pre- and Post-Break

Table 4.3. *Summary of Pre- and Post-Break Performance by Medication Status*

	ADHD off meds (n=8)	ADHD on meds (n=8)	Control (n=9)
	M (SD)		
Pre-break error rate (%)	19.22 (12.20)	11.72 (11.78)	21.97 (15.72)
Post-break error rate (%)	20.78 (24.31)	7.81 (17.60)	9.63 (11.69)
Pre-break Go RT (ms)	278.15 (69.14)	339.89 (60.09)	309.20 (68.52)
Post-break Go RT (ms)	331.66 (41.45)	361.67 (47.67)	349.42 (49.57)

Experimenter-imposed break analyses

The type of experimenter-imposed break did not affect overall performance or the efficacy of the break. False alarm rates in "good-break" blocks were not significantly different from false alarm rates in "poor-break" blocks, $t(19)=.48$, $p=.64$. Similarly, there was no significant difference between error rates in the four trials immediately following the break, $t(19)=1.22$, $p=.24$, or the number of trials until the first error post-"good-break" and post-"poor-break", $t(18)=.73$, $p=.48$. Based on these results, we collapsed the two break types into one experimenter-imposed break category (see Appendix D for summary of descriptive statistics by break-type).

Subject-initiated breaks v. experimenter-imposed breaks

We were interested in determining whether subject-initiated breaks differed from experimenter-imposed breaks. The number of trials to the first post-break error was not influenced by whether the break was subject-initiated or experimenter-imposed, $t(16)=.75$, $p=.47$. This pattern was consistent within each group. Similarly, participants who did not initiate breaks ($n=3$) had the same number of trials to the first post-break error in the experimenter-imposed break block as participants who did initiate breaks ($n=17$), $t(18)=.11$, $p=.92$, which confirms that the participants who initiated breaks were not uniquely positively affected by breaks.

Additionally, the exit questionnaire prompted participants to report which type of break they preferred and why. Five participants preferred experimenter-imposed breaks (4 ADHD, 1 control) because "they were well spaced out" and they provided "something to focus on as a goal". Eleven participants (4 ADHD, 7 control) preferred the subject-initiated breaks because they liked "having the control to rest" when the "mind was wandering and concentration wavering" or when "losing focus" and needing to "re-boot". Two participants preferred no breaks (1 ADHD, 1 control) and 2 participants did not respond or give a preference (1 ADHD, 1 control). The preference for a specific type of break did not impact performance. Participants who preferred the subject-initiated breaks did not show a performance advantage in that block compared to the experiment-imposed block in false alarm rates, $t(9)=1.01$, $p=.34$, or trials to first error post-break, $t(9)=.08$, $p=.94$. Likewise, participants who preferred experimenter-imposed breaks had similar false alarm rates, $t(3)=.92$, $p=.43$, and number of trials to the first post-break error, $t(2)=.85$, $p=.48$, in the experimenter-imposed break block and the subject-initiated break block.

Overall break analyses

Based on these analyses, we considered all of the breaks to assess whether length or the trial preceding the break influenced the effect of the break in terms of number of trials to first post-break error. For the length analysis, breaks were separated into short and long breaks within each subject. For the accuracy analysis, breaks were separated based on the accuracy of the trial immediately preceding the break. Within the ADHD group, the trial preceding the break, but not the length of the break, influenced the effect of the break (Figure 4.4). A medication (on, off) by length (short, long) repeated measures ANOVA failed to identify a significant main effect of length or interaction. A medication (on ,off) by accuracy (inaccurate, accurate) repeated measures ANOVA showed a marginal main effect of accuracy, $F(1,9)=3.42$, $p=.10$ in that there were more trials before the first post-break error if the break was taken after an inaccurate trial compared to an accurate trial. Both analyses identified marginal main effects of medication ($p_{length}=.12$; $p_{acc}=.05$) with ADHD subjects benefitting more from the break on medication compared to off medication. Control subjects benefitted more from short breaks compared to long breaks, $t(9)=4.83$, $p<.01$, but were not affected by the length of the breaks.

