HOW THE MIND WANDERS IN ADHD
AND WHY IT MATTERS

By

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A DISSERTATION

Presented to the Department of Behavioral Neuroscience

and the Oregon Health & Science University

School of Medicine

In partial fulfillment of the requirements for the degree of

Doctor of Philosophy

July 2019

CERTIFICATE OF APPROVAL

This is to certify that the PhD Dissertation of

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Acknowledgments

First and foremost, I would like to thank my mentor, Dr. Sarah Karalunas. I am immensely grateful for her unwavering support and guidance throughout my graduate career as well as her willingness to take me on as her first graduate student. Sarah was instrumental in helping me conceptualize, design, execute, analyze, and write my dissertation. Sarah not only helped me develop skills in critical thinking, study design, and integration of cognitive and clinical neuroscience, she also supported my interests in community-based outreach, student leadership, as well as completing a dissertation on a topic outside her area of expertise. Sarah has been an inspirational example of a successful scientist and I am so appreciative of her dedication to being an excellent mentor.

I would also like to thank my co-mentor, Dr. Joel Nigg. Joel was instrumental in my decision to attend OHSU as well as my ability to work with Dr. Karalunas. I am thankful for the role he played in solidifying my knowledge in theories of attention and ADHD as well as his guidance in figuring out my future career goals. Like Sarah, he was also extremely supportive in allowing me to focus my dissertation work on a topic that interested me and was also instrumental in bringing Dr. Kalina Christoff onto my dissertation advisory committee.

I would also like to thank the members of my dissertation advisory committee: Dr. Suzanne Mitchell, Dr. Michael Pitts, and Dr. Kalina Christoff as well as Dr. Alice Graham for serving as my outside member on my oral exam committee. I would also like to thank the members of the ADHD research study and ATTEND labs for their immense help in data collection and analysis, particularly Brian Shirley, Libby Nousen, Rebecca Feldman, Evan Challem, and Eleanor Battison, and Hanna Gustafsson.

Next, I would like to thank the adults who participated in my study, without whom I would have no dissertation. I would also like to thank the funding that supported both myself and my research including the National Institute of Mental Health (R44 MH099709; K23 MH108656; R37 MH59105), National Center for Advancing Translational Sciences (TL1 TR002371), Ashworth-Thomason graduate training award, as well as travel awards from the OHSU Graduate Student Organization, OHSU SoM alumni association, Mind & Life Institute, and the International Society for Research in Child and Adolescent Psychiatry.

I'd like to thank Bill Griesar for giving me numerous outreach opportunities through NW Noggin as well as invaluable teaching experience at PSU and WSU. Both of these experiences were instrumental in informing my future career goals.

Finally, I would like to thank my family and friends for their endless love, support, and perseverance during my graduate career. I would particularly like to thank my parents, Bob and Jodi Alperin for always believing in me, my grandfather Henry Adelman for teaching me math and science at a young age, my best friend Caity Joy for always being by my side, and my partner Michael Soroka for enduring this journey with me.

Abstract

Mind-wandering (MW), or a shift in attention away from a task, is an extremely common phenomenon. Although often benign, it can be maladaptive when excessive in frequency or occurring during inappropriate times. In the case of attention deficit hyperactivity disorder (ADHD), MW has been found to occur at high rates and is related to impairment and so may provide a new route to intervention or self-help. However, MW is a multi-faceted construct and it remains unclear which specific *types* of MW are related to functional impairment. It is therefore important to dissociate different aspects of MW in order to better understand the mechanisms underlying impairment and ultimately design more targeted interventions.

A neurobiologically-informed framework that captures the multi-faceted nature of MW suggests that MW varies along at least two dimensions: (a) the extent to which is it stimulus-dependent (externally referenced; e.g., being distracted by a fly buzzing around the room) versus stimulus-independent (internally referenced; e.g., worrying about a presentation you need to give tomorrow), and (b) the extent to which its content is spontaneous/variable (e.g., switching from topic to topic), or constrained to a specific topic (e.g., focused on a single train of thought). The current dissertation investigated: 1) whether MW in adults with and without ADHD differed based on these two dimensions and 2) whether the type of MW engaged in was related to functional impairment.

Electroencephalography (EEG) and self-report measures of stimulus-dependent/independent MW and constrained/spontaneous MW were collected while 79 adults with (n = 40) and without (n = 39) ADHD completed a computerized attention task with auditory distractors. Throughout the task, participants were intermittently asked to report on their attentional state as MW or non-MW as well as follow-up questions designed to capture different dimensions of MW. Measures of stimulus-dependent/independent MW included participant’s reports about the degree to which they were attending to their surroundings as well as amplitudes of the N1 and P2 event related potentials (ERPs) elicited by the auditory distractors. Measures of spontaneous/constrained MW included participant’s reports about how freely their thoughts were moving from topic to topic as well as quantification of EEG complexity. Functional impairment and symptom severity were assessed through self-report.

Results were that those with ADHD mind-wandered more than those without ($p < 0.01$). In terms of the specific dimensions of MW, those with ADHD engaged in a greater proportion of spontaneous MW than non-ADHD controls ($p < 0.05$). Auditory ERPs were attenuated during MW and the degree of attenuation was related to increased functional impairment and symptom severity within the disorder (all $p < 0.05$). Additionally, increased levels of stimulus-dependent as well as spontaneous MW were related to increased ADHD symptom severity (all $p < 0.05$)

Overall, this work demonstrated differences in both the quality and quantity of MW in adults with ADHD and provides novel insight into the both the phenomenology of MW as well as mechanisms underlying impairment in ADHD.

Chapter 1: Introduction

Mind-Wandering: Benefits and Consequences

Mind-wandering (MW), defined here as thought processes unrelated to the task at hand (Christoff, 2012; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Smallwood & Schooler, 2006), is a ubiquitous mental phenomenon, yet has only recently become subject to intensive empirical study. People typically spend 30-50% of their waking hours mind-wandering (Christoff et al., 2018; Killingsworth & Gilbert, 2010; Leszczynski et al., 2017; Smallwood & Schooler, 2015). In many cases MW is benign and even helpful for things like planning and creativity (Baird et al., 2012; Baird, Smallwood, & Schooler, 2011; Leszczynski et al., 2017; Marron & Faust, 2019; Mooneyham & Schooler, 2013; Smeekens & Kane, 2016; Stawarczyk, Cassol, & D'Argembeau, 2013). Yet in other instances, MW can be quite maladaptive (e.g., when the frequency is too great or the timing is inappropriate). This has been captured behaviorally where task performance decreases (e.g., increased errors) with increased mind-wandering (Albert et al., 2018; Cheyne, Solman, Carriere, & Smilek, 2009; Feng, D'Mello, & Graesser, 2013; Foulsham, Farley, & Kingstone, 2013; Franklin, Smallwood, & Schooler, 2011; Galéra et al., 2012; He, Becic, Lee, & McCarley, 2011; Kopp, D'Mello, & Mills, 2015; McVay & Kane, 2009, 2012; Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013; Stawarczyk et al., 2013; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011; Yanko & Spalek, 2013). This has been demonstrated on basic attention tasks (Cheyne et al., 2009; McVay & Kane, 2009, 2012; Stawarczyk et al., 2013; Stawarczyk, Majerus, Maj, et al., 2011) as well as on real-world tasks such as reading (Feng, D'Mello, & Graesser, 2013; Foulsham, Farley, & Kingstone, 2013; Franklin, Smallwood, & Schooler, 2011; Kopp, D'Mello, & Mills, 2015; Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013), and driving (Albert et al., 2018;

Galéra et al., 2012; He et al., 2011; Yanko & Spalek, 2013). Further, higher levels of MW has been tied to an array of psychiatric disorders (Franklin et al., 2017; Hoffmann, Banzhaf, Kanske, Bermpohl, & Singer, 2016; Mowlem et al., 2016; Seli, Smallwood, Cheyne, & Smilek, 2015; Smallwood, 2013; Smallwood, O'Connor, Sudbery, & Obonsawin, 2007), most notably depression (Hoffmann et al., 2016; Murphy, Macpherson, Jeyabalasingham, Manly, & Dunn, 2013; Ottaviani et al., 2015; Smallwood & O'Connor, 2011; Smallwood et al., 2007) and ADHD (Biederman et al., 2017; Franklin et al., 2017; Mowlem et al., 2016; Seli et al., 2015; Shaw & Giambra, 1993).

MW is a Poorly Defined and Multifaceted Construct

Despite growing empirical interest in this phenomenon, MW remains a poorly defined construct and describing what does and does not constitute MW has served as a challenge in psychological research. Current debates exist on how to best define MW with some considering MW to be an umbrella term capturing diverse and not necessarily related mental phenomena such as stimulus-independent thought, task-unrelated thought, unintentional thought, and meandering unguided thought (referred to as the family-resemblances view: Seli, Kane, Metzinger, et al., 2018; Seli, Kane, Smallwood, et al., 2018). Conversely, others have argued that an operational definition of MW is needed to distinguish it from other types of thought and define MW as a type of spontaneous thought that is more deliberately constrained than dreaming and less deliberately constrained than creative or goal-directed thought (Christoff et al., 2018).

Despite definitional disagreement, a commonality between these two approaches is the notion that MW is multifaceted and that clearly distinguishing what type of MW is under investigation is imperative to moving this field forward. This approach enables researchers to understand what types of MW are beneficial or impairing and why, so as to design more targeted interventions to reducing MW-related impairment and promote well-being (Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Seli, Kane, Smallwood, et al., 2018).

Whereas Seli et al., propose that MW is a “heterogeneous, fuzzy boundaried construct” and that all researchers need to do is ensure that they define what they mean when they say MW, Christoff et al., consider this approach a threat to the viability of the field of MW since under this family-resemblances view, MW has no concrete definition and is not distinguishable from other cognitive constructs (e.g., inattention or thought). To aid in demonstrating that MW is a distinct mental phenomenon, and to move the field of MW forward in characterizing different dimensions of MW that are related to impairment, the current dissertation tested the effectiveness of examining dimensions taken from a specific, testable model of MW. This model, proposed by Christoff et al. (2016), is a dynamic framework for MW that seeks to capture its multifaceted nature. It focuses on three dimensions of MW: (a) the extent to which it is stimulus-dependent (externally referenced; e.g., being distracted by a fly buzzing around the room) versus stimulus-independent (internally referenced; e.g., worrying about a presentation you need to give tomorrow), (b) the extent to which its content is spontaneous (e.g., freely moving and switching from topic to topic) or constrained to a specific topic (e.g., focused on a single train of thought), and (c) the extent to which constrained MW is deliberately controlled (goal-directed; e.g., while showering you’re figuring out how to plan your day) versus automatically controlled (e.g., while showing you’re unintentionally thinking about the scary movie you just watched). Christoff et al., demonstrates neurobiological support for this framework by aligning recent findings in the literature investigating the neural underpinnings of MW with each of these proposed dimensions.

Although a comprehensive investigation of all three of these dimensions is ultimately encouraged, the first two dimensions were the focus of the current work. This was due to

ADHD-related theoretical interest in stimulus-dependence and variability of thought (reviewed below), as well as practical limitations (e.g., task design, duration of the study) that restricted reliable data collection to two dimensions of MW. **Figure 1** gives examples of the dimensions focused on in this dissertation: stimulus-dependent, stimulus-independent, constrained, and spontaneous MW. Although the implementation of this model is still in its infancy, research thus far has demonstrated that these different dimensions of MW are distinguishable from one another. This has been done by showing that reports about engaging in one type of MW (e.g., stimulus-independent thought) are not highly correlated with reports about engaging in another type of dimension of MW (e.g., spontaneous thought), validating that these are semi-independent dimensions on which MW can be evaluated (Mills, Raffaelli, Irving, Stan, & Christoff, 2018).

Contributions to Definitional Debate and Theories of Attention

There are multiple ways research into MW has occurred. One is in trying to determine what should and should not be classified as MW (as seen in definitional debates); another is to understand the qualities of MW (e.g., *how* do we MW); another is to comprehend what drives MW (i.e., *why* do we MW). Although each of these approaches feeds back on the other and an integration of these multiple approaches is ultimately needed to gain a comprehensive understanding of MW, the current work focused on understanding *how* MW occurs and whether quantifying different qualities of MW could aid in understanding impairment in ADHD. Despite this focused goal, results from the current work will inform both definitional debates of MW as well as research into what drives MW (e.g., attentional control theories of MW).

By focusing on the dynamic framework of MW as proposed by Christoff et al., the current work is in a position to provide evidence either for or against the use of this model as a way to restrict the definition of MW. For example, results from this study have the ability to help determine whether these stated dimensions of MW are not only distinguishable from one another, but also whether they are able to provide unique insight into the drivers of functional impairment.

The current work will also be able to contribute to attentional theories of MW which tend to agree that MW occurs when attentional control fails (McVay & Kane, 2009, 2010, 2012; Schooler, 2002; Thomson, Besner, & Smilek, 2015). One current issue with these theories is that although it is generally stated that attentional control is to blame, there is a lack of elaboration on what it is meant by attentional control (a multi-faceted and highly debated construct, much like MW). This necessitates an integration of current attentional control theory with theory of MW not only to better understand what drives MW, but also to determine whether isolating MW as a phenomenon distinct from “inattention” or “distraction” adds anything to the understanding human cognition, or if it’s merely adding new words to describe old concepts.

The current work, although not designed to address any specific theory of attentional control, has the opportunity to shed light on how to best integrate attentional control theory with theories of MW. For example, by focusing on specific dimensions along which MW varies (e.g., spontaneity of thought), the cognitive operations underlying differences in those dimensions (e.g., maintenance of task goals or conflict monitoring) are more approachable and quantifiable than the cognitive operations underlying MW as a whole. Elucidating these cognitive operations allows for integration with existing cognitive theory which may be far more speculative if using another methodological approach. Further, explaining MW in the context of existing attentional theory may help to reduce a lack of conceptual clarity between MW and a lack of attentional focus.

ADHD and Mind-Wandering

ADHD is a developmental disorder that emerges in childhood, but impairment persists into adulthood in 40-60% of cases, even when full ADHD diagnostic criteria are not met (Fayyad et al., 2017; Rasmussen & Gillberg, 2000; van Lieshout et al., 2016). Accumulated impairments are substantial, including lower occupational attainment, as well as increased marital conflict, traffic accidents, drug and alcohol use, and comorbid mood and anxiety disorders (Adamou et al., 2013; Biederman et al., 1993; Biederman et al., 2006; Bioulac et al., 2016; Kessler, 2006). Individuals with ADHD represent a paradigmatic population where MW is presumably a paramount feature that may significantly influence impairment in work/school, life skills, and interpersonal relationships (Franklin et al., 2017; Mowlem et al., 2016; Seli et al., 2015; Shaw & Giambra, 1993). However, a majority of studies on MW have focused on typically-developing adults. Although valuable in getting a sense of the prevalence of this phenomenon, it excludes atypically-developing individuals where MW is often more pervasive and impairing (Franklin et al., 2017; Hoffmann et al., 2016; Mowlem et al., 2016; Seli et al., 2015; Smallwood, 2013; Smallwood et al., 2007). Because investigation of specific dimensions of MW have not yet been applied to empirical studies of disorders like ADHD, a new opportunity exists to clarify cognitive and neurophysiological mechanisms in this population. Doing so has the translational potential to both (a) increase understanding of the basic cognitive mechanisms of MW in general, and (b) improve understanding of ADHD, possibly contributing to identification of new targets for intervention for this disorder.

Although it is clear that those with ADHD mind-wander more than those without ADHD (Biederman et al., 2017; Franklin et al., 2017; Mowlem et al., 2016; Seli et al., 2015; Shaw & Giambra, 1993), the nature of MW within this population and whether it differs only quantitatively from that seen in typical populations (i.e., increased frequency but with similar types of thoughts) or also qualitatively (i.e., is driven by distinct types of MW) is unclear. The few studies that have investigated qualities of MW in ADHD have focused on the dimension of deliberate vs. automatic (Arabacı & Parris, 2018; Franklin et al., 2017; Seli et al., 2015). This work has found that those with ADHD engage in more automatic MW than those without ADHD (Arabacı & Parris, 2018; Seli et al., 2015) and the degree to which they do this is related to functional impairment (Franklin et al., 2017). This work, although limited in scope, starts to suggest that MW in ADHD may have distinct qualitative features that merit further investigation. Because there is a small body of literature already investigating the deliberate/automatic dimension of MW in ADHD, the current work focused on the two remaining dimensions of Christoff et al's model which have thus far remained uninvestigated.

Measuring MW

Methodologically, due to its inherently subjective nature, self-reports of MW remain a necessary and valid method to measure this phenomenon (Christoff et al., 2016; Smallwood & Schooler, 2015). There are several ways these self-report measures can be collected. One is through administering trait level questionnaires that evaluate the extent to which participants generally mind-wander in their daily lives (Mowlem et al., 2016; Mrazek et al., 2013). This method is quick and simple; however, it relies on retrospective report which introduces issues related to the decay of memory as time passes (Barrouillet, Bernardin, & Camos, 2004). To eliminate issues of retrospection, some experimenters use experience sampling methods where participants are given devices or download an app on their phone that periodically asks them a series of questions throughout their day about what they were just doing and what they were just thinking about (Anderson & McDaniel, 2019; Kane et al., 2017; Mills et al., 2018; Song &

Wang, 2012). A benefit of this method is the ability to assess real-time reporting (or at least immediate recall) of real-world experience, however; control over the environment is extremely limited and the context under which the data is collected is highly variable across individuals and throughout a day (e.g., at work, out with friends, watching TV, running errands, high demand tasks, low demand tasks). In order to solidify a cognitive framework of MW, control over context is valuable in order to isolate specific processes and rule out interference from unknown third variables.

To collect the content of MW in a more controlled setting, a thought probe method can be used in which participants are periodically asked to report their state of mind during a relatively long, boring cognitive task within the lab (Smallwood & Schooler, 2015). At their most basic form, these probes ask the participant whether their mind was wandering or not (Kam & Handy, 2014; Killingsworth & Gilbert, 2010; Mooneyham & Schooler, 2016; Seli, Cheyne, & Smilek, 2013). Additional questions can be added to these probes to better assess the content, quality, or temporal extent of the MW episode (Kane et al., 2007; Mills et al., 2018; Stawarczyk, Majerus, Maj, et al., 2011). Some researchers have used more nuanced questions to understand the specific content of thoughts during MW. For example, work by McVay et al., (2009, 2012; 2013) used probes that distinguish between thoughts about task performance, everyday stuff, current state of being, personal worries, daydreams, or other. Stawarczyk et al. (2016; 2011; 2011), used probes that distinguish between task-relatedness and also stimulus-dependence. Others have used probes to determine the temporal (Anderson & McDaniel, 2019; Baird et al., 2011; Jackson, Weinstein, & Balota, 2013; Poerio, Totterdell, & Miles, 2013; Stawarczyk et al., 2013; Stawarczyk, Majerus, Maj, et al., 2011) or emotional aspects (Killingsworth & Gilbert, 2010; Poerio et al., 2013) of MW content. While some patterns have emerged such as MW being largely encompassed by future oriented thoughts (Anderson & McDaniel, 2019; Stawarczyk et al., 2013; Stawarczyk, Majerus, Maj, et al., 2011) and interfering evaluative thoughts about the task (e.g., “I’m doing well on this task” or “this task is boring”) (McVay & Kane, 2009, 2012; Smallwood, Riby, Heim, & Davies, 2006), due to methodological differences, consolidating findings across studies is a challenge and the conceptual basis for why certain qualities of MW are investigated is lacking. This issue demonstrates the importance of a shift in the field towards utilizing a common theoretical framework, such as the one proposed by Christoff et al. (2016), and as was done in the current dissertation, to guide the development of future thought probes and the field of MW as a whole. Such a shift gives rise to a more standardized approach to investigating this phenomenon as well as provide a theoretical grounding to work from. This is not to say that investigations should be limited to the dimensions proposed by Christoff et al., but rather that investigations into the specific content of MW should be encased within the conceptual framework. For example, when MW is constrained, what is the topic of that constrained MW? When MW is spontaneous, what is the content of those spontaneous thoughts?

Overview of Aims

The current study sought to understand: the extent to which adults with ADHD engaged in stimulus-dependent versus -independent MW (aim 1), the extent to which adults with ADHD engaged in spontaneous versus constrained MW (aim 2), and whether these distinct dimensions of MW related to functional impairment within the disorder (aim 3).

Aim 1: Distinguishing between stimulus-dependent and stimulus-independent MW.

One of the more prevalent theories of MW is called the *perceptual decoupling hypothesis* which states that when MW occurs, attention is shifted to be internally focused in order to maintain the internal train of thought and is decoupled from fully perceiving the external environment

(Smallwood et al., 2011). Evidence for the perceptual decoupling hypothesis has been seen in the co-activation between the default mode network (DMN) and dorsal attention network (DAN) during MW (Christoff et al., 2009; Stawarczyk & D'Argembeau, 2015) suggesting that there is top-down maintenance exerted (via the DAN (Corbetta & Shulman, 2002)) during task-unrelated thought (primarily driven by the DMN (Raichle, 2015)). After the advent of this theory, many researchers began functioning under the assumption that when they were measuring MW, they were measuring perceptual decoupling and therefore stimulus-independent thought (i.e., thought unrelated to the external environment, and internally generated and maintained). In fact, many distinguish MW from distraction stating that MW is a shift in attention towards internally generated stimuli whereas distraction is a shift in attention towards externally generated stimuli (Varao-Sousa, Smilek, & Kingstone, 2018). While perceptual decoupling/stimulus-independence can be an aspect of MW (Mills et al., 2018), it is not the only possibility, and this approach restricts the definition of MW to only include stimulus-independent content. Because of this, few studies have included conditions that enable the investigation of stimulus-dependent MW (i.e., tasks have not included conditions to evaluate susceptibility to external distraction).

