Examining External and Internal Distractibility in Adults with ADHD: An Event-Related Potential (ERP) Study

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Abstract

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Attention Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder historically considered to be a condition of childhood, characterized by deficits in sustained attention abilities. However, more recent literature has not only begun to reveal it as a lifespan disorder persisting well into adulthood but has also increasingly focused on enhanced distractibility (as opposed to an attention deficit per se) as a core feature. Despite this proposed framework, unbiased physiological markers of enhanced distractibility do not exist, and relevant symptoms continue to be evaluated by subjective behavioral and cognitive assessments. More specifically, measuring underlying neural correlates of enhanced distractibility (such as difficulty ignoring irrelevant external stimuli or difficulty disengaging from task irrelevant internal thought) remains a key goal to better understand ADHD. Preliminary studies have begun to investigate these processes in children. Yet given current understanding of the maturational changes associated with attentional control across development, investigation into how this presentation differs in adults is warranted. As such, I aimed in this dissertation to examine neural differences in processing of external and internal distraction (internal distraction characterized here as mind wandering) between adults with and without ADHD, using EEG/event-related potentials (ERPs). To this end, 26 adult men and women with and without ADHD completed one 30-minute long three-stimulus auditory oddball task, and one 30-minute long two-stimulus auditory oddball task, while their behavioral and EEG data were recorded. Study participants also completed several questionnaires probing mood and attention in daily life.

Adults with ADHD showed increased reaction time variability in response to distractor tones as well as a tendency for decreased MMN latency, compared to controls. Additionally, in adults with ADHD, the ERP P3a response to distracting tones was significantly larger in amplitude and significantly shortened in latency than to target tones, a pattern that did not exist for adults without ADHD. Although no neural differences were found during periods of on task versus internally distracted thought, adults with ADHD showed a trend to slowing in response time during periods of mind wandering. Additionally adults with ADHD reported more frequent

engagement in unintentional mind wandering and reported being significantly more impaired by mind wandering in daily life than adults without ADHD.

Overall, these findings contribute to a growing literature examining enhanced distractibility as a key feature of ADHD, providing initial insight into external and internal distraction processes in adults with ADHD. These preliminary results suggest that adults with ADHD may indeed be more "captured" than adults without ADHD by both external and internal distraction. Future work should consider examining the utility of measures of enhanced distractibility, in addition to impaired sustained attention, in the diagnosis of this condition.

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most impairing (Hinshaw, 2018) and common (Kessler et al., 2006) neurodevelopmental disorders occurring across the lifespan. With onset in childhood, and impairments persisting across all developmental stages, ADHD is characterized primarily by developmentally extreme and disruptive levels of inattention, hyperactivity, and impulsivity. Research demonstrates that the presence of ADHD in childhood is associated with a multitude of negative life outcomes, including increased risk for antisocial behavior (primarily in males) and self-harming behavior and suicidality (primarily in females), increased rates of substance abuse, increased levels of family stress and interpersonal relationship strain, decreased educational/vocational attainment, and decreased overall quality of life (Hinshaw, 2018). Research has also consistently demonstrated the significant cost to society of undiagnosed and untreated ADHD, including but not limited to increased rates of violence, incarceration, and recidivism as well as high rates of health impairments and even reduced life expectancy (Harstad et al., 2020; Harpin & Young, 2012; Barkley 2002).

Despite the known functional and economic costs associated with undiagnosed and untreated ADHD, current gold-standard ADHD assessment methods remain based largely on subjective informant report. This methodology has been shown to lead to systematically biased under- and over- identification, depending on circumstance and demographic characteristics. For example, studies have shown that boys are much more likely to be diagnosed with ADHD even when symptoms are comparable, with white boys from single parent households in particular at highest risk for false positive diagnosis (Bruchmüller et al., 2012; Bax et al., 2019; Morgan et al., 2013; Hinshaw & Scheffler, 2014). For a review of ADHD in females, including diagnostic biases, see Hinshaw, Nguyen, O'Grady, and Rosenthal (in press).