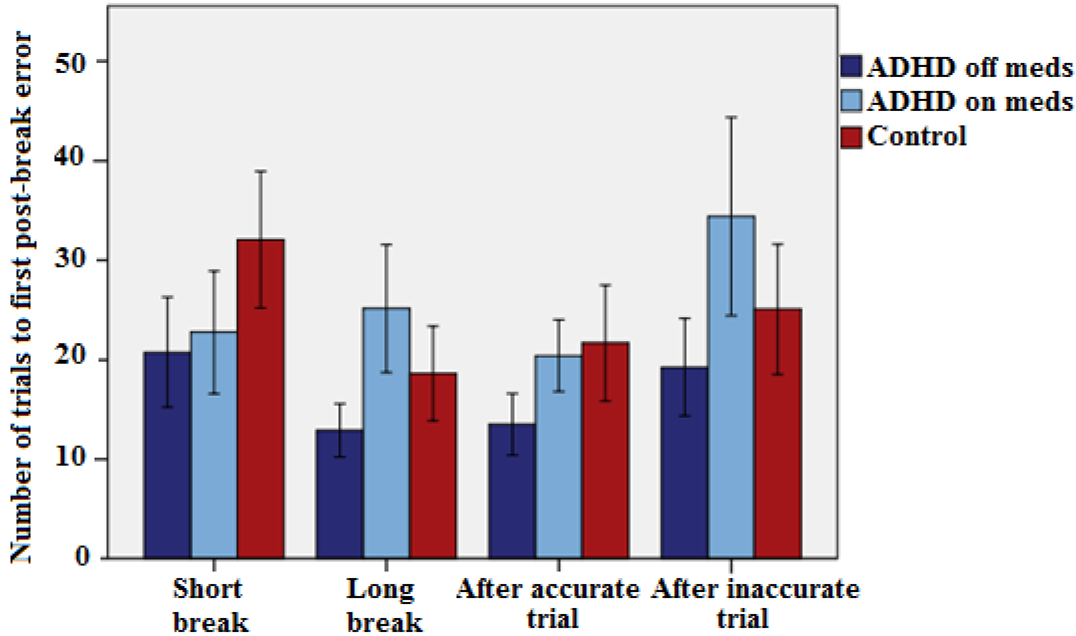

Figure 4.4. Number of Trials to First Post-Break Error Based on Break Length and the Accuracy of the Previous Trial by Medication Status

Discussion

These studies identified the potential utility of using breaks to improve response inhibition in individuals with and without ADHD. Participants who initiated breaks benefitted in the short-term, evidenced by reduced error rates from pre- to post-break, and in the long-term, as indicated by the increased number of trials before the next error and lower overall false alarm rates compared to participants who did not take breaks. The effect of the breaks was apparent to the participants as the majority of them self-reported that the breaks helped their performance on the task.

Although breaks tended to reduce errors, not all errors led to breaks. If participants recognized that breaks helped them, then shouldn't they have initiated breaks after every error? There are a couple explanations for this relationship between errors and breaks. First, some participants operationalized poor task performance as a series of errors instead of a single error. For example, breaks were initiated after "multiple errors", "too many mistakes in a row", "a certain amount of [false alarms.]…about 2-5". These responses suggest that some participants had a specific "error threshold" that they used to determine when they needed to take a break. Our analyses only focused on errors in the trials immediately preceding the break, so it may be possible to explore this "error threshold" to determine if it differs between groups. Another explanation is that participants did not exclusively base their breaks on errors. Some breaks were associated with goals relating to good performance ("I would make the deal with myself that I could take a break after I successfully skipped the next 'x'; "after long stretches without a break"), or time ("…arbitrary time goal (I'll stop at 10:15); "after 21 [letters] I would try and break")". Other breaks were influenced by internal cues such as mind-wandering or mental fatigue. These different strategies may be related to proactive and reactive control. Proactive control occurs when participants actively maintain goal-relevant information and bias their behavior in a goal-driven manner to prevent interference before it occurs (Braver, 2012). In contrast, reactive control occurs after interference has been detected when task goals are re-activated in an effort to resolve the interference. Participants who initiated breaks based on errors may rely more on reactive control, while proactive control drives participants to initiate breaks based on attention in order to prevent an error from being made. Participants who based their breaks on task- and self-based cues benefitted more from the breaks than those who relied on one type of cue, suggesting that a balance of proactive and reactive control may be most beneficial.

Although we asked participants about their break-taking strategy after the task, we are unable to link specific breaks to specific strategies. Strategies could have evolved or changed over the course of the task which could be explored by including a probe when participants initiate a break that asks them why they took that particular break. These probes would enable a deeper understanding of how and when breaks are most beneficial. For example, individuals with

ADHD showed a significant decline in performance from the first half to the second half of the subject-initiated break study. Perhaps a proactive break strategy would be beneficial in the first half, but as performance declines over time participants might need to adopt a reactive break strategy.

The subject-initiated break task showed that individuals with ADHD were capable of self-monitoring their performance and their attention. Individuals with ADHD did not differ from control participants in the number of initiated breaks or in their tendency to base their breaks on overt errors and/or attentional lapses. The results from the subject-initiated break task also demonstrated that breaks could reduce performance deficits associated with ADHD, but that the number and length of the breaks were critical variables. ADHD participants who took more than 3 breaks had comparable false alarm rates to control participants, but ADHD participants who took fewer than 3 breaks exhibited the same performance deficit as those who did not take any breaks. In fact, ADHD participants who initiated more than 3 breaks had false alarm rates that were 12% lower than ADHD participants who took no breaks which is approximately the same reduction in false alarms that ADHD participants experienced when tested on medication compared to off medication in the second study; this pattern emphasizes how helpful these breaks could be for individuals with ADHD. For the ADHD participants who took more than 3 breaks, longer breaks led to more trials before the next error compared to shorter breaks. Despite the fact that ADHD and control participants did not differ in the average length of short and long breaks, control participants were not affected by the length of the break.