One way to address this gap is to include more nuanced probes to distinguish between stimulus-dependent and -independent thought (e.g., were you thinking about your surroundings?) (Christoff et al., 2016; Mills et al., 2018; Song & Wang, 2012). Work by both Mills et al., (2018) and Song et al. (2012) used experience sampling methods to understand the prevalence of certain types of MW that individuals engage in in their daily lives. In contrast to the assumption that MW is primarily stimulus-independent (i.e., internally driven), they found that there was no difference in the rates of stimulus-dependent to stimulus-independent thought. While illuminating for typically developing populations, minimal work has been done to evaluate this dimension in individuals with ADHD,

Beyond including thought probes designed to capture stimulus-dependent vs. independent thought, studies can also include conditions to more objectively evaluate whether MW is stimulus-dependent. One way to do this is to incorporate neuroimaging techniques that can provide convergent data to better validate and isolate MW-related processes. Because MW is a temporally dynamic phenomenon (attentional processes change rapidly over time) temporally precise electroencephalogram (EEG) and event related potentials (ERPs) methods are particularly promising. Although fMRI and EEG both have their strengths as tools for investigating MW, EEG was used here due to its ability to more closely capture time-locked neural phenomenon (e.g., capturing a neural response to a distracting tone during MW), which was a goal of the current work. Further, the context in which EEG is collected (e.g., sitting in a chair in a room looking at a computer) is more akin to what someone may be doing in their daily life as opposed to the context under which one collects fMRI data (e.g., laying in loud narrow tube with earplugs in). Therefore, EEG studies allow for more externally valid experiential self-report data which is particularly important for gaining a clinically relevant measure of MW in ADHD.

ERPs provide a way to measure neurophysiological processes underlying the perception of and attention to sensory stimuli (Luck, 2014). In typically-developing adults, both early (e.g., P1 and N1) and late (e.g., P3a and P3ab) stimulus-locked ERP components to task-relevant stimuli are attenuated during MW (Kam et al., 2012, 2011; Kam, Dao, Stanciulescu, Tildesley, & Handy, 2013; Smallwood, Beach, Schooler, & Handy, 2008). This is often interpreted as supporting the *perceptual decoupling hypothesis* such that this reduction of a neural response to external stimuli during MW reflects a decoupling of perception from external stimuli (Smallwood, 2013; Smallwood & Schooler, 2006). The demonstration that this effect is seen across ERP components suggests that perceptual decoupling is present across cognitive functions, (e.g., perceptual processing (P1/N1), orienting of attention (P3a), decision making and working memory updating (P3b)). This ERP attenuation, has been noted across task modality as well (visual: (Kam et al., 2012; Kam & Handy, 2014; Smallwood et al., 2008); auditory: (Braboszcz & Delorme, 2011; Kam et al., 2011, 2013) and is a consistent and robust finding in the MW/ERP literature.

Overall, ERPs are generally attenuated during MW, regardless of the task modality or the functional significance of various ERP components. To date, this method has been used to evaluate the neural processes related to MW overall, but has not taken advantage of this phenomenon as a way to evaluate specific aspects of MW (e.g., stimulus-dependent vs. stimulus-independent MW). One way to do this is to include task-irrelevant stimuli and evaluate to what extent the brain is responding to distracting stimuli during MW.

Thus far, only two studies evaluating neural responses during MW have included task-irrelevant stimuli. Both found that in typically developing adults, the ERP responses to frequently occurring task-*irrelevant* tones, notably the N1 (Kam et al., 2013) and P2 (Braboszcz & Delorme, 2011), were attenuated during MW. This is in line with the larger body of ERP studies finding an attenuation of ERPs during MW across component type and task modality (Kam et al., 2012, 2011, 2013; Smallwood et al., 2008). Because both the N1 and P2 auditory evoked potentials are modulated by attention (Hillyard, Hink, Schwent, & Picton, 1973; Kam et al., 2013) these findings are consistent with the suggestion that during MW, attention is decoupled from external stimuli and is focused on an internal train of thought. However, again, this hypothesis has never been investigated in ADHD, a population that typically demonstrates increased neural responses to task-irrelevant stimuli (Micoulaud-Franchi, Lopez, et al., 2015; Micoulaud-Franchi, Vaillant, et al., 2015; Sable et al., 2013).

As of yet, no work has used the thought probe method or neuroimaging techniques to disentangle the stimulus-dependence of MW in those with ADHD, a population characterized by their increase in external distractibility (Forster & Lavie, 2016; Pelletier, Hodgetts, Lafleur, Vincent, & Tremblay, 2016). Because external distraction is a hallmark of ADHD, it is plausible that this population would be more susceptible to engaging in stimulus-dependent MW and therefore a greater proportion of their MW would be driven by stimulus-dependent thought as compared to typically developing individuals; however, this has never been formally tested.

Although not directly related to the specific processes involved in MW, a large body of work has investigated aspects of cognitive function in ADHD that can be used to drive hypotheses about what types of MW may be expected in ADHD. For example, a large body of literature suggests that those with ADHD are more susceptible to stimulus-dependent external distractors than typical individuals as seen clinically (American Psychiatric Association, 2013), in ERP studies (Micoulaud-Franchi, Lopez, et al., 2015; Micoulaud-Franchi, Vaillant, et al., 2015; Sable et al., 2013), and behavioral studies (Adams et al., 2009; Adams et al., 2011; Forster & Lavie, 2016; Forster et al., 2014; Pelletier et al., 2016). Although external distraction is distinguishable from stimulus-dependent MW, it can be thought of as a precursor to engaging in more externally-mediated MW. For example, if I am easily distracted by the birds outside the classroom window, I am more likely to start MW about those birds than someone who is not distracted by the birds at all. Neuroimaging studies support the notion that those with ADHD are more susceptible to stimulus-dependent MW. This is based on findings that networks associated with bottom-up attention capture (the ventral attention network and salience network) are more activated in those with ADHD than controls during moments of rest (i.e., periods of time where MW is assumed to be taking place) (McCarthy et al., 2013; Mills et al., 2018; Sidlauskaite, Sonuga-Barke, Roeyers, & Wiersema, 2016). Interestingly, the ventral attention and salience networks have both been associated with the onset of MW (Christoff et al., 2016) and the increased connectivity between the ventral attention and salience networks has been found in ADHD and linked to their high susceptibility to task-irrelevant distraction (Sidlauskaite et al., 2016) However, because no previous research has investigated stimulus-dependent and stimulus-independent MW in adults with ADHD, the degree to which those with ADHD preferentially engage in one type more than the other as compared to typically developing individuals is unclear.

Aim 1 of the current study tested whether the proportion of stimulus-independent to stimulus–dependent MW in individuals with ADHD differed from those without ADHD. Based on the literature, it was hypothesized that for typically-developing controls, MW would be equally distributed across stimulus-dependent and stimulus-independent thought based on self-report (Mills et al., 2018; Song & Wang, 2012), and ERPs would be attenuated to task-irrelevant stimuli during MW. For individuals with ADHD, based on self-report, a greater proportion of MW would involve externally-referenced stimulus-dependent thoughts as compared to controls and ERPs would be less attenuated to task-irrelevant stimuli during MW than non-MW as compared to controls.

Aim 2: Distinguishing between spontaneous and constrained MW. As noted, most MW literature has relied on self-report to determine whether a participant was or was not engaged in MW (Smallwood & Schooler, 2006, 2015). However, like stimulus-dependent and -

independent MW, self-report has rarely been used to distinguish between spontaneous versus constrained thought. In the case of spontaneous MW, thoughts are variable and switching from topic to topic (e.g., thinking about the uncomfortable chair you're sitting in, wondering what you'll eat later, remembering a funny thing someone said earlier). In contrast, with constrained MW, thoughts are relatively stable and fixated on a specific topic (e.g., going over what you'll say in an upcoming meeting). Recent work has suggested using more nuanced self-report measures to capture the distinction between these two types of MW by asking questions such as "how freely were your thoughts moving?" (Christoff et al., 2016; Mills et al., 2018; Smith, Mills, Paxton, & Christoff, 2018). Mills et al. (2018) demonstrated that about 40% of the time participants report being off-task, they report that their thoughts are constrained, and the other 60% of the time they report that their thoughts are spontaneous. This work is in contrast to the assumption that MW is inherently freely moving and suggests that variability of thought content is a dimension of MW that can vary across time and from person to person.

In addition to self-report measures, neurophysiological measures can aid in distinguishing between these two types of MW and can contribute additional insight into the mechanisms underlying distinct types of MW. One such measure is EEG complexity (Bob, Golla, Epstein, & Konopka, 2011; Ibáñez-Molina & Iglesias-Parro, 2014, 2016; Liu, Yan, Chen, & Wang, 2013; Mölle et al., 1996; Mölle, Marshall, Wolf, Fehm, & Born, 1999). Complexity is mathematically calculated by creating a set of m-dimensional vectors by taking m-consecutive data-points from the EEG time-series as the values for the m coordinates of each vector. The vectors are then plotted in m-dimensional space to detect where these vectors converge (known as an attractor). The dimension (akin to degrees of freedom) of the attractor can be calculated and reflects the overall complexity of the underlying dynamic system (Stam, 2005).

While the interpretation of the underlying processes leading to a complex signal is highly theoretical and widely debated (e.g., see Tononi et al., 1998), one prevalent theory, and most relevant to the current study, is that many measures of EEG complexity (e.g., correlation dimension, pointwise correlation dimension, fractal dimension, Lempel Ziv complexity) reflect the number of cell assemblies (e.g., functional networks of neurons) contributing to the EEG signal, with more assemblies reflecting higher complexity (Elbert et al., 1994; Lutzenberger, Preissl, & Pulvermüller, 1995; Stam, 2005).

Despite controversy in how the organization of neural assemblies give rise to this metric, complexity remains a valuable tool for assessing functional states and elucidating behavioral differences. Important for the goals of the current study, these measures have been used to evaluate EEG based brain dynamics during various attentional states (Bob et al., 2011; Ibáñez-Molina & Iglesias-Parro, 2014, 2016; Liu et al., 2013; Lutzenberger, Elbert, Birbaumer, Ray, & Schupp, 1992; Mölle et al., 1996, 1999). Studies have demonstrated less complexity during focused attention tasks (where attention is actively engaged) as compared to rest (where attention is free to wander) (Bob et al., 2011; Liu et al., 2013). Similarly, research has found increases in EEG complexity across the scalp during MW vs. focused attention consistent with MW being a less constrained mental process than focused attention (Ibáñez-Molina & Iglesias-Parro, 2014, 2016). Also, studies of EEG complexity comparing convergent thought (e.g., doing mental arithmetic; similar to constrained thought) and divergent thought (e.g., coming up with as many unusual uses for a credit card as you can, more similar to spontaneous thought) found that divergent thought had more complexity than convergent thought over all EEG sites (Mölle et al., 1996, 1999). Although not directly examined using functional imaging techniques, simulation studies have shown that EEG complexity increases with increased DMN activity and decreased attention-related networks (Ibáñez-Molina & Iglesias-Parro, 2016), a pattern of activation often associated with the act of MW (Christoff et al., 2016; Kucyi, 2018; Mittner et al., 2014). In line with previous work, it was hypothesized that EEG complexity would be greater during MW than focused attention and would also be greater during spontaneous MW than constrained MW.

Five studies to date have used EEG complexity measures to evaluate differences between those with and without ADHD (Chow et al., 2019; Khoshnoud, Nazari, & Shamsi, 2018; Li, Chen, Li, Wang, & Liu, 2016; Sohn et al., 2010; Zarafshan, Khaleghi, Mohammadi, Moeini, & Malmir, 2016a). Because of a diversity of algorithms used to quantify EEG complexity, differences in measurement approach (e.g., measuring certain regions, quantifying complexity within certain frequency bands), as well as differences in task-based recording vs. rest-based recording, results are difficult to consolidate with some finding increases in complexity in ADHD (Khoshnoud et al., 2018; Li et al., 2016; Zarafshan et al., 2016a) and others finding decreases (particularly when an entropy algorithm is used) (Chow et al., 2019; Khoshnoud et al., 2018; Li et al., 2016; Sohn et al., 2010). Further, the sample sizes in these studies are quite small with the largest samples including 30 individuals with ADHD (Chow et al., 2019; Zarafshan et al., 2016a) while all others had an average group size of ~12 (Khoshnoud et al., 2018; Li et al., 2016; Sohn et al., 2010). Of note, only two of these studies has evaluated complexity during an attention-based task (Sohn et al., 2010; Zarafshan et al., 2016a) with one finding an increase in right hemisphere complexity in ADHD (Zarafshan et al., 2016a) and the other finding a decrease in frontal complexity (entropy) in ADHD (Sohn et al., 2010). Most importantly, these studies are largely exploratory and data driven, looking for any group differences in complexity as opposed to a hypothesis driven approach, using complexity measures to answer an empirical question.

ADHD is a disorder marked by enhanced attentional variability (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Kuntsi & Klein, 2012). A large body of evidence supporting this comes from the ubiquitous finding that those with ADHD have increased reaction time (RT) variability as compared to typically developing controls (Gmehlin et al., 2014; Hervey et al., 2006; Karalunas, Huang-Pollock, & Nigg, 2012; Kofler et al., 2013; Leth-Steensen, Elbaz, & Douglas, 2000). This increase in RT variability is often translated in the context of the *default mode hypothesis* which suggests that difficulty with sustained attention in ADHD is a result of difficulty transitioning from a resting state (e.g., DMN activation) to a cognitive state (e.g., frontoparietal network activation) (Sonuga-Barke & Castellanos, 2007). In other words, sustained attention deficits in ADHD are driven by an inability to modulate and maintain focused attention. This is further supported by studies which have found a decrease in theta phase variability in those with ADHD (Baijot et al., 2017; Groom et al., 2010; McLoughlin, Palmer, Rijsdijk, & Makeig, 2014; Michelini et al., 2018), a neurophysiological marker that is associated with the coordination and employment of attentional control (Clayton, Yeung, & Cohen Kadosh, 2015; Helfrich, Breska, & Knight, 2019) which is important for maintaining attentional focus and inhibiting distraction (Corbetta & Shulman, 2002; Petersen & Posner, 2012; Posner & Petersen, 1990).

While attentional variability has been examined during externally focused attention (e.g., during various cognitive tasks), no work has investigated whether enhanced attentional variability is also seen during internal cognition (i.e., MW). It has been proposed that difficulty with maintaining constrained attention in ADHD may drive not only the greater occurrence of MW overall, but also difficulty in stabilizing attention on a particular train of thought (Smallwood, 2013). It was therefore hypothesized that those with ADHD would engage in a larger proportion of spontaneous MW as compared to typically developing adults (Christoff et al., 2016); however, this had not been formally tested.

The idea that those with ADHD engage in more spontaneous thought is also consistent with an fMRI study demonstrating that those with ADHD show increased connectivity in the medial temporal lobe subnetwork of the DMN (believed to reflect the generation of spontaneous thought) and decreased connectivity in the core of the DMN (reflecting constrained thought) (Anderson et al., 2014; Christoff et al., 2016). Again, whether MW in ADHD is characterized by more variability in content than in typical development has never been examined.

Aim 2 of the current study tested whether the proportion of constrained to spontaneous MW in individuals with ADHD differed from those without ADHD. For self-report data, it was hypothesized that those with ADHD would report a greater proportion of spontaneous vs. constrained MW as compared to controls. For EEG data, it was hypothesized that those with ADHD would show a larger increase in complexity during MW vs. non-MW as compared to controls. Both of these would demonstrate that for individuals with ADHD a greater proportion of MW would involve freely moving spontaneous thoughts as compared to typically developing adults.

Aim 3: How aspects of MW are related to ADHD features and functional impairment. Although the onset of ADHD occurs during childhood, symptoms often persist into adulthood, particularly symptoms of inattention (Achenbach, Howell, Mcconaughy, & Stanger, 1998; Millstein, Wilens, Biederman, & Spencer, 1997), and are associated with significant functional impairment (Biederman et al., 2006; Biederman, Petty, Evans, Small, & Faraone, 2010; Faraone et al., 2000; Kessler, 2006; Sobanski et al., 2007; Uchida, Spencer, Faraone, & Biederman, 2018). For example, the multimodal treatment study (MTA), one of the longest running study of prospectively followed children with ADHD to date, found that children who have symptoms that persist into adulthood are more likely to get fired, be on public assistance, not get a college degree, engage in risky behavior, and have a host of comorbid disorders such as substance use disorder, anxiety, and depression as compared to those whose symptoms do not persist into adulthood (Hechtman et al., 2016). Further, adults with ADHD are more likely to have occupational difficulties (Adamou et al., 2013), be arrested (Biederman et al., 2006; Klein et al., 2012), be divorced (Michielsen et al., 2015; Murphy & Barkley, 1996), have lower socioeconomic status (Galéra et al., 2012), develop comorbid psychiatric disorders (Katzman, Bilkey, Chokka, Fallu, & Klassen, 2017; Murphy & Barkley, 1996; Sobanski et al., 2007), and have lower satisfaction with family, social, and professional lives (Biederman et al., 2006; Pinho, Manz, DuPaul, Anastopoulos, & Weyandt, 2017; Quintero, Morales, Vera, Zuluaga, & Fernández, 2017) than typically developing adults.

The frequency of MW is related to functional impairment in ADHD (Franklin et al., 2017; Mowlem et al., 2016; Seli et al., 2015; Shaw & Giambra, 1993), and may even be a better predictor of functional impairment than ADHD symptoms (Asherson, Buitelaar, Faraone, & Rohde, 2016; Mowlem et al., 2016). However, due to the multi-dimensional nature of MW, it remains unclear whether the frequency of MW drives impairment or whether increases in specific types or qualities of MW drive impairment. Clarifying the specific aspects of MW that best predict impairment is important for elucidating specific mechanisms driving impairment which ultimately allows for more effective and targeted treatments or interventions.

There is accumulating evidence that the type of MW is important to consider when trying to predict impairment in ADHD (Franklin et al., 2017; Seli et al., 2015). For example, Seli et al. (2015), found that automatic MW (referred to as spontaneous MW in their work) was related to

ADHD symptom severity, whereas deliberate MW was not. Similarly, Franklin et al. (2017) found that the level of awareness of MW (akin to the automatic/deliberate dimension of MW) mediated the relationship between ADHD symptoms and MW-related impairment such that MW without awareness (or automatic MW) was more impairing in ADHD. However, the literature is limited both in number and by the dimensions of MW investigated which begs for additional studies.

Although group effects should have been detectible in the current experiment, ADHD is cognitively and affectively heterogeneous and group effects may be driven by a subset of individuals (Fair, Bathula, Nikolas, & Nigg, 2012; Karalunas, Fair, et al., 2014; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Particularly by adulthood, substantial differences in functional impairment also exist (Faraone, Biederman, & Mick, 2005; Hechtman et al., 2016; Swanson et al., 2017). Because of this, it is especially important to examine continuous individual differences in the mechanisms underlying MW and how those are related to functional impairment within the disorder. Understanding how the mechanisms underlying MW relate to functional impairment will help clarify the processes related to poor outcomes in this disorder, and if successful, may help set a stage for designing the appropriate interventions to reduce disorder-related impairment. For example, if it’s determined that freely moving thought during MW is the best predictor of impairment, this would encourage the development and implementation of interventions that specifically aim to reduce the spontaneity of thought during MW, such as specifically tailored mindfulness-based interventions.

Aim 3 sought to explore the relationship between the type of MW and functional impairment in those with ADHD with the goal of determining whether specific aspects of MW better predicted impairment than MW frequency alone. It was hypothesized that specific aspects of MW (e.g., susceptibility to stimulus-dependent MW and/or spontaneity of the content of MW) would be independent predictors of functional impairment that contributed unique variance beyond what was predicted by overall MW frequency alone

Chapter 2: Methods

Participant Recruitment and Rule-outs

Adults ages 18-40 were recruited via public advertisements as part of an ongoing funded study of adults with ADHD (R44 MH099709) and were then screened to establish eligibility and diagnostic criteria. Adults were chosen for the current study to enhance the limited research on ADHD in adults, for alignment with the broader MW literature which has thus far primarily focused on adults, as well as feasibility (e.g., the parent study recruited adults). Applicants underwent a 15-minute phone screen to identify basic eligibility criteria (e.g., age, medications, health status) and rule outs.

Rule-outs were: history of neurological impairment such as seizure history, head injury with loss of consciousness, or stroke; other major medical conditions such as cerebral palsy, brain tumor, or cancer; current substance dependence; a prior diagnosis of intellectual disability, autism spectrum disorder, fetal alcohol syndrome, Tourette's disorder, PTSD, or psychosis, left-handedness; and any non-stimulant psychotropic medications (with the exception of SSRIs and SNRIs for those with an ADHD assignment). Those taking non-stimulant medications were excluded due to the inability to safely complete wash-out and eliminate medication-dependent effects on cognitive performance (Rosenblat, Kakar, & McIntyre, 2015). ADHD participants on serotonin selective reuptake inhibitors (SSRIs) or serotonin and norepinephrine reuptake inhibitors (SNRIs) did not wash out and were included due to high comorbidity rates in this disorder and in an effort to reduce recruitment limitations. Of note only two ADHD participants in the study were taking SSRIs and analyses were repeated without these participants to ensure that results were not driven by those on SSRIs. Additional exclusionary criteria determined by a clinical interview and neuropsychological testing included currently experiencing a major depressive episode, meeting criteria for substance use disorder, or having an estimated IQ<80.

Overview of Procedures

All procedures were approved by the OHSU Institutional Review Board. Enrolled adults completed a series of online questionnaires as well as three in-person visits for the parent-grant. At onsite visit 1 they completed a diagnostic interview, standardized IQ (WASI-II) and neuropsychological assessments (e.g., DKEFS). At visit 2, an EEG task, not part of the current study, was administered. At visit 3, participants in the study repeated the EEG task (not part of the current study) that was administered in visit 2. To participate in the current study, participants were given the option of completing an additional EEG test and questionnaires as part of their 3rd visit (Controls: 57.5%; ADHD: 48.7%) or to come in for a separate 4th visit (Controls: 42.5%; ADHD: 51.3%). Of note, participants who chose to do an extended 3rd visit and those who chose to do a separate 4th visit did not differ in age, ADHD symptom severity, task performance, or EEG measures (all ps > 0.17).

To meet the a priori target sample size of 80 (see power analysis at the end of the methods section for details), additional participants were recruited outside of the parent study (n=11). These participants completed identical screening, diagnostic, and neuropsychological measures as those recruited through the parent study. Eligible participants were then invited to complete a single EEG testing visit where they completed questionnaires and experimental measures for this study (similar to participants in the parent study who selected to complete a 4th visit). Of note, participants recruited outside of the parent study did not differ from those recruited through the parent study in age, IQ, or symptom severity (all ps > 0.15). See **Figure 2** for a breakdown of recruitment flow including numbers of participants who underwent phone screens, participated in each visit in the study, and those who were excluded at each phase of recruitment.

Determining Diagnostic Grouping

ADHD symptom assessment. Self-report of current and childhood ADHD symptoms was assessed with a semi-structured interview with a masters-degree level clinician or the PI of the current dissertation (DSM-5 Adult ADHD Clinical Diagnostic Scale [ACDS] (Adler & Spencer, 2004)) as well as standardized questionnaires (Barkley Adult ADHD Rating Scale (BAARS) and Connors' Adult ADHD Rating Scale (CAARS)) (Barkley, 2011).

Informant measures of clinical symptoms were also be obtained for diagnostic assignment (Kooij et al., 2008; Zucker, Morris, Ingram, Morris, & Bakeman, 2002). To further validate past childhood symptoms of ADHD, a parent or former guardian of the participant was asked to complete the BAARS (Barkley, 2011) rating symptoms of the participant during childhood. An additional informant (e.g., spouse or close friend) was also asked to complete the BAARS (Barkley, 2011) rating current ADHD symptoms. This conforms to best practices for determining validity of ADHD in adults (Dulcan, 1997; Gibbins & Weiss, 2007; Sibley et al., 2012).

Comorbid symptoms. The Mini International Neuropsychiatric Interview (MINI (Sheehan et al., 1998)), a structured clinical interview, was also administered by a masters-degree-level clinician or the PI of the current dissertation to assess other psychiatric disorder symptoms (Lecrubier et al., 1997).

Final diagnostic assignment. See **Table 1** for a breakdown of how participants were assigned to a group. In line with DSM-5 criteria, in order to be assigned to the ADHD group, participants needed to have ≥5 current inattentive or hyperactivity symptoms, at least mild impairment resulting from these symptoms, as well as evidence that the onset of symptoms occurred prior to the age of 12 (American Psychiatric Association, 2013). The following algorithm was developed to balance the need to maintain a high standard of determining ADHD status while also retaining feasibility of recruiting the sample. Current ADHD symptom count was taken from the BAARS (self- and informant report) and ACDS (self-report).

To be in the ADHD group, (a) at least one reporter (informant or self) must have endorsed ≥5 current symptoms on either the BAARS or ACDS; (b) and at least one reporter must endorse ≥3 childhood inattentive or hyperactive symptoms also on either the BAARS or ACDS; (c) the participant must report at least mild impairment on the ACDS; (d) for both the child and adult symptom domains, both reporters must report a minimum of 2 symptoms within the inattentive or hyperactive domain on either the BAARS or ACDS; and (e) participants must have a T-score >65 on at least one ADHD related scale on the CAARS.

To be in the control group, (a) both reporters (participant and informant) must agree that the participant has ≤3 current inattentive and hyperactive symptoms on the ACDS and BAARS (b) and <3 childhood inattentive and hyperactive symptoms on the ACDS or BAARS; (c) the participant must report no impairment on the ACDS; and (d) the participant must have T-scores <60 on all ADHD related scales on the CAARs.

Only participants who fell into ADHD or Control groups were eligible for the study.

EEG Testing Visit Procedure

Participants were assessed for state sleepiness (Stanford Sleepiness Scale) (Hoddes, Zarcone, & Dement, 1972) and if they indicated they were considerably tired (denoted as a 5 or higher on the 8 point scale), their visit was rescheduled. Participants were also asked to refrain from recreational drug use and discontinue stimulant medication use for at least 24 hours prior to their visit. Abstinence was confirmed through oral report as well as through a urine screen (iCUP) that tested for the 13 most commonly abused recreational and prescription drugs. If the urine screen came back positive, the visit was rescheduled. An exception was made for THC if the participant reported abstinence for the last 24 hours. Due to slow metabolism, THC remains in the urine long after the psychoactive properties have worn off (Moeller, Lee, & Kissack, 2008). Urine screens may not have been collected at the EEG visit if participants reported abstinence and their previous screen(s) had come back negative. Participants chose the start time of their visits which ranged between 9:00am and 6:00pm. Of note, time of day that the visit took place was not related to the amount of MW participants reported engaging in during the visit. Nicotine use, marijuana use, and time of day of the visit (morning: 9:00am-11:59am, afternoon: 12:00pm-2:59pm, early evening: 3:00pm-6:00pm) are all reported in **Table 2** and do not differ between groups.

Measures.

Sustained attention to response task (SART). The SART (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) is a well-established go/no-go task that measures attention (Smallwood et al., 2008; Smilek, Carriere, & Cheyne, 2010). This task was chosen for the current study due to its prevalence in the MW literature as a relatively long and boring task that is effective in inducing high rates of mind-wandering (Kane et al., 2017; McVay & Kane, 2009, 2012; Stawarczyk & D’Argembeau, 2016; Stawarczyk, Majerus, Catale, & D’Argembeau, 2014; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, et al., 2011), as well as its use in MW studies using ERPs (Denkova, Brudner, Zayan, Dunn, & Jha, 2018; Kam et al., 2011; Smallwood et al., 2008). Although the SART is also a measure of inhibitory processes, no-go trials are not included in analyses in the current study and only serve as a way to keep the participants engaged with the task, which is consistent with how this task is most often used in the MW literature (Baldwin et al., 2017; Bastian & Sackur, 2013; Smallwood et al., 2008).

This task was programmed using Python 2.7. Participants responded with a button press to a pseudorandom series of digits 1-9 and withheld that response to the digit, “3”, appearing 11% of the time. **Figure 3** depicts an example of an experimental run and shows that each digit appeared one at a time for 250 ms followed by a centrally located fixation cross presented for 900-1100 ms. 500 Hz tones of a duration of 200 ms (distractors) were presented 400-650 ms after the offset of each visual stimulus, during the fixation period, for 75% of trials. For the other 25% of trials, “auditory blank” trials occurred where there was no tone following the visual stimulus (Tusch, Alperin, Holcomb, & Daffner, 2016). Tones were presented through speakers with an intensity of 75dB SPL (Cid-Fernández, Lindín, & Díaz, 2016; Tusch et al., 2016). Participants were told to ignore these tones and to keep their attention on the visual task. Each block varied in length from 30-90 seconds. The blocks included 26-66 visual stimuli and 20-49 auditory stimuli. A total of 45 blocks were presented in the task for a total of ~2070 visual stimuli and ~1550 auditory stimuli. The task was ~60 minutes in duration. Tasks of this length are commonly used in studies with adults with and without ADHD (Cross-Villasana et al., 2015; Kam et al., 2012, 2013; Kim, Liu, Glizer, Tannock, & Woltering, 2014) and are sufficient in length to elicit MW (McVay & Kane, 2009, 2012; Smallwood et al., 2008).

Thought probes. At the end of each block, participants answered five questions assessing their attentional state (Mills et al., 2018). Participants responded on a continuous scale from (1) *not at all* to (7) *very much* to five separate questions. The question was written at the top of the screen, and to respond, participants placed a slider along a line with “not at all” on one end and “very much” on the other. Slider placements corresponded to a numerical value between 1 and 7 that participants were blind to. Prior to the task, participants were provided with an explanation of each of the thought probes with examples (see **Appendix A**). The following questions were asked:

1. Were you thinking about something other than what you were doing?
2. Were you thinking about your surroundings?
3. Were your thoughts moving about freely?

Of note, two additional probes were administered evaluating the emotional content of the participant's thoughts. However, they were not analyzed in the current study due to being beyond the scope of the current aims. After participants completed all thought probes, the task continued to the next block.

No-go trials (i.e. trials with a "3" presented) did not occur within 10 trials (12 seconds) preceding a thought probe. This was in order to be able to analyze only go trials preceding thought probes (more details provided in the analysis section).

Rest task. Participants also completed an 18-block rest task. Each block was 30-70 seconds long and consisted of a fixation cross on which participants were asked to focus their gaze. At the end of each block a series of thought probes would appear. Probes were identical to the SART except that the first probe asking "were you thinking about something other than what you were doing" was omitted. Participants were given no specific task other than the gaze in the direction of the fixation cross. This task took ~20 minutes.

Thought probe confidence. After completing both the SART and rest task, participants completed a single thought probe confidence rating scale which was comprised of 6 questions asking about their confidence in responding to the thought probes. Participants answered each question on a 4-point likert scale from (1) *not confident* to (4) *very confident.* The first question asked how confident they were overall when responding to the thought probes while the five additional questions asked about confidence in responding to each of the five different thought probe types (see **Appendix B**). The thought probe confidence questionnaire was implemented after data collection had already begun and is missing for the first 12 participants ($ADHD_n = 6$).

All participants were included in all primary analyses; however, sensitivity analyses were conducted only including those who rated their confidence as a 2, 3 or 4. These follow-up analyses resulted in excluding no participants' data from probe 1 ("were you thinking about something other than what you were doing?") or probe 2 ("were you thinking about your surroundings?") analyses, and two participants' data from probe 3 analyses ("was your mind moving about freely?"). When considering confidence ratings, a 2 (group: ADHD, control) x 3 (thought probe: 1, 2, and 3) linear mixed model revealed a main effect of thought probe ($F(1,134) = 15.16$, $p < 0.001$). Confidence ratings were higher on thought probe 1 than on thought probe 2 and thought probe 3. There was no effect of group or a group x probe interaction ($ps > 0.52$).

Weiss functional impairment rating scale self-report (WFIRS-S). The WFIRS-S was used to assess functional impairment and was chosen due to its specificity of assessing impairment in ADHD, the wide range of domains it covers, as well its prevalence of use in the literature (Canu, Hartung, Stevens, & Lefler, 2016; Hartung et al., 2016; Lin, Lo, Yang, & Gau, 2015). This 70-item questionnaire assesses seven domains of functioning (family, work, school, life skills, self-concept, social, and risk). For each of the items, participants indicated how much difficulty they have had in that area using a 4-point scale with responses ranging from never to very often. The internal consistency for each scale (Cronbach's alpha = 0.84-0.93) as well as the global impairment score (total of all scales) (Cronbach's alpha = 0.96) in the WFIRS-S all demonstrate high internal consistency in addition to construct, predictive, and discriminant validity (Canu et al., 2016; Weiss, McBride, Craig, & Jensen, 2018).

EEG Recording and Preprocessing

EEG was recorded from each adult at a sampling rate of 500 Hz with 96 Ag-AgCl active electrodes using the open source software PyCorder v1.0.9. The electrode array is based on the international 10-20 system centered at Cz. EEG signals were amplified by a BrainVision actiCHamp2 amplifier.

Recordings took place while participants completed the SART and rest task. EEG data was analyzed using ERPLAB (Lopez-Calderon & Luck, 2014) and EEGLAB (Delorme & Makeig, 2004) toolboxes that operate within the MATLAB framework**.** Raw EEG data was referenced offline to the average of all channels. EEG signals were filtered using an IIR filter with a bandwidth of .01–50 Hz. Eye artifacts were removed by independent component analysis (Jung et al., 2000). Trials were discarded from the analyses if they contained baseline drift or movement artifacts ± 90 μV. Individual channels responsible for rejecting greater than 20% of trials were interpolated using EEGLABs interpolation function.

General Analysis

Analyses pertinent to all aims are described first, followed by aim specific analyses.

Determining MW and non-MW blocks. A continuous scale was used in order to capture nuance that could be missed when asking questions with a binary response; however, categorization was necessary in order to complete analyses which required a dichotomous assignment of MW and non-MW. Each block was categorized as MW or non-MW based on the participant’s response to the first thought probe which asked “were you thinking about something other than what you were doing?” Blocks preceding responses of 1-3.5 on that thought probe were categorized as non-MW blocks. Blocks preceding responses of 4.5-7 on that thought probe were categorized as MW blocks. Blocks preceding responses between 3.5 and 4.5 were not categorized due to the ambiguous nature of a response that lies in the middle of this scale.

This method of dichotomization was chosen to balance obtaining confidence that responses fell more towards one end of the spectrum (i.e., by removing responses around “4”) while also preserving the number of trials that fell into each of those categories. Other more conservative methods, (e.g., using a 1 as non-MW and 2-7 as MW (Mrazek et al., 2012)) may be more sensitive in isolating fully attentive moments from MW episodes; however, this results in a skew in the number of trials which fall into each category, greatly reducing blocks categorized as non-MW. Although not an issue for behavioral comparisons, this skew would greatly impact the EEG analyses in the current study since a minimum number of trials is required to reliably measure ERPs (of note, 37 participants would have too few trials during non-MW blocks to be included in ERP analyses in this study if using this criteria). Methods of dichotomizing continuous scales akin to what was done in the current work has been utilized in other studies (Christoff et al., 2009; Mills et al., 2018; Qin, Perdoni, & He, 2011).

Responses to the remaining thought probes: “were you thinking about your surroundings?” and “were your thoughts moving about freely?” were also dichotomized. Only responses that occurred during MW blocks (defined as trials preceding a response between 4.5 and 7 on the first thought probe) were used in calculations. Similar to the dichotomization of the first thought probe, responses between 1 and 3.5 were coded as stimulus-independent MW for the second thought probe and constrained MW for the third thought probe, while responses between 4.5 and 7 were coded as stimulus-dependent MW for the second thought probe or spontaneous MW for the third thought probe.

Based on the literature, 12 seconds prior to each report should reliably capture the reported attentional state (MW or non-MW) (Christoff et al., 2009; Kam et al., 2012, 2011, 2013; Smallwood et al., 2008). Trials that occurred 12 seconds (10 trials) prior to a thought probe were used in analyses. For ERP analyses, only correct responses were included to eliminate motor and error-related processing differences. Trials that occurred in a MW block were considered MW trials while trials that occurred within a non-MW block were considered non-MW trials (Kam et al., 2012, 2011, 2013; Smallwood et al., 2008). Sensitivity analyses were conducted with trials occurring 6 seconds (5 trials) prior to thought probes in order to determine whether patterns of results were specific to the time interval examined. Although p-values determine the significance of the effects with each of these tests (for 12 seconds and for 6 seconds), they are insufficient in determining whether effects *differ* between the 12 second and 6 second analyses. Because of this, for tests where p-values differed between 12 and 6 second analyses, confidence intervals for the effects of interest were examined for overlap. Interpretation of results considered both differences in p values, directions of effects, as well as overlap of confidence intervals.

Task performance. Mean reaction time (RT), standard deviation of reaction time (SDRT), errors of omission, and errors of commission were calculated for the overall task. Additionally, RT, SDRT, and errors of omission were also calculated separately for MW and non-MW blocks. Errors of commission could not be calculated for MW and non-MW blocks since there were no no-go stimuli within the 12 seconds prior to the thought probes.

Statistical Analysis

Specific analyses used to test hypotheses are described under each aim below.

Normality, outliers, and missing data. Variables were assessed for normality first by examining the distribution of the data and assessing for outliers. Outliers were data points that were 4 or more standard deviations from the mean. If detected, outliers were removed from the data. Normality was then assessed using the Shapiro-Wilks test of normality with a threshold of $p < 0.05$. If the test were positive, skewness and kurtosis were examined. Variables with a skewness and kurtosis less than or greater than 2 were considered non-normal (Kim, 2013). Of note, only N1 mean amplitude was non-normal in the current study due to an outlier. This participant's N1 data was removed from all analyses. Once removed, the N1 data became normally distributed. One control participant's SART data was not used due to early discontinuation as well as not providing any report of their attentional state during the task. No variables met criteria for being non-normal and no transformations or non-parametric tests were used.

Full information maximum likelihood methods were used to account for missing data for all regression analyses which were carried out using MPLUS 7.2 (Graham, 2009; Muthén, & Muthén, 1998). Pairwise deletion was used in all linear mixed models which were carried out in SPSS (*IBM SPSS Statistics for Windows*, 2017). Additional information on when each of these tests were used is under each aim below.

Aim 1: Proportion of Stimulus-Dependent and Stimulus-Independent MW in ADHD

Self-report data.

Data preprocessing. For each participant, the percentage of stimulus-independent and stimulus-dependent MW were calculated by dividing the number of reported stimulus-dependent or independent blocks by the total number of MW blocks and multiplying by 100.

Statistical analyses. To determine whether those with ADHD engage in a larger proportion of stimulus-dependent to stimulus-independent MW as compared to controls, the percentage of stimulus-dependent and stimulus-independent MW were submitted to a linear mixed model with a compound symmetry repeated covariance structure. Linear mixed models are a well-established method for analyzing data with repeated measures and, in contrast to methods like repeated measures ANOVA which uses listwise deletion when data points are missing, has the advantage of being able to better accommodate missing data using pairwise deletion (Gueorguieva & Krystal, 2004; McCulloch & Searle, 2000; SPSS, 2005; Verbeke & Molenberghs, 2000). In the linear mixed model, MW type (stimulus-dependent or -independent) was the within-subjects variable and group (ADHD or control) was the between-subjects variable. All linear mixed models were carried out using SPSS v.25.0 (*IBM SPSS Statistics for Windows*, 2017). It was hypothesized that a group x MW type interaction would reveal that those with ADHD engage in proportionally more stimulus-dependent MW than the control group.

EEG data.

Data preprocessing. Epochs were time-locked to the onset of the auditory distractors. The sampling epoch for each trial was 1,200 ms, including a 200 ms pre-stimulus period that was used to baseline correct the epoch. The mean amplitude of the auditory N1 was measured from 75-150 ms post auditory stimulus and the P2 was measured from 150-225 ms post auditory stimulus at a fronto-central electrode cluster (comprised of the average of Fz and the eight surrounding electrodes) (Hillyard et al., 1973; R. Näätänen & Teder, 1991). See **Tables 3 and 4** for correlations between the 8 electrode sites for the N1 and P2 respectively. Because of the influence of the N1 on the P2 and the high correlation between these components in the current dataset ($\beta = 0.57$; the larger the N1, the smaller the P2) the N1 amplitude was regressed onto the

P2 amplitude and a residual P2 score was used in all analyses (referred to as the rP2). The conceptual benefits and issues associated with this approach are elaborated upon in the Discussion section. N1 and rP2 difference waves were calculated by subtracting the ERP during non-MW from the ERP during MW (MW – non-MW).

Ensuring appropriate number of trials. Because the number of trials was dependent on participants' reports of MW, it was possible that a participant could have very few, or even zero, trials for MW or non-MW conditions. The minimum number of trials needed to accurately measure the ERPs of interest was determined by calculating the mean amplitude of the N1 or P2 at the fronto-central electrode cluster for increasing numbers of trials within each subject. This process was iterated 50 times and the variance for each trial number was calculated and graphed (Navajas, Nitka, & Quian Quiroga, 2017). The number of trials needed was decided by balancing a cutoff that would ensure adequate retention of data as well as a point at which the variance began to plateau based on visual inspections. This was done for both the N1 and P2 separately. For both the N1 and P2, 30 trials was the point at which a sufficient amount of data could be retained and the slope of the variance began to plateau. Data from participants with trial numbers below the threshold were removed from analyses and missing data techniques were used.