Due to the limited sample size in the second study, we cannot draw strong conclusions about whether experimenter-imposed breaks show the same benefit as subject-initiated breaks. Based on the present data, it seems that the initiation of the break does not impact the benefit of the break. Interestingly, the majority of the control participants preferred the subject-initiated breaks but half of the ADHD participants endorsed a preference for experimenter-imposed breaks. Unfortunately, participants only reported their break-taking preference after the second session, so we are unable to determine whether medication influenced the preference for subject-initiated or experimenter-imposed breaks.

In general, it seems that individuals with ADHD are capable of using breaks to compensate for their issues with response inhibition and mind-wandering. ADHD participants benefitted more when they took more than 3 breaks and when they took longer breaks, and this strategy could be applied in a variety of settings. Although more research needs to be done to determine whether ADHD participants would benefit from enforced breaks, currently the critical factor seems to be the break itself and not the initiation of the break.

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Appendix C: Supplementary Table for Chapter III, Experiment 1

Table 4.4. *Summary of Questionnaire Measures by Break Number*

	No breaks	Breaks	Fewer than 3 breaks	More than 3 breaks
	M (SD)			
CAARS-Inattention	55.85 (14.16)	58.11 (12.83)	58.81 (12.13)	57.34 (13.73)
CAARS-Hyperactivity	48.69 (12.98)	51.41 (10.57)	52.50 (10.63)	50.21 (10.54)
IMI: Interest	11.31 (4.71)	13.10 (6.37)	12.88 (6.55)	13.34 (6.28)
IMI: Competence	17.77 (5.42)	22.57 (7.11)	22.19 (7.15)	23.00 (7.18)
DDFS	33.00 (6.48)	39.45 (12.77)	38.17 (11.93)	41.00 (14.20)
CFQ	107.00 (17.03)	111.91 (44.49)	115.75 (47.29)	107.30 (42.91)
Conscientiousness	121.22 (18.80)	122.33 (14.82)	120.50 (17.24)	124.26 (11.92)
SRIS: Engage	22.78 (3.19)	22.59 (4.42)	22.05 (5.20)	23.16 (3.48)
SRIS: Need	22.33 (4.03)	22.85 (4.06)	22.30 (4.26)	23.42 (3.86)
SRIS: Insight	26.11 (4.62)	27.67 (5.34)	27.15 (5.26)	28.21 (5.50)

Appendix D: Supplementary Tables for Chapter III, Experiment 2

Table 4.5. *Summary of Performance by Session and Counterbalance*

	Session 1	Session 2	Counterbalance 1	Counterbalance 2
	M (SD)			
Subject-initiated break block				
False alarms (%)	40.50 (19.61)	42.50 (23.36)	37.32 (11.33)	41.50 (21.71)
Number of breaks	2.20 (1.93)	1.80 (1.62)	1.30 (1.25)	2.40 (1.82)
Length of breaks (s)	36.35 (30.26)	35.30 (19.69)	22.68 (15.75)	43.34 (27.18)
Experimenter-imposed break block				
False alarms (%)	42.00 (15.93)	43.75 (24.16)	44.00 (12.03)	39.25 (20.55)
Break length (s)	20.27 (10.17)	18.89 (5.45)	25.92 (11.11)	18.27 (6.90)
Full task				
False alarms (%)	41.25 (17.10)	43.12 (22.69)	40.67 (9.15)	40.37 (20.49)

Note: Counterbalance 1 had the subject-initiated break block first; Counterbalance 2 had the experimenter-imposed break block first

Table 4.7. *Summary of Performance by Experimenter-Imposed Break Type*

	"Good-break"	"Poor-break"
False alarms (%)	41.07 (19.55)	39.55 (15.12)
Post-break error rate (%)	20.66 (15.00)	24.26 (21.72)
Number of trials to first post-break error	5.63 (7.56)	3.13 (5.55)

Chapter IV

General Discussion

Summary

This dissertation addressed two goals: (1) to establish a specific link between mind-wandering and response inhibition in ADHD; (2) to assess a potential compensatory strategy to reduce performance deficits associated with regulatory difficulties in ADHD. Our first experiment used a non-clinical sample to establish the appropriate task parameters before testing the task with a clinical sample. Individuals with heightened ADHD symptomatology, as indexed by above average inattention scores, had higher false alarm rates and a higher proportion of task-unrelated thoughts compared to participants with average levels of inattention. To modify the task for the clinical sample in the second experiment, we increased the length of the task and decreased the frequency of probes to maximize the opportunity to measure task-unrelated thoughts. In line with our hypotheses, we found that individuals with ADHD reported more task-unrelated thoughts than control participants, and that reports of mind-wandering were more often preceded by errors compared to reports of task-related thoughts. For some participants, the mind-wandering probes served as external cues that helped participants re-focus on the task. The results of these two experiments support a specific link between mind-wandering and response inhibition in ADHD.