The mean number of MW trials was 147 (SD = 78; ADHD = 169, SD = 70; Control = 125, SD = 80) and the mean number of non-MW trials was 94 (SD = 78; ADHD = 74, SD = 64; Control = 113, SD = 86). With a cutoff of 30 trials, 8 participants were missing data for MW trials ($ADHD_n$ = 2) and 14 participants were missing data for non-MW trials ($ADHD_n$ = 7) (total of 22 participants, $ADHD_n$ = 9). See **Figures 4a and 4b** for a depiction of the variance change in amplitude measurement over increasing number of trials for the N1 (4a) and P2 (4b).

Statistical analyses. To determine whether those with ADHD are more susceptible to stimulus-dependent MW, N1 and rP2 amplitude to the auditory distractors were submitted to two separate linear mixed models with attentional state (MW or non-MW) as the within-subjects factor and group (ADHD or control) as the between-subjects factor. It was hypothesized that a group x attentional state interaction would show that those with ADHD demonstrate less attenuation during MW vs. non-MW states as compared to the control group demonstrating an increased susceptibility to stimulus-dependent MW.

Response to probe 2 was regressed onto N1 and rP2 difference waves in two separate linear regression analyses to determine whether this ERP measure was related to self-report of stimulus-dependent/-independent MW. All regressions were carried out using MPLUS (7.2) (Muthén, & Muthén, 1998).

Aim 2: Proportion of spontaneous and constrained MW in ADHD

Behavioral data.

Data preprocessing. For each participant, the percentage of constrained and spontaneous MW were calculated by dividing the number of reported constrained or spontaneous blocks by the total number of MW blocks and multiplying by 100.

Statistical analyses. To determine whether those with ADHD engage in a larger proportion of spontaneous to constrained MW as compared to controls, the percentage of constrained and spontaneous MW were submitted to a linear mixed model with MW type (constrained vs. spontaneous) as the within-subjects variable and group (ADHD vs. control) as the between-subjects variable. It was hypothesized that a group x MW type interaction would show that those with ADHD engage in a greater proportion of spontaneous MW than controls.

EEG data.

Data preprocessing. Epochs were time-locked to the onset of the go-correct visual stimuli. The sampling epoch for each trial was 1,200 ms, including a 200 ms pre-stimulus period that was used to baseline correct the epoch. EEG segments were averaged (ERPs were calculated) and the 200 ms baseline was not included when calculating complexity values (i.e., 12 one second epochs were averaged together). Complexity was calculated for MW and non-MW trials separately as well as for all go correct stimuli regardless of attentional state reported. Because complexity is sensitive to signal noise (Skinner, Molnar, & Tomberg, 1994; Stam, 2005), 30 epochs were randomly selected from each condition for each subject to ensure more similar signal-to-noise ratio in the signals. Similar strategies have been reported in the literature (Müller & Lindenberger, 2012).

Complexity values were calculated with the widely used Skinner's algorithm to calculate pointwise correlation dimension (PD2) (Skinner et al., 1994; Skinner, Molnar, Vybiral, & Mitra, 1992) using the Dataplore software package (Datan Software and Analysis GmbH, Teltow, Germany). PD2 is a mathematical measure derived from non-linear system theory that has frequently been used to measure overall complexity of EEG brain dynamics, particularly during various attentional states (Lutzenberger et al., 1992; Mölle et al., 1996, 1999). Aside from being used in other studies assessing attention, PD2 was chosen for the current study because the data generated from EEG is a non-stationary time-series and unlike other algorithms which assume stationarity of the signal (e.g., simple correlation dimension), PD2 allows a way to detect the complexity within a nonstationary time-series of dynamic data (Skinner et al., 1994, 1992). First the system dynamics were reconstructed with the time delay (τ) of 1 (2 ms) consistent with similar work (Müller & Lindenberger, 2012). A time delay of 1 allowed for all 500 data points to be included in the calculation of complexity. The maximum embedding dimension (which sets the dimension of the state space) was set to 12. This value was based on the point at which the estimated dimensions become saturated (i.e., the point at which the complexity values no longer change) and is in line with what has been used in other EEG studies (Aftanas et al., 1998). To ensure that results were not dependent on the embedding dimension chosen, analyses were re-run with an embedding dimensions of 16 which has been used in another EEG based studies of complexity using the PD2 algorithm (Müller & Lindenberger, 2012). The dimensionality of the resulting attractor was calculated using the following formula: PD2(i) = logC(r,i)/log(r). The pointwise correlation integral (C(r,i)) will be calculated based on:

$$C(r,i) = \frac{1}{N-1} \sum_{j=0;j \neq i}^{N-1} \theta(r - ||\widehat{x_i} - \widehat{x_j}||)$$

where r is the radius of the state space neighborhood around x, $\widehat{x_i}$ and $\widehat{x_j}$ are the state space coordinates with the delay τ, N is the length of the signal, and θ is the Heavyside function defined as:

$$\theta(x) = \begin{cases} 0 \; if x < 0 \\ 1 \;\; if x \geq 0 \end{cases}$$

The PD2 value is the dimension of an attractor of the time-series which reflects the system's dynamic complexity.

Complexity values were also calculated during the rest task in order to demonstrate that complexity is greater on a task where more MW should be occurring (i.e., participants should have more focused attention and therefore less complexity overall during the SART than during the rest task). Rest complexity was calculated the same way as SART complexity, by averaging together 1 second epochs for the 12 seconds prior to the thought probe.

Statistical analyses. To determine whether those with ADHD engage in a larger proportion of spontaneous MW than control subjects, complexity values were submitted to a linear mixed model with attentional state (MW vs. non-MW) as the within-subjects variable and group (ADHD vs. control) as the within-subjects variable. It was hypothesized that a group x attentional state interaction would show that those with ADHD have higher complexity values during MW than non-MW as compared to controls reflecting an increase in spontaneous vs. constrained MW in the ADHD group.

Response to thought probe assessing the degree to which the participant was MW (probe 1) was regressed onto complexity values to all go-correct stimuli using linear regression to determine whether complexity overall was related to MW report. Response to the thought probe assessing how freely moving the participant's thoughts were (probe 3) was also regressed onto complexity values during MW using linear regression to determine whether this measure was related to self-report of the movement of thought during MW.

Aim 3: Exploring the relationship between the type of MW and functional impairment in those with ADHD

Data preprocessing. A global impairment score was calculated as the average score across all scales on the WFIRS-S. MW count was calculated as the total number of blocks where MW was reported. N1 and rP2 difference wave amplitudes were calculated by subtracting non-MW ERPs from the MW ERPs. Complexity during MW was also used as well as the average response to thought probes 2 ("were you thinking about your surroundings?") and thought probe 3 ("was your mind moving about freely?").

Statistical analysis. Multiple linear regressions were computed to predict: 1) ADHD symptom severity (inattentive, hyperactive/impulsive and total self-reported symptoms from the

BAARS); 2) global functional impairment; and 3) task performance all within the ADHD group only. For each of these outcomes, a multiple linear regression was run with MW count, the average response to thought probe 2, the average response to thought probe 3, N1 difference wave, rP2 difference wave, and MW complexity score. Regressions were run using MPLUS (7.2) (Muthén, & Muthén, 1998).

Covariates

For linear mixed models and regression analyses across all aims, due to the possible effects of biological sex on task performance and ERPs (Bourisly & Shuaib, 2018; Melynyte, Ruksenas, & Griskova-Bulanova, 2017; Melynyte, Wang, & Griskova-Bulanova, 2018), sex (male/female) was entered as a covariate in each of these models. Reported results include sex as a covariate if it were significant within the model. If not, it was removed as a covariate.

Although the age of participants ranged between 18 and 40, evidence that there are age-related changes within that window is minimal; with most work examining age-related changes on performance and ERPs in groups above or below our age range. Age was not correlated with SART performance or ERP amplitude in the current sample (all ps > 0.31) and was not used as a covariate. IQ is often lower in adults with ADHD (Bridgett & Walker, 2006). While covarying for IQ controls for group differences in intelligence, controlling for this variable eliminates the influence of fundamental qualities of an ADHD population therefore reducing external validity (Dennis et al., 2009; Mackenzie & Wonders, 2016). Because of this, primary analyses did not include covarying IQ. Similarly, stimulant medication is only used in the ADHD group (21 participants prescribed) and also varies with symptom severity. In order to ensure that symptom severity was not being controlled for, medication status was not used as a covariate. See **Table 2** for descriptive statistics of group differences in medication prescriptions.

Power Analysis

Power was assessed using G power (Erdfelder, Faul, & Buchner, 1996). A priori power analysis indicated that an overall n of 80 (40 per group) would give adequate power to detect effects and interactions of interest and was the target n for the current study. The final sample size was extremely close to this target. For mixed linear model analyses, the current total sample size of 79 (40 controls and 39 with ADHD) gave power = 0.80 to detect medium-size group effects (d=0.60), small attentional state effects (d = 0.20) and small interaction effects (d=0.20). For multiple linear regression analyses, the current total sample gave power = 0.80 to detect medium effect sizes (d = 0.34). For self-report measures, large effect sizes for a group difference has been found (d = 0.80 – 2.30) (Mowlem et al., 2016; Seli et al., 2015). For ERP analyses, a medium effect size for a group effect (ADHD vs. controls) (d = 0.64 – 0.69) for early auditory ERPs is generally found (Barry et al., 2009; Kilpeläinen et al., 1999). This effect size is also typical for studies of cognitive and attentional features in ADHD (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). A large effect size for an attention effect (MW vs. non-MW) for early auditory ERPs in a typically developing population has also been found (d = 1.02) (Kam et al., 2013). For complexity analyses, previous work has found a medium to large effect size for the attentional effect of interest (constrained vs. spontaneous thought) (d = 0.78 – 1.20) (Mölle et al., 1996; Mölle, Pietrowsky, Fehm, & Born, 1997) in typically developing individuals. Studies investigating EEG complexity in ADHD have found large effect sizes for a group effect as well (ADHD vs. controls) (d = 0.78 – 1.05) (Fernández et al., 2009; Zarafshan, Khaleghi, Mohammadi, Moeini, & Malmir, 2016b). Given that prior work has consistently found medium and, more often large, effects for the effects of interest, our sample size and power to detect medium and small effects should be more than adequate.

Chapter 3: Results

Analyses are broken down by aim. Preliminary analyses are presented first (e.g., task performance, overall MW report).

Preliminary Data Description and Descriptive Results

Participant characteristics. ADHD and control groups did not differ by age, sex, or IQ. There were also no group differences in the session length, time of day of the visit, hours of sleep the previous night, marijuana use, nicotine use, or SSRI prescriptions. Despite a similar number of hours of sleep, those with ADHD reported being sleepier at the start of the EEG visit. Because of this, sensitivity analyses for tests under each aim were run with reported sleepiness as a covariate. As expected, individuals with ADHD had more ADHD symptoms, comorbid disorders, and were more likely to be prescribed stimulant medication than controls. See **Table 2** for participant demographics, clinical scores, and drug/medication use.

SART thought probes. Participants with ADHD reported more MW on the SART than controls. This was demonstrated through those with ADHD having more MW blocks ($F(1,76) = 6.40$, $p = 0.01$), fewer non-MW blocks ($F(1,76) = 6.12$, $p = 0.02$), and a higher average response to thought probe 1 asking “were you thinking about something other than what you were doing?” ($F(1,76) = 8.59$, $p = 0.004$). MW (based on response to thought probe 1) increased over time on task, ($F(21.14,1522.13) = 5.09$, $p < 0.001$). This effect was not modulated by group (no group x time on task interaction: $F(21.14,1522.13) = 1.03$, $p = 0.43$). See **Figure 5** for a depiction of how MW increased over time for both the control and ADHD groups.

Results for the individual thought probes related to stimulus-dependent thought and spontaneous thought are presented under their respective aims (i.e., analyzing stimulus-dependence overall and spontaneity overall as they pertain to the specific aims rather than in combination with each other).

SART task performance. Group effects were examined for performance on the entire task (regardless of MW report) and are presented in **Table 5**. Below is a description of the effects of MW on task performance. These were conducted by comparing performance scores during MW and non-MW trials in order to replicate findings that performance decreases during MW and also to determine whether the performance-related decline during MW was greater in ADHD (group x attentional state interaction).

A 2 (attentional state: MW vs. non-MW trials) by 2 (group; ADHD vs. control) linear mixed model revealed a significant attentional state effect for RT (F(1,71.09) = 13.93, p < .001), SDRT (F(1,76.36) = 5.94, p = .02), and errors of omission (F(1,74.66) = 11.44, p = .001). RTs were faster, SDRT were greater, and there were more errors of omission during MW trials. There was a significant effect of group for SDRT (F(1,77.41) = 5.96, p = .02) and errors of omission (F(1,78.58) = 6.60, p = .01) such that the ADHD group had greater SDRT and errors of omission than the control group. No group x attentional state interactions were significant (all ps > 0.25). Overall this demonstrates that performance decreased during MW and this effect was not enhanced in the ADHD group.

Aim 1

Self-report. A 2 (attentional state; percentage of stimulus-dependent blocks vs. percentage of stimulus-independent blocks) by 2 (group; ADHD vs. control) linear mixed model was run to determine whether those with ADHD engage in proportionally more stimulus-dependent MW than controls (determined by a group x attentional state interaction).

A main effect of attentional state was found where stimulus-independent MW was reported more often than stimulus-dependent MW (F(1,73.00) = 24.16, $p < 0.001$). Neither an effect of group (F(1,73.00) = 0.55, p = 0.46) nor group x attentional state interaction (F(1,73.00) = 0.25, p = .62) reached significance. This did not support the hypothesis that those with ADHD would engage in more stimulus-dependent MW than controls. See **Figure 6** for a depiction of results.

ERPs. Figure 7a and 7b shows grand average ERPs for the ADHD and Control groups under MW and non-MW trials for both 12 (7a) and 6 (7b) second analyses. 2x2 linear mixed model (again, attentional state (MW vs. non-MW) by group (ADHD vs. control)) were used to determine whether the amplitude difference between MW and non-MW trials differed between those with and without ADHD. N1 and P2 results are reported in terms of mean amplitude.

Auditory N1. Using epochs occurring 12 seconds prior to the thought probes, effects of group, attentional state, or group x attentional state interaction did not reach significance (all ps > 0.31). This analysis thus failed to support the hypothesis of either an overall attentional state effect or of a group x attentional state interaction and does not support that those with ADHD demonstrate a diminished attenuation of the N1 during MW and are therefore more susceptible to stimulus-dependent MW.

Auditory N1 sensitivity analysis. Unlike the 12 second analysis, sensitivity analysis examining the N1 during the 6 seconds prior to the thought probe did reveal a main effect of attentional state (F(1,39.09) = 7.51, p = 0.009, d = 0.13) with a confidence interval that did not overlap with the 12 second effect. In line with the ERP literature, and supporting the hypothesis, the N1 amplitude was smaller during MW than non-MW. This finding suggests that a 12 second interval may be too large to accurately capture the reported attentional state. However, like the

12 second analysis, the interaction between attentional state and group failed to reach significance ($p = 0.30$) also failing to support the hypothesis that those with ADHD would show a diminished attenuation of the N1 during MW.

Auditory rP2. Effects of group, attentional state, or a group x attentional state interaction did not reach significance (all ps > 0.29). This analysis did not support our hypothesis of an overall attentional state effect or a group x attentional state interaction and does not support that those with ADHD demonstrate a diminished attenuation of the rP2 during MW and are therefore more susceptible to stimulus-dependent MW.

Auditory rP2 sensitivity analysis. Analyzing the rP2 during the 6 seconds prior to the thought probe did not differ from the 12 second analysis and revealed no significant main effects or interactions (all ps > 0.26).

Relationship between self-report and ERP measures. The average response to thought probe 2 (“were you thinking about your surroundings?”) was regressed onto the N1 difference wave and rP2 difference wave to determine whether this hypothesized ERP measure of susceptibility to stimulus-dependent MW was related to report of stimulus-dependent MW. N1 difference wave was marginally related to probe 2 ($\beta = 0.20$, $p = .09$). The more attenuated the N1 during MW, the more stimulus-dependent MW was reported. The rP2 difference wave was not related to probe 2 ($p = 0.50$). See **Table 6** for betas, standard errors, and p values.

Aim 2

Self-report. A 2 attentional state (constrained blocks vs. spontaneous blocks) by 2 group (ADHD vs. control) linear mixed model was run to determine whether adults with ADHD engaged in proportionally more spontaneous MW than controls (group x attentional state interaction).

A main effect of attentional state demonstrated that all participants reported engaging in more spontaneous MW than constrained MW (F(1,73.00) = 51.45, $p < 0.001$). This was qualified by a group x attentional state interaction (F(1,73.00) = 4.63, p = .04). While both the control and ADHD group demonstrated more spontaneous than constrained thought, this effect was of greater magnitude in the ADHD group (F1,38) = 71.50, $p < 0.001$, d = 5.86) than in the control group (F1,35) = 8.67, p = 0.006, d = 2.71). These results support our hypothesis that those with ADHD engaged in a greater proportion of spontaneous MW than controls. The main effect of group did not reach significance (F1,73.00) = 0.22, p = 0.64). See **Figure 8** for a depiction of the results.

Complexity.

Validation of Complexity using Rest Task. In order to confirm that complexity was measuring the expected phenomenon, overall complexity on the SART (complexity to all go correct stimuli) was compared to overall complexity on the rest task. It was expected that complexity would be increased on the rest task since MW overall should be increased on that task. A 2-task type (SART vs. rest) by 2 group (ADHD vs. Control) linear mixed model revealed a main effect of task type (F(1,76.82 = 181.35, $p < 0.001$) supporting the hypothesis that complexity during the rest task was greater than the complexity during the SART.

To further confirm that the complexity was capturing the expected phenomenon, the amount of spontaneous MW engaged in during the SART was compared to the amount of MW engaged in during the rest task (both based on the thought probe asking how freely moving the participant's thoughts were). A 2 task (SART vs. rest) linear mixed model did not reveal a main effect of task (F(1,71) = 2.45, p = 0.12). Although not reaching statistical significance, the pattern trended in the expected direction with 77.12% of MW being spontaneous during the rest task and 71.22% of MW being spontaneous during the SART.

SART. 2 attentional state (MW vs. non-MW) by 2 group (ADHD vs. control) linear mixed models were used to determine whether the EEG complexity for MW and non-MW trials differed between those with and without ADHD during the SART.

There was a marginally significant effect of attentional state (F(1, 62.04) = 3.63, p = 0.06, d = 0.22). This was in the expected direction such that complexity was higher during MW vs. non-MW. A main effect of group and the group x attentional state interaction both did not reach significance (all ps > 0.18). These results did not support the hypothesis that those with ADHD would demonstrate a larger effect of attentional state (i.e., more complexity during MW than non-MW) than controls.

SART complexity sensitivity analysis. Sensitivity analysis looking at complexity values occurring 6 seconds prior to the thought probe revealed a main effect of attentional state (F(1,59.77) = 10.04, p = 0.002, d = 0.35) where complexity was greater during MW than non-MW trials. There was also an interaction between group and attentional state (F(1,59.77) = 4.96, p = 0.03). In line with the hypothesis, the attentional state effect for the control group did not reach significance (F(1,27.65) = 0.46, p = 0.50, d = 0.20), whereas in the ADHD group, complexity during MW was greater than complexity during non-MW (F(1,31.62) = 10.79, p = 0.002, d = 0.48).

However, for both the main effect of attention and for the interaction, confidence intervals for the 6 second and 12 second effects greatly overlapped. This suggests that while effects become statistically significant when examining data 6 seconds prior to the thought probe, due to overlapping confidence intervals with the 12 second analyses, the 6 second analysis is not capturing something unique from the 12 second analysis. These results are interpreted further in the Discussion section taking both results from the 12 and 6 second analyses into consideration. See **Figure 9** for a depiction of results for both 12 second and 6 second intervals.

Because of previously reported relationship between increased EEG complexity and decreased P3b ERP component to visual stimuli (a component generated in the current study, although not examined in primary analyses) (Jia, Li, & Yu, 2017) as well as the well-established finding that the P3b is reduced in those with ADHD (Szuromi, Czobor, Komlósi, & Bitter, 2011), the relationship between complexity and the P3b was examined in the current work. A negative relationship was found such that the greater the complexity, the smaller the P3b amplitude ($\beta = -0.29$, $p = 0.01$). Although there were no group differences in the P3b in the current study ($F(1,75) = 1.53$, $p = 0.22$) sensitivity analyses were run with P3b amplitude as a covariate. Statistical significance and patterns of results did not change from models without this covariate suggesting that effects are driven by complexity rather than the influence of the P3b on complexity.

Relationship between self-report and complexity measures. The average response to thought probe 1 (“were you thinking about something other than what you were doing?”) was regressed onto the complexity measure for all go correct stimuli to see if complexity overall were related to MW. Thought probe 3 (“was your mind moving about freely?”) was regressed onto complexity score during MW to see if increased complexity during MW report was reflecting increased thought movement during MW (as captured by self-report on probe 3). Complexity was related to report of MW such that the higher the complexity, the more the participant reported MW, $\beta = 0.28$, $p = 0.003$; however, the relationship between complexity and freedom of thought movement during MW did not reach significance ($\beta = 0.11$, $p = 0.32$). See **Table 6** for betas, standard errors, and p values.

Aim 3

Analyses predicting symptom severity, functional impairment, and task performance only included ADHD participants in order to understand how aspects of MW predict individual differences within the disorder rather than between those with and without ADHD. If including all participants in regression analyses, significant tests would effectively be predicting group differences since those with ADHD systematically are more impaired, have more severe ADHD symptoms, and perform more poorly on the task.

MW frequency, report on thought probe 2 (“were you thinking about your surroundings?”), report on thought probe 3 (“was your mind moving about freely?”), N1 difference wave, P2 difference wave, and complexity during MW were all used as individual predictors of each outcome (symptom severity, functional impairment, task performance). See **Tables 7-9** for betas, standard errors, and p values from the multiple regressions. See **Table 10** for correlations between each predictor included in the regressions.

Group differences in functional impairment. One-way ANOVAs demonstrated that those with ADHD reported more impairment than the control group. This was true in their report of global impairment ($F(1,77) = 50.63$, $p < 0.001$) as well as their report on all other facets of functional impairment assessed: family ($F(1,77) = 9.26$, $p = .003$), work ($F(1,75) = 29.16$, $p < 0.001$), school ($F(1,50) = 24.21$, $p < 0.001$), life skills ($F(1,77) = 50.92$, $p < 0.001$), self-concept ($F(1,77) = 32.59$, $p < 0.001$), social ($F(1,77) = 23.55$, $p < 0.001$), and risk ($F(1,77) = 9.70$, $p = 0.003$).

Predicting symptom severity. Outcome variables included BAARS self-report of inattention, hyperactivity/impulsivity, and total symptoms (three separate regressions were run). Multiple linear regressions revealed that the rP2 difference wave predicted total ADHD symptoms ($\beta = -0.33$, $p = 0.03$) which was driven by inattention symptoms ($\beta = -0.34$, $p = 0.02$). Greater attenuation of the rP2 during MW was associated with greater ADHD symptom severity. Both probe 2 and probe 3 response also predicted total ADHD symptoms ($\beta = 0.26$, $p <0.05$ and $\beta = 0.34$, $p = 0.02$ respectively) which was driven by hyperactivity/impulsivity symptoms ($\beta = 0.30$, $p = 0.02$ and $\beta = 0.40$, $p = 0.001$ respectively). Greater stimulus-dependent MW and greater spontaneous MW were associated with higher ADHD symptom severity. N1 difference wave was marginally related to total ADHD symptoms ($\beta = 0.25$, $p = 0.09$). Less attenuation of the N1 during MW was associated with higher ADHD symptom severity. No other variables predicted ADHD symptoms (all ps > 0.11).

Assessing reporter bias. To determine whether the relationship between self-reported MW and self-reported symptoms were due to having the same reporter, the regression was also run with informant report on total symptoms as the outcome. In this model, self-report measures were no longer related to symptom severity (all ps > 0.64).

Predicting functional impairment. Outcome included global impairment from the WFIRS-S. Multiple linear regression revealed that the rP2 difference wave ($\beta = -0.63$, $p < 0.001$) significantly predicted global impairment. This relationship survived controlling for ADHD symptoms ($\beta = -0.57$, $p = 0.001$). A more attenuated rP2 during MW predicted greater impairment. No other variables predicted global impairment (all ps > 0.30).

Predicting task performance. Outcome variables included average RT, SDRT, and errors of commission on the SART (three separate regressions were run). Multiple linear regression revealed that MW count predicted SDRT ($\beta = 0.35$, $p = 0.03$). The more participants mind-wandered on the task, the more variable their RT. No other variables predicted SDRT and no variables predicted average RT or errors of commission (all ps > 0.25).

Sensitivity analysis for rP2 findings. Greater attenuation of the rP2 difference wave was found to be related to total ADHD symptoms, inattention symptoms, and global impairment. In order to address issues revolving around including this residualized variable alongside the N1 (which had all of its variance removed from the rP2), analyses were rerun several ways.

In including the non-residualized P2 (normal mean amplitude measure of the P2) to see if effects are specific to the rP2, the P2 remained significant in all models (impairment: $p < 0.001$; inattention: $p = 0.05$; total symptoms: $p < 0.02$). Models were also rerun by including an N1 to P2 peak to peak measure (instead of the N1 and P2 separately). This measurement technique is used when the N1 and P2 are considered non-independent components that can essentially be lumped together in a single measurement. The peak to peak measure was significant in the model predicting impairment, but not symptoms (impairment: $p < 0.001$; inattention: $p = 0.18$; total symptoms; $p = 0.16$). In excluding the rP2 to see if effects would be present when the model included the N1 alone, no effects were seen for the N1 (impairment: $p > 0.29$; inattention: $p > 0.90$; total symptoms: $p > 0.39$). This sensitivity analysis suggests that because N1 alone does not predict these outcomes and because multiple ways of measuring the P2 do predict the outcomes, effects are specific to the P2.

Interactions between MW Dimensions

In order to determine whether group differences in spontaneous MW were specific to stimulus-dependent or stimulus-independent MW (i.e., is this increase in spontaneous MW in ADHD driven by spontaneous/stimulus-dependent or spontaneous/stimulus-independent MW) a multivariate ANOVA was run with diagnostic group as the between subject variable and three dependent variables. The first re-examined group differences in stimulus-dependent MW using the average response to the thought probe evaluating this dimension. In line with findings from aim 1, this analysis revealed no main effect ($p > 0.64$). The second re-examined group differences in spontaneity of though during MW using the average response to the thought probe evaluating this dimension. In line with aim 2, this analysis revealed that those with ADHD engaged in more spontaneous thought while MW ($F(1,71) = 5.30$, $p = 0.02$). The final evaluated group differences in an interaction term of these two scales (stimulus-dependent x spontaneity of thought) to determine whether the group difference in spontaneous MW was driven by either stimulus-dependent or stimulus-independent MW. This analysis revealed no interaction ($p > 0.20$) demonstrating that although those with ADHD engage in more spontaneous MW, this is not specific to stimulus-dependent or stimulus-independent MW.

Sensitivity Analysis for all Models within Each Aim

To ensure results were not driven by confounding variables, all analyses were re-run without the two ADHD participants prescribed SSRIs or controlling for: stimulant medication prescription, sleepiness, comorbid generalized anxiety disorder, or comorbid depression. Each covariate was entered into each model one at a time. Models including the response to thought probe 3 were rerun without the two participants who rated the confidence of their report as “not confident” for this probe. Models including complexity were rerun using complexity measures with an embedding dimension of 16 (instead of 12) to confirm that the current results were not driven by the embedding dimension used.

The removal of participants, change in embedding dimension, or addition of each of these covariates did not alter the patterns of results for analyses in aims 1 and 2. For aim 3, only one result was altered. When controlling for stimulant medication prescription, MW count no longer predicted increased SDRT ($\beta = 0.20$, $p = 0.23$).

Chapter 4: Discussion

Summary of Overall Aim and Results

MW is a ubiquitous phenomenon increased in those with ADHD (Franklin et al., 2017; Mowlem et al., 2016; Seli et al., 2015; Shaw & Giambra, 1993). Although this increase in frequency has been related to functional impairment (Mowlem et al., 2016), it is unclear whether those with ADHD merely mind-wandered more and this increased quantity of MW is impairing, or whether there is something qualitatively different about their MW, and that's what drives impairment. The current study suggests that individuals with ADHD not only mind wander more than their typically-developing counterparts, but that their mind wandering is also qualitatively different. Adults with ADHD engaged in proportionally more spontaneous thoughts while MW as compared to typically-developing individuals. While as a group, those with ADHD did not engage in proportionally more stimulus-dependent MW than controls, increased stimulus dependence and increased spontaneity of thought during MW predicted impairment over and above frequency of mind wandering alone.

Aim 1: Stimulus-Dependent versus Stimulus-Independent MW

In contrast to hypotheses, those with ADHD did not engage in more stimulus-dependent externally focused MW than typically developing controls. This finding was consistent across levels of analyses with both self-report and ERP analyses revealing no group x attentional state interactions.

Self-report findings. Although there were no interactions, based on self-report data, all participants engaged in more stimulus-independent than stimulus-dependent MW. This finding is in contrast to findings from experiencing sampling studies where participants were asked about the content of their thoughts throughout their daily lives. These studies, although few, have found that people engage in equal amounts of stimulus-dependent and –independent MW (Mills et al., 2018; Song & Wang, 2012).

It is important to note the contextual difference between the current dissertation work and these studies. Here, MW was assessed in the lab as opposed to being assessed outside the lab, and a lack of correlation between lab-based and daily-life based MW report has been found (Kane et al., 2017). The current findings suggest that within the lab, MW is more likely to be stimulus-independent, regardless of diagnosis. Other studies assessing lab-based MW have utilized multiple choice thought probes, many which have included options related to stimulus-dependent MW (e.g., thoughts were focused on the "external environment" or were "task-unrelated and stimulus-dependent") (Kane et al., 2017; Stawarczyk & D'Argembeau, 2016; Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011). This work has also found similar quantities of stimulus-dependent and –independent MW (Stawarczyk et al., 2014; Stawarczyk, Majerus, Maquet, et al., 2011); however, these results should be taken with some caution since this work does not statistically test differences between these types of MW (rather they report percentages) and the sample sizes are fairly small.

One hypothesized reason for the low percentage of stimulus-dependent thought during MW in the current work is that participants were completing the SART and thought probes in a small room, by themselves, with the lights off, and there were very few external distractions that may have caught their attention. This hypothesis is supported by real-world experience sampling studies (where MW data was collected in contexts where more external distraction is present) finding equal amounts of stimulus-dependent and stimulus-independent MW (rather than more stimulus-independent MW as seen in the current work) (Mills et al., 2018; Song & Wang, 2012). It is possible that if completing this task in a more distraction ridden location (e.g., outside or in a busy hallway), participants, particularly ADHD participants, would have been more prone to engaging in stimulus-dependent MW. It would be interesting to see how results from the current study differ from experience sampling in daily life in those with and without ADHD. Although still in its infancy, wireless EEG technology (Debener, Minow, Emkes, Gandras, & de Vos, 2012) could be employed in future work in order to collect both neural and self-report data in a real world setting.

Despite limitations related to the context under which MW was reported, the current findings do contribute to a limited set of rigorously designed studies to assess differences in stimulus-dependent and –independent MW and suggest that stimulus-independent MW is more prevalent in the laboratory setting and that those with ADHD do not engage in a greater proportion of stimulus-dependent MW that controls under this context. Additionally, the current work also suggests that stimulus-dependence is a valid dimension along which MW varies. This was demonstrated by ~35% of all reported MW falling into the stimulus-dependent category and argues against a classification of MW as being strictly stimulus-independent.

ERP findings. Overall, ERP results were convergent with the self-report results and suggest that those with ADHD are *not* more susceptible to stimulus-dependent MW than typically developing controls as reflected by a lack of group x attention state interactions for both the N1 and rP2 to task-irrelevant tones. Although self-report measures may be limited by the current environmental context (i.e., participants being in a small enclosed room with limited distraction), the measurement of the ERPs are immune (or at least more immune than the self-report) to this potential confound. Because the ERPs were a marker of the *susceptibility* to stimulus-dependent MW, where MW was currently focused (i.e., stimulus-dependent or -independent) should not have impacted whether the participant would be more likely to shift their attention to an external distractor during MW. A lack of group x attentional state interaction for the ERPs allays some concern that the result for the self-report measure was due to the current context, and solidifies the conclusion that those with ADHD are not more likely to engage in proportionally more stimulus-dependent than -independent MW as compared to typically developing controls.

Despite this lack of interaction, and although the primary analyses evaluating ERPs occurring 12 seconds prior to the probe did not demonstrate an attentional state effect, sensitivity analyses examining ERPs 6 seconds prior to the probes did demonstrate the expected attentional state effect for the N1. In line with findings from the literature, this component was attenuated during MW (Kam et al., 2013). The fact that this effect was specific to the 6 second analysis suggests that MW report may be more reliable during this shorter interval. Choosing a 12 second window for primary analyses was well justified since most studies investigating ERPs during MW have used a 12 second window and have found that ERPs are attenuated during MW (Denkova et al., 2018; Kam et al., 2012, 2011; Kam, Xu, & Handy, 2014; Smallwood et al., 2008; Xu, Friedman, & Metcalfe, 2018). One explanation for the discrepancy between the current study and the literature is that the strength of this attentional effect may vary based on task modality and stimulus-relevance. A majority of previous work have investigated ERP responses to visual stimuli. There are two studies that have examined the auditory N1 during MW (Kam et al., 2011, 2013), both finding an attenuation of the N1 during MW, although these studies are limited and the sample sizes are small ($n \approx 20$). Additionally, both of these studies included attended-to auditory stimuli leaving it unclear whether MW effects are less robust when examining the N1 response to task-irrelevant tones. Because studies are so few, future work should examine the effects of auditory task-relevance on the attenuation of the N1 during MW as well as examine changes in this attentional state effect over different temporal windows preceding thought probes.

In contrast to previous findings (Braboszcz & Delorme, 2011), the rP2 did not demonstrate this main effect of attentional state. While the functional significance of the N1 and P2 components are often lumped together and described as both being modulated by attention and reflecting early auditory stimulus processing (Hillyard et al., 1973; Risto Näätänen, Kujala, & Winkler, 2011), there is evidence to support that these two components are distinct from one another (Crowley & Colrain, 2004). For example, the P2 increases to a greater magnitude than the N1 in response to increased auditory signal intensity (Alder & Alder, 1989), the N1 is reduced in patients with unilateral temporal-parietal lesions whereas the P2 is unchanged (Knight, Hillyard, Woods, & Neville, 1980; Knight, Scabini, Woods, & Clayworth, 1988), the P2 increases with stimulus repetition while the N1 decreases (Costa-Faidella, Baldeweg, Grimm, & Escera, 2011; Hsu, Hämäläinen, & Waszak, 2014), and source localization studies have found differing generators for the N1 and P2 (Godey, Schwartz, de Graaf, Chauvel, & Liégeois-Chauvel, 2001; Verkindt, Bertrand, Thevenet, & Pernier, 1994). The support for the N1 and P2 being distinct components ameliorates some concern regarding different attentional state findings between the N1 and rP2.

Although the auditory N1 is a relatively well-studied ERP component, the auditory P2 is far less studied and the functional significance of this component has not been well-established. The N1 is associated with early perceptual detection of an auditory stimulus that has been shown to be modulated by attention (Hillyard et al., 1973; Risto Näätänen et al., 2011). While the P2 is far less well-characterized than the N1, work suggests that the P2, in addition to detecting auditory stimuli and being modulated by attention, is also related to higher order functions such as acoustic memory and identifying stimulus features (Crowley & Colrain, 2004; Ross & Tremblay, 2009). The discrepancy in results between the N1 and rP2 could be due to differences in the specific processes affected by MW. For example, MW may result in a reduction in the basic processing of a tone (N1), whereas functions related to early stimulus categorization (P2) remain intact.

Alternatively, the attenuation of the N1, but not the rP2 during MW might be a reflection of the current task design. Because the tones are task-irrelevant, repetitive, and in competition with an attention-based visual task, the functions represented by the rP2 may be less necessary overall (e.g., a floor effect of the rP2 response since no elaborative processing is necessary for these tones). Although the work by Braboszcz et al., (2011) found that the P2 to task-irrelevant auditory tones was attenuated during MW, these tones were presented during an *internally* focused attention task (counting one's breath). It is possible that the competing visual stimuli in the current task consumed resources that would otherwise be allocated to processing the tones, resulting in a muted rP2 response. Additional work is needed not only to understand the functional difference between the auditory N1 and P2, but also to solidify the effects of MW on these components in the context of different task demands.

Relationship between self-report and ERP measures. The N1 and rP2 difference waves were not related to the participant's self-reported amount of stimulus-dependent MW. The ERPs, while being measured in response to the externally distracting tones, do not reflect that the participant is currently engaging in stimulus-dependent MW in that moment. Rather, the ERPs were used as a marker of *susceptibility*. If you are more responsive to distracting tones while MW, this suggests that you are more *susceptible* to stimulus-dependent MW, but not necessarily actively engaging in stimulus-dependent MW at that moment. In fact, the direction of your attention itself during MW (stimulus-dependent or -independent) should not impact the ERP response. Rather, the likelihood that you will respond to stimuli outside of your current train of thought (i.e., the susceptibility of your attention to shift to a distracting external stimulus) drives the magnitude of the response to the tone during MW. Therefore, although tapping the same dimension of MW, this lack of a relationship between ERP difference waves and self-report of stimulus-dependent MW is not particularly surprising since the probe was capturing where their MW was focused on in the *current* moment (or at least the moments just before the probe) whereas the ERP measures were capturing their general *susceptibility* to stimulus-dependent MW and was not reflecting the content of their MW in the present moment. To date, no other study has directly related ERPs during MW and non-MW episodes to self-report of MW content. Additional work is needed that relates ERP measures to self-report measures in order to better understand what these neurophysiological markers are representing.

Aim 1 conclusions, limitations, and future directions. It was hypothesized that those with ADHD would engage in proportionally more stimulus-dependent MW than typically developing controls. This hypothesis was based on the large body of literature demonstrating that those with ADHD are more susceptible to external distraction that those without ADHD (Forster & Lavie, 2016; Pelletier et al., 2016) and this aim sought to test the idea that because of this increased distractibility to external stimuli, those with ADHD would also engage in more externally-dependent MW. Both self-report and neurophysiology results suggest that this was not the case, and that adults with and without ADHD do not differ in the degree they engage in stimulus-dependent and -independent MW.

MW and distraction are highly related, but distinct phenomena, as demonstrated in work showing that MW is related to aspects of external distractibility, but not distractibility in all of its facets (e.g., MW is related to interference from task-irrelevant but not task-relevant distractors) (Forster & Lavie, 2014). Although studies are limited, previous work suggests that internal and external distraction may be driven by common attentional mechanisms. This is supported by a study that found that increased MW is related to increased external distractor interference (Forster & Lavie, 2014). In other words, internally and externally driven distraction are correlated such that an increased tendency to be *internally* distracted is related to an increased tendency to be *externally* distracted. Findings in the current dissertation are in line with this such that those with ADHD did not preferentially engage in stimulus-dependent (externally mediated) MW, but rather engaged in increased amounts of both stimulus-dependent and stimulus-independent MW as compared to controls (based on raw counts rather than percentages which are presented in the results). While previous work supports the notion that those with ADHD are more susceptible to external distraction (Forster & Lavie, 2016; Pelletier et al., 2016), no work, to the best of my knowledge, has specifically investigated how this finding carries over to internal cognition within those with ADHD. The current works provides some evidence that increased distractibility in ADHD is not specific to external stimuli, but rather carries over to aspects of internal cognition as well.

While increased distractibility and inattention are hallmarks of ADHD, those with ADHD are also prone to becoming hyper-focused (Asherson, 2005; Schecklmann et al., 2008; Sedgwick, Merwood, & Asherson, 2018). One opposing hypothesis is that those with ADHD become hyper-focused on their internal train of thought while mind-wandering and therefore demonstrate decreased responsiveness to the stimuli in their environment (or increased perceptual decoupling). However, this is not an explanation for the current findings since increased perceptual decoupling in this group would have been demonstrated by increased attenuation of their ERPs during MW as compared to controls which was not found.

According to perceptual load theory, the low perceptual load in the current task should have allowed for high levels of distractibility (Lavie, 2005) and increased MW (Forster, 2013; Forster & Lavie, 2009). It was expected that those with ADHD would demonstrate an overall larger N1 and rP2 to distracting tones demonstrating that overall, they were more distracted by the task-irrelevant stimuli. However, no group differences were seen in these components which calls into question whether the tones were distracting enough to elicit the expected increased interference response in those with ADHD. If this is the case it would affect the interpretation of the ERP results (the lack of a group x attentional state interaction as well as the lack of relationship between ERP measures and stimulus-dependent MW). Future work should include more salient distractors as well as conditions with and without distractors to better understand how aspects of stimulus-dependent MW relate to ERP responses to task-irrelevant stimuli.

Aim 2: Constrained versus Spontaneous MW

In line with the stated hypothesis, individuals with ADHD engaged in more spontaneous than constrained thought during MW as compared to typically developing controls. This finding was consistent across levels of analyses with both self-report and complexity analyses revealing group x attentional state interactions.

Self-report findings. Only one study to date has evaluated movement of thought during MW. Mills et al. (2018) found, in line with the findings in the current work, that typically developing individuals engaged in more spontaneous than constrained MW during their daily lives. The current findings add to extremely limited studies directly examining spontaneity of thought during MW and suggest that MW is largely encompassed by spontaneous thought under both lab-based and real-world conditions.

Despite MW being largely encompassed by spontaneous thought (~70% of the time) the remaining 30% of reports were those of constrained thoughts. Again, as demonstrated by Mills et al., restricting MW to be defined as freely moving thought would mean misclassifying or neglecting to capture 30% percent of MW report.