The next aim was to assess the efficacy of breaks to alleviate the performance deficits associated with ADHD. The first experiment allowed participants to choose if and when to take breaks. The subject-initiated break task showed that individuals with ADHD were capable of self-monitoring their performance and attention: they did not differ from control participants in the number of initiated breaks or in the tendency to base their breaks on overt errors and/or attentional lapses. Breaks had an immediate and enduring positive impact on performance in individuals with and without ADHD, but the number and length of breaks were critical to ADHD participants. Taking more than 3 breaks allowed ADHD participants to compensate for their attentional deficits and improved their performance to the level of control participants. Those ADHD participants also benefitted more from their longer breaks. The second study included subject-initiated breaks and experimenter-imposed breaks, and ADHD participants were also tested on and off of their stimulant medication. Individuals with ADHD were more motivated and performed better when they were on medication compared to when they were off medication. Although the sample size was limited, the data suggest that individuals benefit equally from subject-initiated and experimenter-imposed breaks.

Limitations

There are limitations associated with the sample population. Most of the ADHD were recruited from the University of Michigan and consequently may represent more high-functioning individuals with ADHD. It is likely that these students have developed compensatory strategies in order to overcome the negative consequences related to their ADHD symptoms. Such strategies may not be employed by all individuals with ADHD, and thus the conclusions regarding the ability of ADHD participants to self-monitor their thoughts and behavior may not be applicable. Additionally, the participants in these studies were young adults with an average age of 18-20 years. More research is needed to explore ADHD in older individuals. Most studies that have investigated the persistence of ADHD symptoms into adulthood have not tested adults over the age of 30 (Faraone & Biederman, 2005; Faraone, Biederman, & Mick, 2000). In order to fully understand adult ADHD, more effort should be made to expand the age range in studies evaluating symptomatology and cognitive deficits in ADHD.

Future Directions

Future work would benefit from a deeper understanding of the qualitative experiences underlying the observed results. As discussed previously, episodes of mind-wandering could have different effects on performance depending on the awareness/intentionality and the content of the episode. The inclusion of mind-wandering probes also affected performance in ADHD participants based on whether they perceived the probe as helpful or hurtful. Additionally, the benefit of self-initiated breaks may relate to the strategy that participants employed to determine when to initiate a break. It is important to continue to probe participants regarding their subjective experience in order to gain insight into how mind-wandering and breaks impact performance.

Incorporating neuroimaging methods could further elucidate the relationship between mind-wandering, breaks, and response inhibition. When participants reported that they were experiencing task-unrelated thoughts immediately prior to the probe, they were also more likely to have made errors in the preceding trials which suggests that mind-wandering episodes lead to those errors. However, it is possible that participants are inferring their mental state from their performance in that they assume that they were off-task because they made an error. Similarly, the self-reported break-taking strategies indicate that some participants were able to recognize when their attention was drifting off-task and based their breaks on that internal cue, but we are unable to determine the accuracy of their perceptions (e.g. it is unclear how often they actually took breaks when they should have, especially if they experienced episodes of mind-wandering that lacked awareness). Incorporating EEG would allow us to investigate mind-wandering and error awareness covertly, and using fMRI could show how breaks affect activity in different neural networks.

and would also show how breaks affect activity in the different neural networks.

This dissertation only focused on the detrimental effects of ADHD and mind-wandering, but researchers have also documented benefits. Both ADHD and mind-wandering are related to better scores on measures of divergent creative thinking, which measure the ability to generate multiple ideas or solutions to a problem (Baird et al., 2012; White & Shah, 2006; White & Shah, 2011). In fact, Baird and colleagues found that when giving participants time to incubate on a divergent-thinking problem, participants did better when the incubation period was filled with an undemanding task that stimulated mind-wandering compared to a demanding task or a rest break (2012). These results illustrate that the costs or benefits associated with mind-wandering and rest breaks may be related to the specific task. There may also be times when there is overlap between mind-wandering and breaks; Smallwood and Schooler suggested that "mind wandering may also be useful by providing mental breaks to relieve boredom from monotonous activities" (Smallwood & Schooler, 2015; pg. 21). It is possible that breaks help performance in part because they allow participants to mind-wander in a context that does not negatively affect the task.

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