Complexity findings. Results from the complexity analysis were convergent with self-report findings. Despite the group x attentional state interaction being significant only during the sensitivity analysis examining complexity occurring 6 seconds prior to the thought probes (as opposed to 12 seconds as was done in the primary analysis), considering the results from both analyses points in the direction of a meaningful interaction that merits interpretation. For the primary analysis, although the interaction was not significant at $p = 0.18$, the attentional state effect for the ADHD group was marginal ($p = 0.06$) while there was no significant attentional effect for the control group ($p = 0.72$). The interaction and ADHD attentional state effect became significant in the sensitivity analysis. Although according to the confidence intervals, which greatly overlapped, it cannot be concluded that the primary and sensitivity analyses were demonstrating significantly different effects, but integration of these results suggest that those with ADHD engaged in proportionally more spontaneous than constrained MW as compared to the control group. These results may also suggest that, like the N1 attentional state effect, a smaller window of analysis may be necessary to accurately capture neural states that coincide with the self-reported state, and in this case, particularly for those with ADHD. Due to the novel nature of the complexity analysis and the relatively small effect sizes for these effects, this result should be interpreted with some caution and future studies are needed using both complexity as well as other neurophysiological markers (e.g., time-frequency markers) that may reflect variability of thought processes.

One thing potentially influencing the complexity measures was the ERPs triggered by task stimuli, particularly the P3b (Jia et al., 2017) which is generally reduced in those with ADHD (Szuromi et al., 2011). This was addressed in the current study and the relationship between increased complexity and decreased P3b amplitude was replicated from previous work (Jia et al., 2017). Despite this relationship, including the P3b as a covariate in the main analyses did not alter results confirming that results for the complexity measures were not driven by differences in the P3b.

Relationship between self-report and complexity. EEG complexity values were related to the degree of MW (as measured by probe 1) and were also greater during the rest task (where increased MW was expected) as compared to the attention-based SART task, adding to the evidence that complexity increases with MW (Ibáñez-Molina & Iglesias-Parro, 2014, 2016). Although complexity was greater during rest than the SART, report of spontaneous MW was not significantly greater during the rest task. Additionally, although EEG complexity was theorized to reflect the degree of the freedom of thought movement during MW (Mölle et al., 1996, 1999), there was no relationship between complexity during MW and self-report of spontaneity of thought.

There are several potential reasons for this lack of relationship that guide future research. One is that there is a difference between these measures in their sensitivity to capture differences along the continuum of constrained to spontaneous thought. For example, self-report was reliant on participants moving a cursor on a non-delineated line and the difference between highly spontaneous thought and very highly spontaneous thought is blurred and left up to the opinion of the participant. Whereas complexity is not reliant on subjective markers of the constrained to spontaneous dimension and may more sensitively capture the nuanced difference between highly and very highly spontaneous thought. An alternative explanation is that because the thought probe capturing spontaneity of thought was presented third, due to degradation of memory and decreased reliability of report over time (Barrouillet et al., 2004), this thought probe may not have most accurately reflected the participants actual previously occurring mental state. Further support for this comes from the fact that confidence ratings on this thought probe was lower than the other two (although the general rating reflected confidence). To address this, future work could counterbalance thought probes to ensure that time since reported mental state does not remain as a potential confound.

Aim 2 conclusions, limitations, and future directions. It was hypothesized that those with ADHD would engage in proportionally more spontaneous MW than typically developing controls. This hypothesis was largely based on findings related to increased variability in attention in ADHD (Huang-Pollock et al., 2012; Kofler et al., 2013). Although this has been established on tasks of external attention, the current work sought to determine whether increased attentional variability (in the form of increased spontaneous thought) was also found during internal attention states. Both self-report and neurophysiological results supported this hypothesis and suggest that adults with ADHD do preferentially engage in more spontaneous MW than controls. This work adds a unique contribution showing that deficits in maintaining attention on a single task or topic can be seen across contexts (e.g., externally focused attention as well as internally focused attention) and are enhanced in those with ADHD.

The finding that spontaneous thought during MW is increased in ADHD helps tie together some disparate findings in the neuroimaging literature and points towards the role of the balance between the DMN and fronto-parietal control network (FPN) in the occurrence of MW. During cognitive tasks, in typically developing individuals, the DMN is negatively correlated with the FPN (Fox et al., 2005). In ADHD, there is a reduction in this negative correlation demonstrating difficulty inhibiting DMN activity (Mills et al., 2018; Sonuga-Barke & Castellanos, 2007). This deficit in balancing DMN and FPN activity has been hypothesized to drive the increased attentional variability in ADHD (Sonuga-Barke & Castellanos, 2007). DMN activity in addition to FPN activity is increased during MW vs. focused attention. In addition to reflecting increased attentional variability, this lack of appropriate coordination between the DMN and FPN in ADHD may reflect the increased propensity to MW (although this has never been directly examined). In addition, one study found increased connectivity in the medial temporal lobe subcomponent of the DMN in those with ADHD (Anderson et al., 2014), a subnetwork thought to reflect increased spontaneous (rather than constrained) MW (Christoff et al., 2016). To better clarify mechanism and more directly measure this relationship, future work should relate self-report and/or EEG complexity measures reflecting spontaneity of thought during MW with the functional relationship between the DMN and FPN in those with ADHD.

Aim 3: Predicting Functional Impairment

Both increased stimulus-dependent MW as well as increased freedom of movement while MW were related to ADHD symptom severity. Further, the degree to which those with ADHD perceptually decouple from distracting tones during MW predicted both ADHD symptom severity as well as global functional impairment. These results demonstrate that specific qualities of MW not only predict impairment, but also that they are better predictors of impairment than MW frequency alone.

This finding is in line with the small body of research that has demonstrated that specific aspects of MW are able to differentially predict symptom severity (Franklin et al., 2017; Seli et al., 2015). For example, Franklin et al. (2017) found that the relationship between the frequency of MW and symptom severity was stronger when MW was automatic (i.e., not deliberate). Additionally, Seli et al. (2015) found that automatic MW predicted symptoms severity whereas deliberate MW did not. This early work demonstrates that specific qualities may be better predictors of impairment; however, work on this has been limited and has not investigated how stimulus-dependence and the spontaneity of thought contribute to ADHD-related impairment. The current work contributed novel insights into these specific dimensions of MW and how they might be related to symptom severity.

Interestingly, self-report of stimulus-dependent MW and spontaneity of thought were both related specifically to hyperactivity/impulsivity symptoms and not inattention symptoms. Similar results have been reported in other work with MW being related to increased hyperactivity/impulsivity symptoms under multiple test conditions, whereas inattention symptoms were only related to MW during a high load task (Arabacı & Parris, 2018). This means that both the lack of perceptually decoupling from stimuli in the environment in combination with a decreased ability to maintain attentional focus (i.e., have constrained thought) is more predictive of hyperactivity/impulsivity than engaging in other types of MW. What both of these dimensions of MW have in common, is their potential relationship to inhibitory function. Increased stimulus-dependent MW can be conceptually related to a decreased ability to inhibit the response to external and irrelevant stimuli, whereas increased spontaneous MW can be conceptually related to an inability to inhibit extraneous thoughts from entering the stream of consciousness. Because hyperactivity/impulsivity symptoms in adult

ADHD have been found to be driven by impulsivity/disinhibition and not hyperactivity symptoms (Kooij et al., 2008; Mick, Faraone, & Biederman, 2004), this relationship between these specific facets of MW and hyperactivity/impulsivity symptoms, hint at a potential role of inhibitory function underlying increases in stimulus-dependent and particularly spontaneity of thought during MW (although it is acknowledged that impulsivity is not always the same as disinhibition; see Nigg, 2017). Future would could specifically design studies to investigate facets of impulsivity and disinhibition to better understand how they are related to qualities of MW in those with ADHD.

The rP2 DW was related to both symptom severity and functional impairment, although the direction of this effect was opposite of what was expected. Whereas a decrease in the attenuation of the rP2 to MW would reflect more susceptibility to stimulus-dependent MW, the current finding was that the more attenuated the rP2 during MW, the more impaired the individual. This attenuation of the rP2 during MW can be translated as reflecting the phenomenon of perceptual decoupling, or the shift of attention towards internal thought. The act of perceptual decoupling does not necessarily mean that during the task individuals were not MW about things in their external environment. Perceptual decoupling merely reflects that attention was less focused on the task stimuli resulting in attenuated ERPs during MW. Previous work has found that ERPs are attenuated during MW in response to standard tones, but not to deviant tones (Kam et al., 2013). Although the auditory stimuli were the same frequency and duration throughout the task, the fact that they only occurred 75% of the time and their onset was jittered may have made them deviant or novel-like to the participants. This would mean that a lack of attenuation to the tones would be an adaptive response potentially reflecting the ability to “snap out” of an internal train of thought to attend to something salient in the environment (Kam et al., 2013). Therefore, a lack of this adaptive response, i.e., an increased attenuation of the P2 during MW, would be maladaptive and would be expected to predict impairment.

Interestingly, this effect was only seen in the rP2 and not in the N1 and sensitivity analyses suggested that this was not specific to the use of a residualized P2 since results were replicated using other measures of the P2. As previously mentioned, the functional distinction between the N1 and P2 is poorly established; however, some evidence suggests that the P2 involves higher order operations not captured by the N1 (e.g., feature selection, stimulus identification, and memory) (Crowley & Colrain, 2004; Ross & Tremblay, 2009). The results here may reflect that while a reduction in the response to a sound in your environment during MW may not be detrimental to functioning (as reflected in the N1), a reduction in the ability to identify potentially salient features of a sound in your environment (as reflected in the P2) results in impairment.

Limitations

Self-report. A potential driver of the positive relationship between self-reported MW (increase stimulus-dependent and spontaneous MW) and increased ADHD symptom severity is that the same reporter was providing both measures. If these findings were a result of reporter bias, this would call into question the validity of the main finding that specific qualities of MW are related to symptom severity. Support for report bias comes from the finding that relationships were no longer present when informant report of symptoms was used as the outcome measure. However, some concern for this can be alleviated from findings that probe responses were not related to *all* other self-report measures (e.g., probe ratings were not related to self-rated impairment) suggesting some specificity to this relationship. One potential reason why we might see probe responses differentially related to self-report of symptoms only is that the features captured by the probes are particularly internally mediated (i.e., not easily observed) and may be related to symptoms that the participant themselves are more likely to be aware of.

Participant bias. One potential issue with the thought probe method is that participants become aware of the content that they are being evaluated on which could result in a bias in their responses (e.g., the act of asking someone what they are thinking about over and over again may impact how they MW or the frequency with which they MW). With the current experimental design, it is not possible to eliminate this potential bias; however, the convergence of self-report with physiology is reassuring. By discovering reliable non-self-report-based measures of specific aspects of MW, current results suggest these measures can be used in future work without the use of the thought probe method therefore eliminating potential participant bias.

Additional Considerations and How to Move Forward

Contribution to definitional debates of MW. The current work utilized the dynamic framework of MW as proposed by Christoff et al., which, in opposition to the family-resemblances view, is aligned with the argument that MW is a specific cognitive construct with definable boundaries. Although not a primary aim of this dissertation, by using the dimensions of MW proposed in the framework, there is a unique opportunity to comment on the usefulness of both these specific dimensions as well as comment on how a restricted definition of MW may or may not enhance the field as a whole.

In examining how much MW in each of these dimensions occurred during the SART (i.e., stimulus-dependent/spontaneous; stimulus-dependent/constrained; stimulus-independent/spontaneous; stimulus-independent/constrained) it was revealed that while there were differences in how frequently participants engage in each of these types, each dimension was engaged in for a significant portion of the task (i.e., all percentages were significantly different from zero). This suggests that these dimensions are valid qualities that participants can report having their thoughts vary along. If restricting the definition of MW to be stimulus-independent spontaneous thought (as is acceptable under the family resemblances view), over 50% of MW episodes would either be misclassified (most likely the most common in current research) or completely neglected if experimenters are explicit with their subjects to only report they are mind-wandering when they are having stimulus-independent spontaneous thought.

Although thoughts during MW appear to vary along the dimensions focused on in the current work, there is a practical issue with this framework. Although it conceptually distinguishes what is and is not MW, those lines are challenging to establish in a research setting. For example, MW can vary from constrained to spontaneous, however in the framework, extremely constrained thoughts (e.g., obsessions or rumination) are not included in the conceptual definition of MW. However, when evaluating MW on a constrained to spontaneous scale, participant reports of constrained thought may very well include ruminative or obsessive thought. Therefore, the practicality of accurately employing this model is potentially limited.

Because the self-report along these dimensions can easily bleed into constructs considered outside of what is defined as MW, this increases the value of using neuroimaging and physiologically based measures to help distinguish between types of thought that lie outside the boundaries of what defines MW. One way to implement this type of work is to recruit samples particularly prone to thought processes that lie on the extremes of these dimensions (e.g., those with depression or OCD in the case of ruminative or obsessive thoughts) so it can be determined whether these types of thoughts can, in any way, be reliably distinguished from thoughts that would fall into the range of MW as proposed in the model. If so, there is immense promise to this model, if not, the model may need to be revised to better align conceptual underpinnings with practical limitations.

Through the use of a constrained definition of MW with specified dimensions that the phenomenon varies along, this work demonstrates that the dynamic framework does provide additional insight that is lost when merely measuring MW as a whole (e.g., MW count did not predict symptoms or impairment whereas specific dimensions of MW did). This is not to say that the model is perfect and complete, but rather that there is utility in continuing to investigate and restrict the definition of MW to specific aspects that can be distinguished from other aspects of internal thought.

MW in ADHD: is it always detrimental? In the context of ADHD, the propensity to MW is often viewed as a negative trait that is related to symptom severity and disorder-related impairment (Franklin et al., 2017; Mowlem et al., 2016). While acknowledging that MW has been found to be related to enhanced creativity and often includes future oriented or goal-based thought, this dissertation revolved around the notion that MW is problematic in ADHD. While there is evidence in the current work that increased rates of specific facets of MW are related to symptom severity and impairment, no measures of positive outcomes were included (e.g., enhanced creativity, satisfaction with life, etc.). Future work including both typically developing and non-typically developing individuals should seek to understand not only what is impairing about MW, but also what facets of MW are potentially beneficial. For example, constrained goal-directed thought during MW may be related to positive outcomes, whereas extreme spontaneous thought during MW may be related to impairment. In addition to types of MW predicting differential outcomes, the context under which MW is prevalent has the potential to greatly impact how detrimental or beneficial MW is. For example, MW during a class lecture might be related to impaired academic performance, whereas MW during a bus ride to work may result in figuring out the solution to a work-related issue. Although not demonstrated in the current work where performance was poorer when individuals were MW, it is possible that under alternative contexts, the act of MW, particularly during a low demand repetitive task, may serve as an arousal mechanism that actually maintains performance rather than negatively affecting it. In line with this, a dishabituation hypothesis has been suggested predicting that switching focus between external stimuli and mind-wandering content may “refresh” the processing of external stimuli and reduce habituation effects (Mooneyham & Schooler, 2016). Gaining a comprehensive view of the qualities (e.g., spontaneous or constrained), contexts (e.g., high or low load), as well as moderating variables (e.g., motivation, reward, executive function) that drive both MW-related impairment as well as MW-related enhancement are important not only for understanding MW as a construct, but also in the context of designing interventions to both reduce impairment and promote well-being.

Aspects of MW and their relationship to attentional control. While MW is undoubtedly an attention-based phenomenon, because of definitional debate, the line between MW and other more commonly studied facets of attention (e.g., sustained attention, selective attention, attentional control) is blurry. One strength of approaching MW research by defining and isolating specific dimensions of MW is that these dimensions allow for isolation of specific cognitive processes. In other words, the cognitive underpinnings of a subcomponent of MW, such as spontaneity of thought, is more easily isolated than those underlying the multi-faceted black-box construct of MW as a whole. Through this approach, researchers are better able to contribute to theories of *why* MW occurs.

Most theories of MW, in some way, conclude that MW occurs when attentional control fails (McVay & Kane, 2009, 2010, 2010, 2012; Schooler, 2002; Thomson et al., 2015). Because attentional control, much like MW, is a multi-faceted process with numerous underlying theories as to what this "controller" refers to (e.g., Verbruggen, McLaren, & Chambers, 2014), merely stating "it's attentional control's fault" is unsatisfying at best. The current approach of investigating specific dimensions of MW, although not specifically aimed at informing attentional theories of MW, provide some potential insight into the mechanisms driving this loss of attentional control.

Although there are many diverse theories of attentional control, many discuss the function of two core processes that interact. These are 1) the maintenance of goal representation and 2) the ability to detect and resolve conflict (Baumeister & Heatherton, 1996; Braver, 2012; Engle & Kane, 2004; Petersen & Posner, 2012). Understanding the interaction between these two components during MW ultimately involves an investigation of the interaction between multiple facets of MW, which was not done here; however, some hypotheses can be posited.

The maintenance of goal representations is a way to bias attention to enhance the distinction between targets and distractors (Braver, 2012). A goal maintenance failure, or a failure in the ability to inhibit distraction is not only seen in the onset of MW, but is arguably continued during the active process of MW. This explains why a majority of MW tends to be more spontaneous (i.e., moving from topic to topic) because there is a general lack of maintenance of attention and therefore a lack of inhibition of other (external or internal) distractors. In the context of ADHD, there is not only an increased amount of MW in general, but also an increased in the amount of spontaneous MW pointing to a decreased maintenance function. This hypothesis is supported by functional neuroimaging work that relates this maintenance function with the fronto-parietal network, a network with decreased activity during cognitive tasks in those with in ADHD (Castellanos & Proal, 2012; Silk, Vance, Rinehart, Bradshaw, & Cunnington, 2008).

Although not included in the current work, the automatic/deliberate dimension of MW might serve as a good dimension to better understand the role of conflict monitoring during MW. Measuring the degree to which individuals are engaging in automatic vs. deliberate MW may inform the degree to which they have a failure of conflict monitoring, with increased failure associated with increased automatic MW (due to an inability to notice and therefore correct when attention has shifted away from task goals). Previous work has found that MW in ADHD is predominantly automatic and the more automatic their MW is, the more impaired they are (Franklin et al., 2017; Seli et al., 2015). This failure in the cognitive monitoring domain of attentional control is supported by both neuroimaging and ERP research with participants with ADHD demonstrating reductions in regions (primarily the anterior cingulate) (Bush et al., 1999; Castellanos et al., 2008) as well as components (primarily the error related negativity) (Marquardt, Eichele, Lundervold, Haavik, & Eichele, 2018; Wiersema, van der Meere, & Roeyers, 2005) associated with conflict monitoring/processing ability during cognitive tasks.

Although the hypotheses above are speculative, they suggest that studying different dimensions of MW in populations with a large body of literature investigating attentional control deficits (such as an ADHD population) allows for the integration of existing research on facets of attentional control with theories of MW. This is not to say that specific facets of MW are new names for specific facets of attentional control (e.g. “spontaneous MW” is not synonymous with “goal maintenance failure”), but rather that because of the clear role of attentional control in the onset and maintenance of MW, researching specific aspects of MW in different populations has promise for informing theories of attention and attentional control both within and beyond the field of MW.

While most underlying theories of MW have focused on top-down attentional control, there could also be bottom-up homeostatic explanations for MW. For example, MW may serve as a mechanism to maintain an optimal arousal state =. Investigations into the role of more bottom-up mechanisms driving MW could be particularly salient for understanding MW in the context of ADHD since several theories of the disorder revolve around dysregulation of energetic state (Killeen, Russell, & Sergeant, 2013; Sergeant, 2000). It has also been proposed that different arousal states are associated with different types of MW (e.g., high arousal during MW is associated with more engaging spontaneous thought) (Unsworth & Robison, 2018). Although the work investigating bottom-up contributions and interactions with MW are extremely limited, there is immense potential for future work to continue to elucidate both bottom-up and top-down mechanisms involved in MW.

Conclusion

This was the first study to examine stimulus-dependent and spontaneity of MW in those with ADHD in addition to being the first to couple self-report measures of MW with neurophysiological measures in this population. The results of the current dissertation suggest that those with ADHD engage in more spontaneous MW than typically developing individuals; the amount of spontaneous and stimulus-dependent MW predicts hyperactivity/impulsivity symptoms, and the degree to which they perceptually decouple from distracting stimuli during MW predicts impairment. This work contributes novel information that can help aid future work investigating both the phenomenology of MW as well as the mechanisms of impairment in ADHD.

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Figure 1. Depiction and examples of the dimensions of MW focused on in this dissertation

	Stimulus-Dependent	**Stimulus-Independent**
Constrained	Thinking about the buzzing fly in the room	Thinking about a presentation you need to give later
Spontaneous	Thinking about the fly in the room, then the lights being too bright, then your growling stomach	Thinking about the presentation you need to give, then the dinner you will cook later, then that old friend you ran into earlier today

Figure 2. Recruitment flow

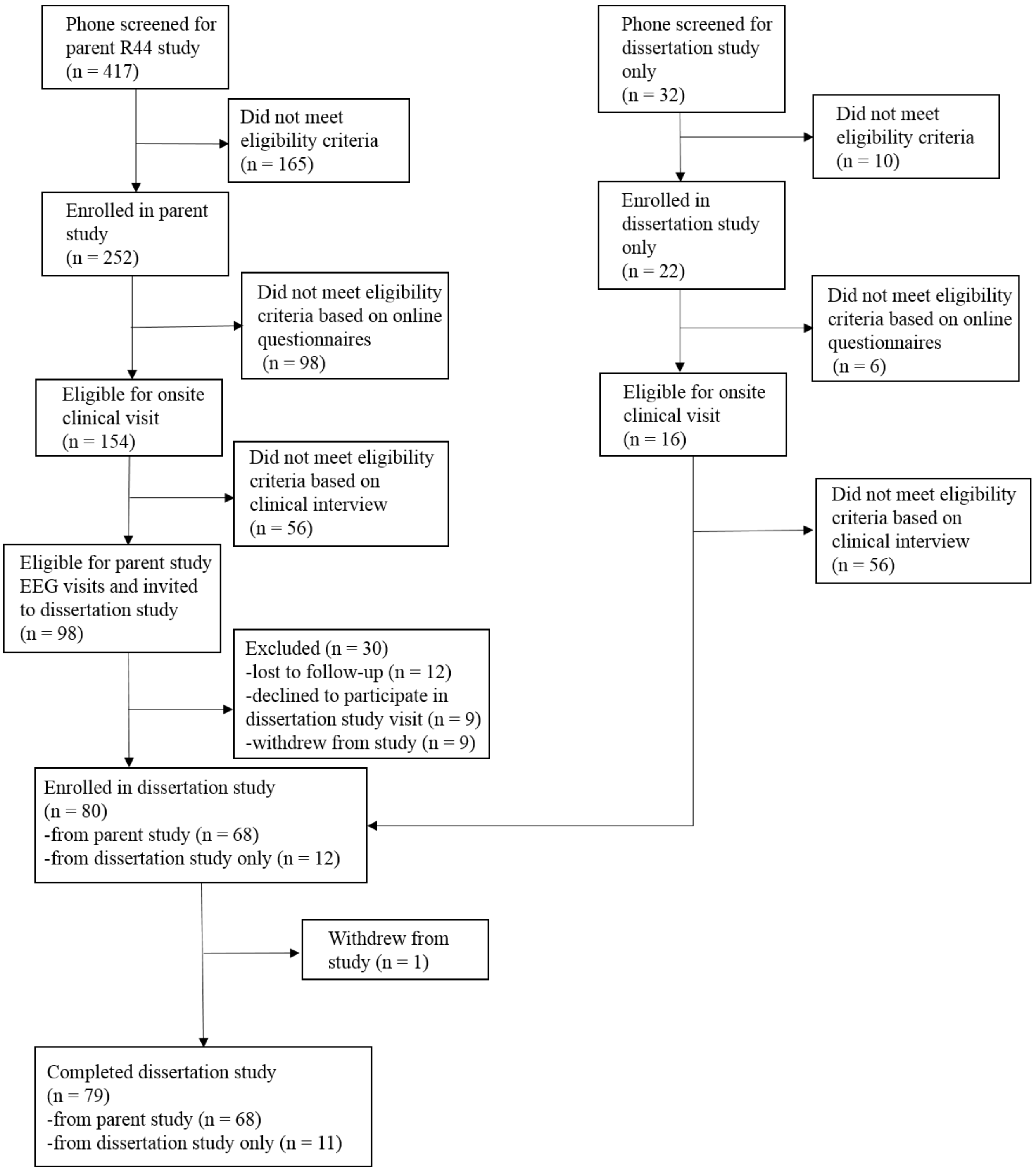

Figure 3. Depiction of a SART experimental run

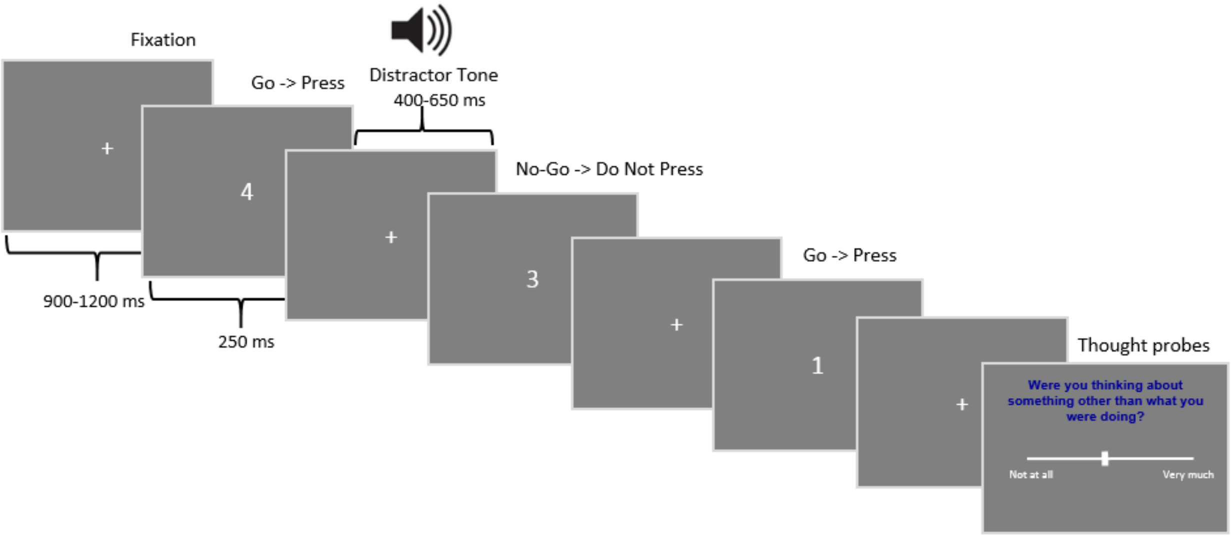

Figure 4. Depiction of the change in variance with an increase in number of trials for the a) N1 and b) P2

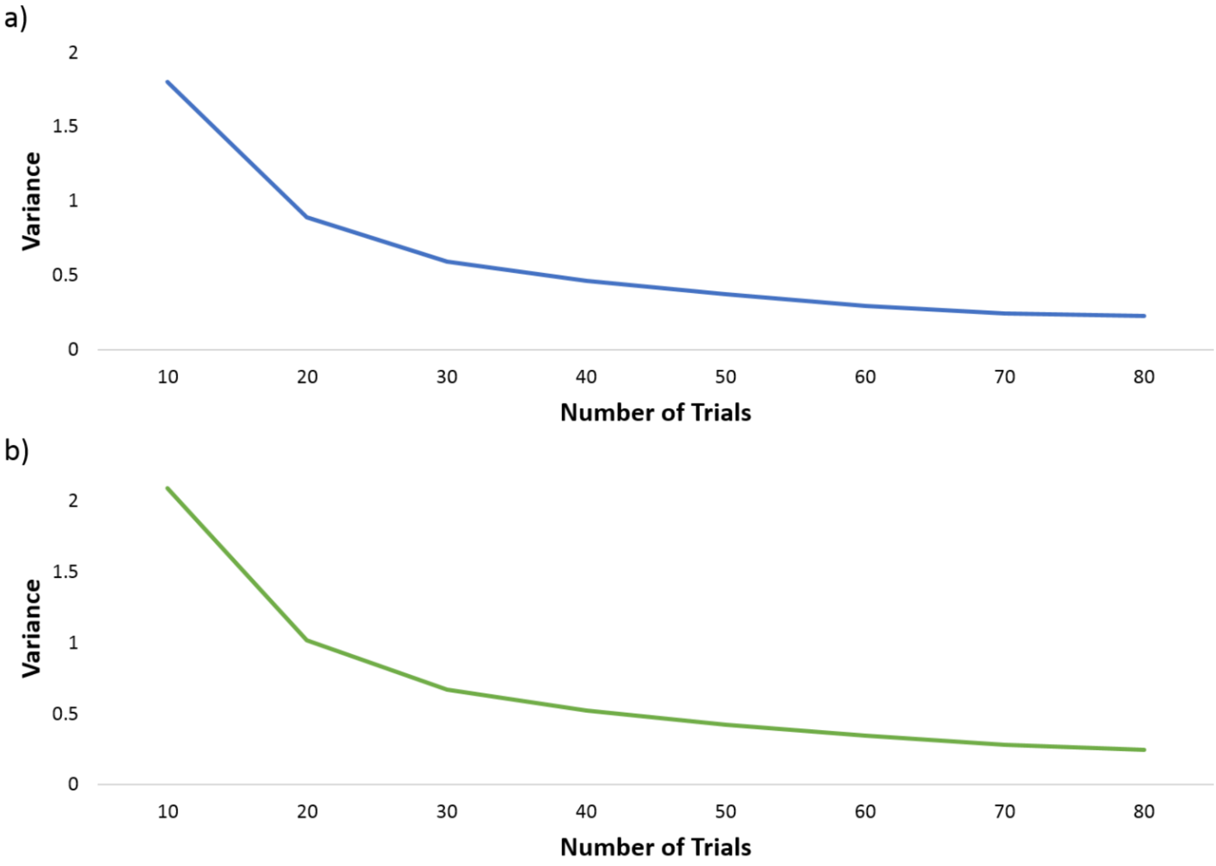

Figure 5. Graph of the increase in the amount of MW across time on task for the control and ADHD groups. The average response to the thought probe is based on the response to the firs thought probe asking “were you thinking about something other than what you were doing?”

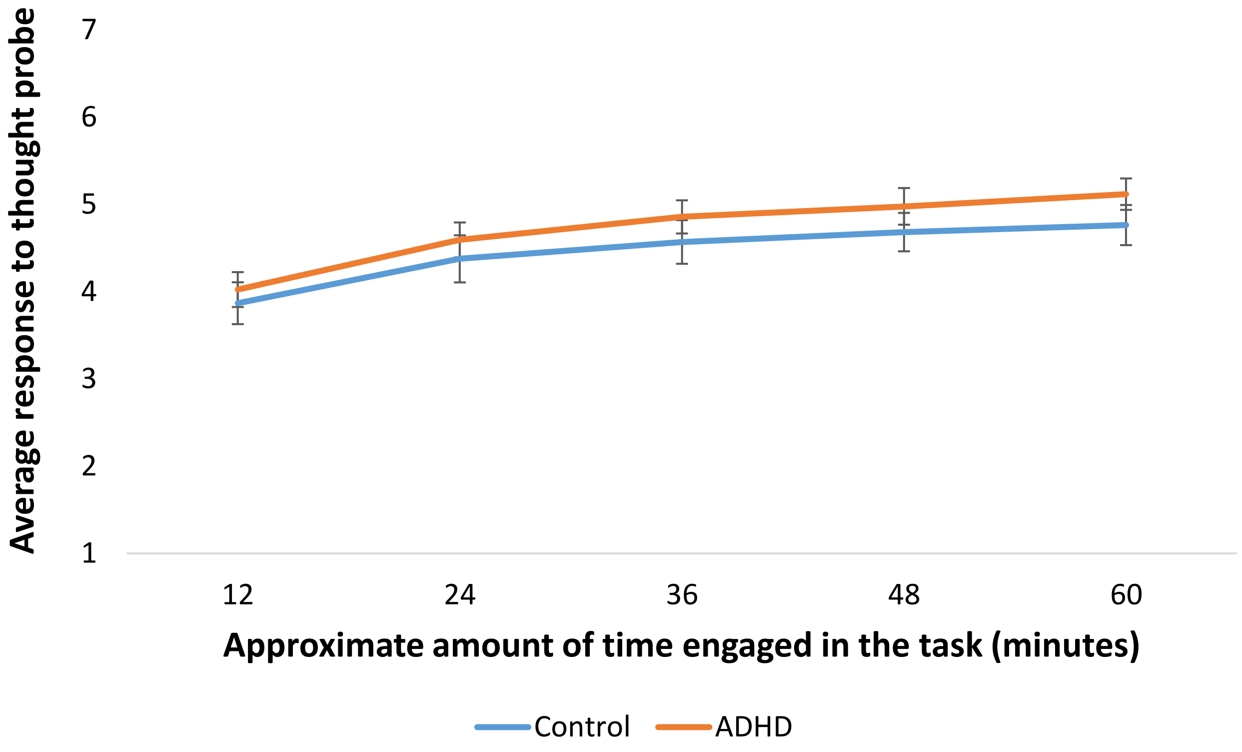

Figure 6. Bar graph representing the percentage of thought probes responded to as either stimulus-dependent or stimulus-independent for Control and ADHD groups.

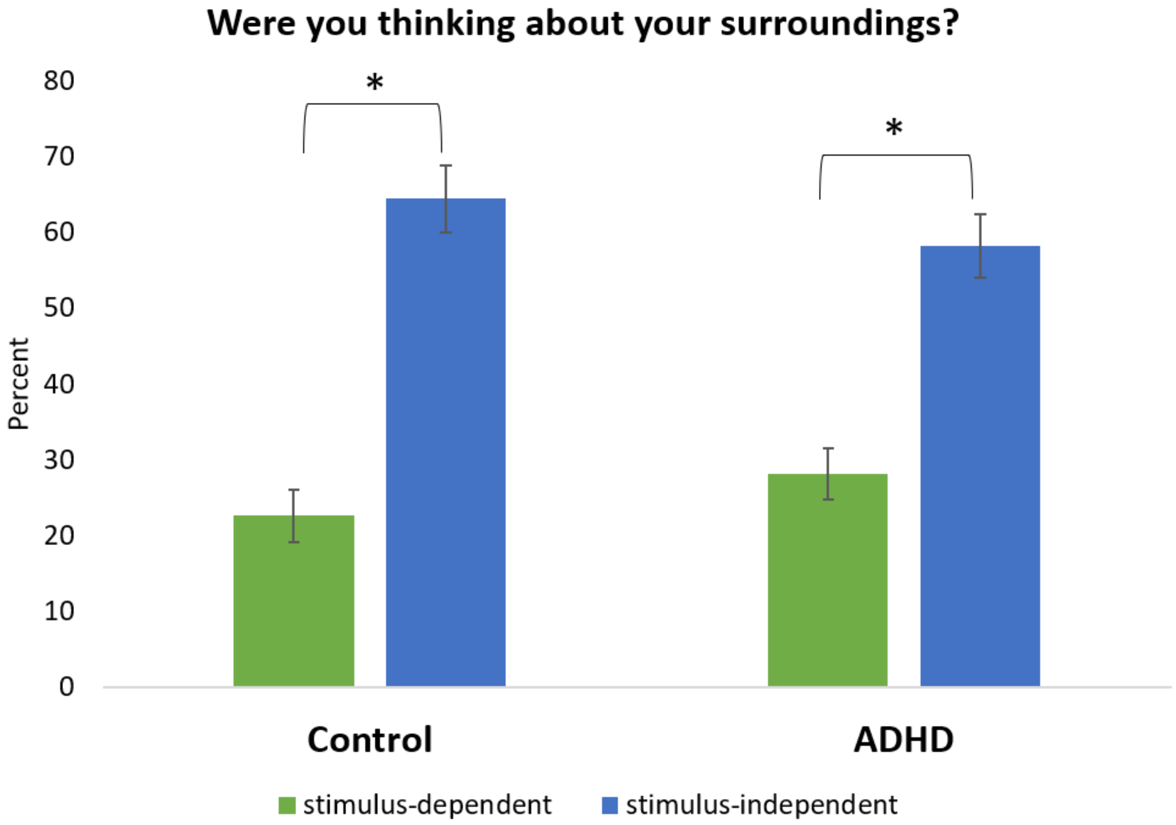

Figure 7. Depiction of grand average ERPs from a cluster of fronto-central electrodes during MW (green) and non-MW (blue) trials for Controls (right panel) and ADHD (left panel) groups. The time windows in which the N1 and P2 were measured are outlined. ERPs for 12 seconds (a) and 6 seconds (b) are depicted.

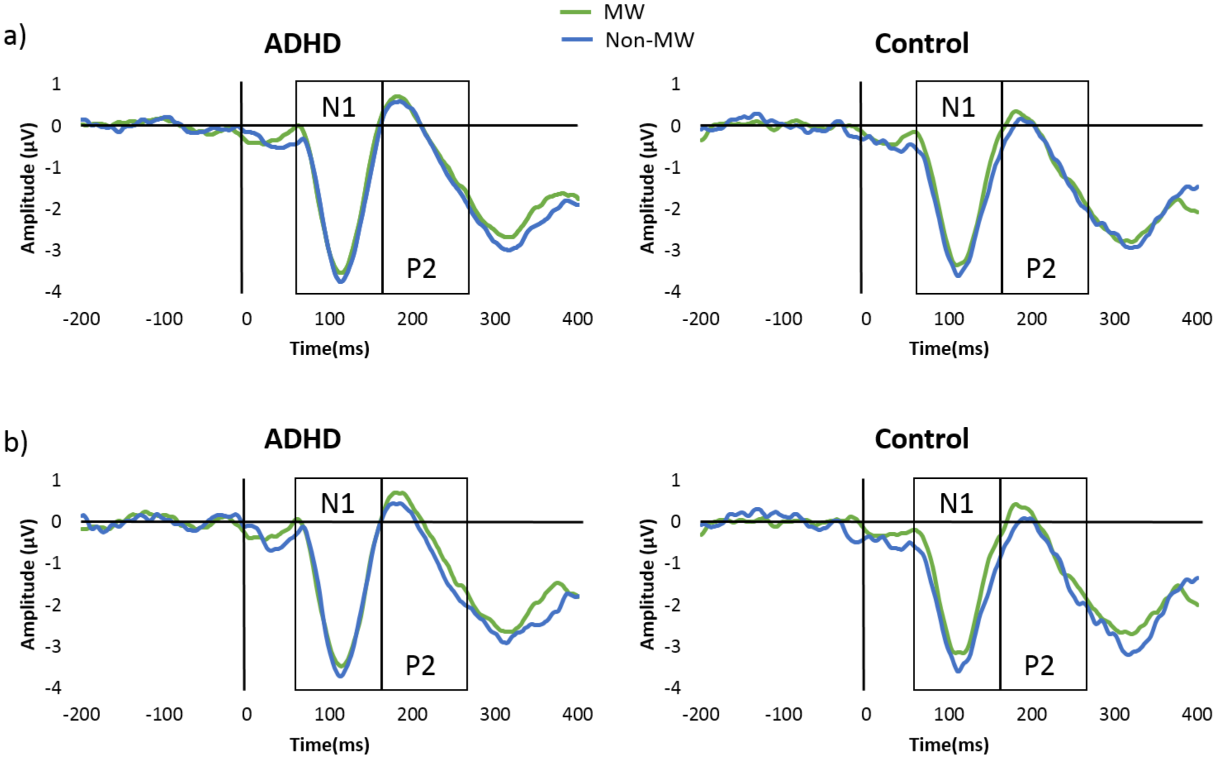

Figure 8. Bar graph representing the percentage of thought probes responded to as either constrained or spontaneous for Control and ADHD groups.

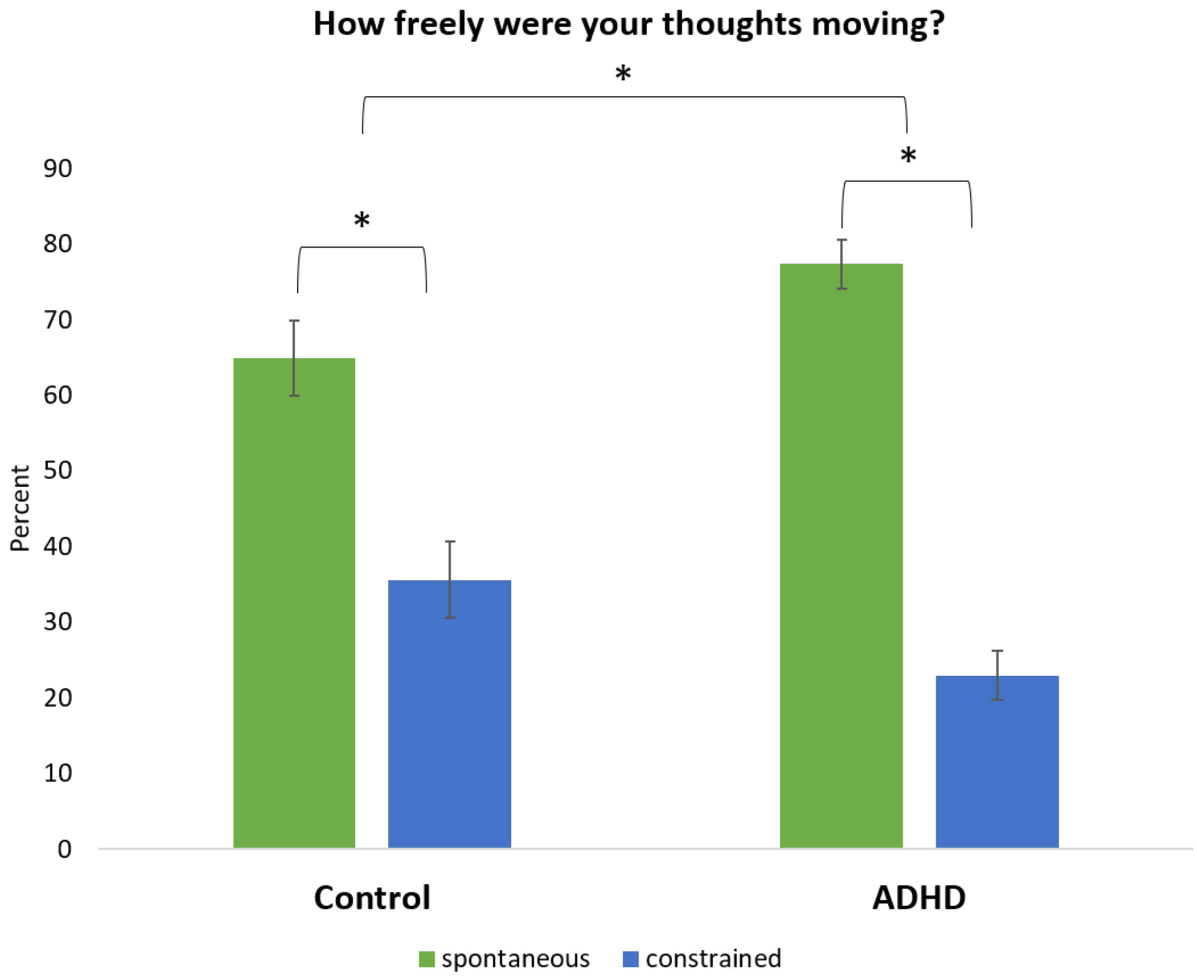

Figure 9. Bar graph of complexity scores during MW and non-MW trials for Control and ADHD groups. Complexity from 12 second (a) and 6 second (b) analyses are depicted.

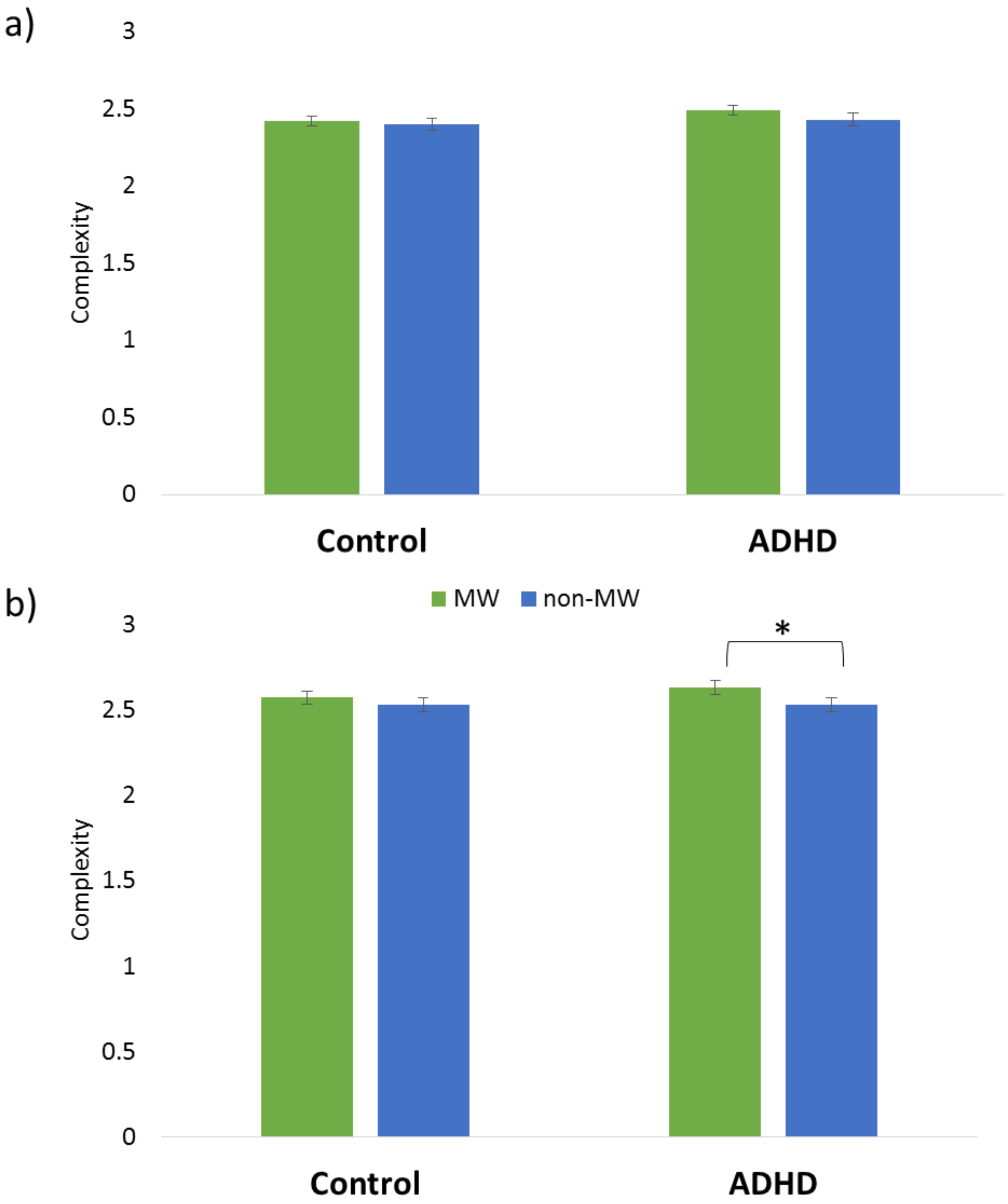

Table 1. Criteria for group diagnosis

	ADHD		**Control**	
	Current Symptoms	*Childhood Symptoms*	*Current Symptoms*	*Childhood Symptoms*
ACDS and BAARS	≥5 inattentive OR hyperactive Sx on ACDS OR BAARS by at least one reporter AND ≥2 inattentive or hyperactive Sx on ACDS OR BAARS by both reporters	≥3 inattentive OR hyperactive Sx on ACDS OR BAARS by at least one reporter AND ≥2 inattentive or hyperactive Sx on ACDS OR BAARS by both reporters	≤3 inattentive AND hyperactive Sx on ACDS AND BAARS by both reporters	< 3 inattentive AND hyperactive Sx on ACDS OR BAARS by both reporters
CAARS	T-score >65 on at least one ADHD related scale		T-score < 60 on all ADHD related scales	
Impairment on ACDS	At least mild impairment		No impairment	

ACDS = Adult ADHD Clinical Diagnostic Scale; BAARS = Barkley Adult ADHD Rating Scale;
CAARS = Connors' Adult ADHD Rating Scale

Table 2: Demographic information and clinical scores

	Control	**ADHD**	**F**	**Effect Size (95% CI)**
n	40	39		
Age (years)	28.67 (4.97)	29.71 (5.69)	0.72	0.20 (-1.40 - 3.48)
IQ	116.50 (11.33)	111.44 (14.37)	3.03	0.40 (-10.85 - 0.73)
Sex (male:female)	18:22	20:19	X^2=0.31	
Session length (long:short)	23:17	19:20	X^2=0.61	
Time of day of visit (morning:afternoon:early evening)	10:14:16	14:9:16	X^2=1.74	
Hours of sleep the previous night	7.70 (0.73)	7.47 (0.94)	0.69	0.27 (-0.79 - 0.33)
Sleepiness	1.63 (0.67)	1.92 (0.62)	4.20*	0.46 (0.009-.59)
Inattention Symptoms				
ACDS	0.13 (0.52)	5.54 (2.65)	156.17**	2.90 (4.55-6.28)
BAARS (self-report)	0.10 (0.38)	5.26 (2.22)	209.43**	3.30 (4.45-5.87)
BAARS (informant report)	0.51 (1.43)	4.05 (2.78)	49.54**	1.64 (2.54 - 4.54)
Hyperactivity/impulsivity Symptoms				
ACDS	0.05 (0.32)	4.16 (2.70)	88.95**	2.19 (3.24 - 4.98)
BAARS (self-report)	0.28 (0.51)	4.15 (2.37)	102.56**	2.31 (3.12 - 4.64)
BAARS (informant report)	0.51 (1.48)	2.84 (2.56)	21.81**	1.09 (1.27 - 3.17)
Other Psychiatric Disorders				
Major Depressive Disorder (met criteria:did not meet criteria)	8:32	22:17	X^2=11.11**	
Generalized Anxiety Disorder (met criteria:did not meet criteria)	1:39	7:32	X^2=5.18*	
Medication Use				
Prescribed Stimulant Medication (yes:no)	0:40	21:18	X^2=29.34**	
Prescribed SSRI/SNRI (yes:no)	0:40	2:37	X^2=2.11	
Drug Use				
Marijuana (yes:no)	14:26	13:26	X^2=0.02	
Nicotine (yes:no)	3:37	3:36	X^2=0.001	

* p < .05; ** p < .001

ACDS = Adult ADHD Clinical Diagnostic Scale; BAARS = Barkley Adult ADHD Rating Scale; SSRI = selective serotonin reuptake inhibitor; SNRI = serotonin norepinephrine reuptake inhibitor

All symptom counts are for current symptoms

Sleepiness measured from the Stanford Sleepiness Scale and ranged from 1 (wide awake) to 4 (somewhat foggy)

Table 3. Correlations between the N1 mean amplitude measured at each electrode included in the frontal cluster

	Afz	F1	F2	AFF1h	FFC1h	FFC2h	AFF2h	FCz
	r	**r**	**r**	**r**	**r**	**r**	**r**	**r**
Fz	0.91	0.97	0.99	0.97	0.97	0.98	0.80	0.95
Afz		0.89	0.91	0.96	0.85	0.86	0.75	0.78
F1			0.96	0.96	0.96	0.95	0.77	0.91
F2				0.97	0.96	0.98	0.82	0.93
AFF1h					0.94	0.94	0.78	0.88
FFC1h						0.98	0.74	0.97
FFC2h							0.78	0.98
AFF2h								0.73

Table 4. Correlations between the P1 mean amplitude measured at each electrode included in the frontal cluster

	Afz	F1	F2	AFF1h	FFC1h	FFC2h	AFF2h	FCz
	r	**r**	**r**	**r**	**r**	**r**	**r**	**r**
Fz	0.85	0.96	0.97	0.94	0.96	0.95	0.95	0.90
Afz		0.83	0.83	0.94	0.74	0.75	0.92	0.61
F1			0.93	0.94	0.93	0.91	0.92	0.86
F2				0.93	0.92	0.94	0.96	0.87
AFF1h					0.87	0.86	0.97	0.75
FFC1h						0.96	0.86	0.94
FFC2h							0.87	0.95
AFF2h								0.77

Table 5. Task performance

	Control	**ADHD**	**F**	**Effect Size (95% CI)**
RT (ms)	361.65 (41.17)	354.10 (52.54)	0.50	0.14 (-27.71-14.49)
SDRT (ms)	80.78 (21.85)	96.02 (28.10)	7.15*	0.52 (1.76 - 25.24)
errors of commission (%)	3.77 (1.54)	4.86 (1.64)	6.41*	0.66 (0.33 - 1.75)
errors of omission (%)	1.48 (2.30)	4.17 (6.70)	5.62*	0.46 (0.03 - 4.68)
accuracy (%)	94.74 (3.47)	90.97 (7.54)	8.09*	0.57 (-6.12 - -0.68)
MW trials only				
RT	363.63 (50.14)	342.54 (5.48)	2.82	0.41 (-46.14 - 3.95)
SDRT	28.98 (12.20)	36.48 (16.94)	4.51*	0.51 (0.46 - 14.54)
errors of omission	2.11 (4.26)	5.91 (8.98)	5.12*	0.55 (0.45 - 7.15)
accuracy	97.89 (4.26)	94.09 (8.98)	5.12*	0.55 (-7.15 - -0.45)
Non-MW trials only				
RT	375.24 (42.32)	359.07 (57.89)	1.78	0.33 (-40.36 - 8.01)
SDRT	23.33 (12.72)	29.15 (21.02)	1.96	0.34 (-2.47 - 14.11)
errors of omission	1.05 (1.92)	3.16 (5.00)	5.41*	0.57 (3.00 - 39.16)
accuracy	98.95 (1.92)	96.84 (5.00)	5.41*	0.06 (-39.16 - -3.00)

* p < .01; ** p < .001

RT = reaction time; SDRT = standard deviation of reaction time

Table 6. Relationship between thought probes and ERP and complexity values

	Propensity to MW			*Stimulus-dependence*			*Spontaneity*		
	B	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**
N1 DW mean amplitude	--	--	--	0.20	0.12	0.09	--	--	--
P2 DW mean amplitude	--	--	--	-0.11	0.16	0.50	--	--	--
SART Complexity (all go correct)	**0.28**	**0.10**	**0.003**	--	--	--	--	--	--
SART Complexity (MW)	--	--	--	--	--	--	0.11	0.11	0.32

DW = difference wave
N1 and P2 difference waves (MW-non-MW) are for ERPs occurring 12 seconds prior to the probe
Probe 1 = “were you thinking about something other than what you were doing?”
Probe 2 = “were you thinking about your surroundings?”
Probe 3 = “how freely were your thoughts moving?”

Table 7. Multiple linear regression of MW measures to predict global impairment within the ADHD group

	Global Impairment		
	B	**SE**	**p**
MW frequency	-0.10	0.19	0.60
Probe 2	0.05	0.14	0.73
P2 DW	**-0.63**	**0.14**	**<0.001**
N1 DW	0.05	0.13	0.73
Probe 3	0.14	0.14	0.30
SART complexity (MW)	0.12	0.12	0.32

DW = difference wave
N1 and P2 DWs (MW-non-MW) are for ERPs occurring 12 seconds prior to the probe
Probe 2 = “were you thinking about your surroundings?”
Probe 3 = “how freely were your thoughts moving?”

Table 8. Multiple linear regression of MW measures to predict SART task performance within the ADHD group

	RT			*SDRT*			*Errors of Commission*		
	B	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**
MW frequency	0.19	0.17	0.3	**0.35**	**0.16**	**0.03**	0.07	0.17	0.67
Probe 2	-0.13	0.16	0.43	-0.12	0.18	0.49	-0.09	0.17	0.59
P2 DW	-0.01	0.16	0.95	-0.05	0.17	0.76	-0.07	0.19	0.71
N1 DW	-0.08	0.17	0.63	-0.01	0.17	0.93	0.13	0.16	0.40
Probe 3	-0.14	0.16	0.37	0.07	0.16	0.69	0.10	0.18	0.59
SART complexity (MW)	-0.12	0.13	0.36	0.03	0.13	0.82	-0.11	0.16	0.50

RT = reaction time; SDRT = standard deviation of reaction time; DW = difference wave
Probe 2 = “were you thinking about your surroundings?”
Probe 3 = “how freely were your thoughts moving?”
Probe 3 = “how freely were your thoughts moving?”

Table 9. Multiple linear regression of MW measures to predict ADHD symptoms within the ADHD group

	Self-report inattention symptoms			*Self-report hyperactivity/impulsivity symptoms*			*Self-report total symptoms*			*Informant total symptoms*		
	B	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**
MW frequency	0.14	0.14	0.32	0.04	0.14	0.76	0.14	0.14	0.32	-0.01	0.20	0.96
Probe 2	0.07	0.11	0.54	**0.29**	**0.12**	**0.02**	**0.23**	**0.12**	**0.05**	-0.06	0.13	0.64
P2 DW	**-0.34**	**0.15**	**0.02**	-0.11	0.15	0.44	**-0.33**	**0.15**	**0.03**	0.27	0.17	0.10
N1 DW	0.14	0.17	0.45	0.22	0.17	0.21	0.25	0.15	0.09	-0.23	0.18	0.20
Probe 3	0.14	0.14	0.31	**0.36**	**0.11**	**0.001**	**0.31**	**0.11**	**0.01**	0.01	0.15	0.97
SART complexity (MW)	-0.24	0.15	0.12	-0.10	0.13	0.46	-0.22	0.14	0.11	0.29	0.19	0.12

DW = difference wave
N1 and P2 DWs (MW-non-MW) are for ERPs occurring 12 seconds prior to the probe
Probe 2 = “were you thinking about your surroundings?”
Probe 3 = “how freely were your thoughts moving?”
All symptom counts are from the BAARS

Table 10. Correlations between predictors used in the multiple linear regressions

	Probe 2			*Probe 3*			*N1 DW*			*P2 DW*			*SART complexity (MW)*		
	B	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**	**B**	**SE**	**p**
MW frequency	0.11	0.19	0.59	**0.42**	**0.18**	**0.02**	-0.09	0.24	0.71	0.42	0.23	0.07	**0.38**	**0.15**	**0.01**
Probe 2				-0.06	0.20	0.77	0.12	0.17	0.49	-0.15	0.23	0.51	0.08	0.16	0.60
Probe 3							-0.18	0.14	0.20	0.07	0.19	0.71	0.003	0.17	0.99
N1 DW										0.29	0.15	0.06	0.06	0.19	0.71
P2 DW													0.11	0.14	0.43

DW = difference wave

N1 and P2 DWs (MW-non-MW) are for ERPs occurring 12 seconds prior to the probe

Probe 2 = “were you thinking about your surroundings?”

Probe 3 = “how freely were your thoughts moving?”

Appendix A. Script read to the participants with an explanation of each of the thought probes with examples

1) Say, **"The first asks "Were you thinking about something other than what you were doing?" What you're doing is hitting the spacebar to every number except the number 3, so if you're thinking about something other than that, like what you ate earlier or the trip you're going on next week, you would place the slider here** <point> **where it says very much.**
   If your attention was completely on the task you would place the slider here <point> **where it says not at all.**
   If your attention fell somewhere between those two extremes, you would place the slider along this line depending on how on or off task your thought were. When you've placed your slider you can hit the spacebar to move on. Do you have any questions about this thought probe before we move onto the next one?" hit the spacebar to move to the next thought probe
2) Say, **"The second thought probe asks "Were you thinking about anything in your surroundings?" Things in your surroundings include anything around you, for example anything you can see in the room, body sensations you might have like hunger, pain, or an itch, any sounds you hear, etc. If your thoughts were mostly about something in your surroundings, you would place the slider here** <point> **where it says very much.**
   If your thoughts were not about anything in your surroundings, you would place the slider here <point> **where it says not at all.**
   If your thoughts fell somewhere between those two extremes, you would place the slider along this line depending on how much your thoughts were related to your surroundings. For any thoughts you might have about the task, if they're about the physical features of the task like the color of the screen or the volume, those things should be rated as related to your surroundings, so closer to 'very much'. If you're having thoughts about your performance on the task, like 'I'm doing really well', or the quality of the task like 'this task is boring', those should be rated as less about your surroundings so closer to 'not at all'. When you've placed your slider you can hit the spacebar to move on. Do you have any questions about this thought probe before we move onto the next one?" Hit the spacebar to move to the next thought probe
   Say, **"The third thought probe asks "Was your mind moving about freely?" If your thoughts were moving very freely from topic to topic, you would place the slider here** <point> **where it says very much.**
   If your thoughts were restricted to a single topic, you would place the slider here <point> **where it says not at all.**
   If your thought movement fell somewhere between those two extremes, you would place the slider along this line depending on how freely your thoughts were moving. When you've placed your slider you can hit the spacebar to move on. Do you have any questions about this thought probe before we move onto the next one?" Hit the spacebar to move to the next thought probe
3) Say, **"The fourth thought probe asks two questions. The first is "How negative or positive were your thoughts?" If you were having very positive thoughts, you would place the slider here** <point> **where it says positive.**
   If you were having very negative thoughts you would place the slider here <point> **where it says negative.**

If your thoughts fell somewhere between those two extremes, you would place the slider along this line depending on how negative or positive your thoughts were. The second question asks "How strong was that emotion?" If your emotion was very strong, you would place the slider here <point> **where it says strong.**
If your emotion was not strong, you would place the slider here <point> **where it says weak.**
If your thoughts fell somewhere between those two extremes, you would place the slider along this line depending on how strong your emotion was. When you've placed both sliders you can hit the spacebar to move on. Do you have any questions about this thought probe?" Hit the spacebar to go to the next screen

4) Say, **"If you feel unable to answer any of the thought probes or if you feel like they are not applicable to the thoughts you were having, you can leave the slider in the middle of the scale. After you respond to all of the thought probes, the task will continue. Before you start the full task you will complete a short practice. Hit the spacebar to begin"**
5) Once the practice is over, make sure they understand the task and then say, **"Now you'll go on to the main task which will last about an hour. Remember that your job is to hit the spacebar as quickly and accurately to all of the numbers except the number 3 and to answer the thought probes about any thoughts you were having just before the thought probes appeared. Feel free to take breaks during the thought probes if you need to."**

Appendix B. Thought probe confidence questionnaire

The questions in this scale ask you about your confidence in responding to the thought probes.

1 = Not confident 2 = Somewhat confident 3 = Confident 4 = Very confident

1. Overall, how confident were you in your ability to answer the thought probes?	1 2 3 4
2. How confident were you in your ability to answer the first thought probe asking: “Were you thinking about something other than what you were doing?”	1 2 3 4
3. How confident were you in your ability to answer the second thought probe asking: “Were you thinking about your surroundings?”	1 2 3 4
4. How confident were you in your ability to answer the third thought probe asking: “How freely were your thoughts moving?”	1 2 3 4
5. How confident were you in your ability to answer the fourth thought probe asking: “How positive or negative were your thoughts?”	1 2 3 4
6. How confident were you in your ability to answer the fifth probe asking: “How strong was that emotion?”	1 2 3 4