Existing diagnostic methodologies lack reliable and objective neural indicators of presence or absence of the disorder. Additionally, although current conceptualization of ADHD has begun to consider enhanced distractibility, as opposed to diminished sustained attention as a potential core feature of the disorder, extant diagnostic methodologies continue to focus heavily on assessment of impaired attention in determining a final diagnosis. Compounding this issue, accurate diagnosis of ADHD in adulthood, as opposed to childhood, poses additional and unique challenges and barriers, with many adults going undetected (Asherson et al., 2012). For example, clinicians face increased difficulty obtaining accurate developmental and family history when assessing for ADHD in adults (Wasserstein, 2005). As well, most adult-related assessment is based on client self-report only, highlighting the need for independent verification of symptoms and impairments.

As a first step toward improving diagnosis of ADHD in adulthood, in this work I aim to address current gaps in the literature highlighted above by examining the neural correlates of distraction processing in adults with ADHD, through the use of electroencephalogram (EEG), particularly the use of event-related potential (ERP).

1.1 Enhanced Distractibility in ADHD

To date, ADHD has been largely conceptualized as a deficit in sustained attention—that is, impaired ability to voluntarily direct attention toward a task-relevant stimulus over an extended period of time (American Psychiatric Association, 2013). However, replicated evidence suggests strongly that individuals with ADHD are in fact able to sustain attention in particular situations, namely high reward (Douglas & Parry, 1983) or low noise/reduced distraction environments (Vaughan, et al., 2014). For example, Vaughan and colleagues demonstrated that differences in performance on cognitive testing measures between children and adolescents with and without ADHD can be largely eliminated by changes in the testing environment. Specifically, although children with ADHD performed significantly worse than children without when tested in a group setting, this difference ceased to exist when children were tested in reduced-distraction individual-examination settings (Vaughan et al., 2014). Though this study does not examine group differences in sustained attention and distractibility processes per se, such findings challenge the contention that observed impairments in ADHD are driven solely by attention-related deficits (see also Hinshaw, 2018; Sonuga-Barke et al., 2010). Furthermore, behavioral tests of distraction—defined as the involuntary capture of attention by task-irrelevant stimuli—have demonstrated improved sensitivity and specificity in the detection of ADHD when compared to tests of sustained attention (Berger & Cassuto, 2014). Importantly, while sustained attention and distraction processes have been shown to be linked to one another, sustained attention may be impacted by separate factors unrelated to distractibility such as cognitive fatigue. As such, differentiation of these processing abilities is important in understanding the cognitive profile of individuals with ADHD. In fact, the conceptualization of ADHD as a variegated condition related to multiple executive functions and multiple causal factors is gaining traction (Hinshaw, 2018; Nigg, Sibley, Thapar, & Karalunas, 2020). Thus, conceptualization of ADHD has begun to consider enhanced distractibility in addition to diminished sustained attention, as a potential core feature of the disorder.

Definitions of distraction and distractibility vary widely in the existing literature. The present work defines distraction as an involuntary attentional orienting toward a task-irrelevant stimulus. The term distractibility refers to the extent to which attentional resources are allocated to, and/or task-related performance is interrupted by, such distracting stimuli. Thus, increased distractibility indicates increased attentional allocation to and increased task interruption by task-irrelevant stimuli.

Distracting stimuli can be either external (e.g., a loudly ticking clock) or internal (e.g., self-generated task-irrelevant thoughts). Extant literature consistently demonstrates increased external *and* internal distractibility in people with ADHD when compared to control populations (Adler, 2004; Bozhilova et al., 2018; Fassbender et al., 2009; Franklin et al., 2017; Gumenyuk et al., 2005; Seli et al., 2015). A particularly appropriate measure of brain activity associated with the processing of both external and internal distraction is the event-related potential (ERP) technique (Luck, 2005). ERP is a noninvasive EEG method of investigating electrophysiological correlates of cognitive processes, providing an objective measure of cognitive functions. It reflects a summation of electrical potentials generated in response to specific events. ERPs are described in terms of latency, which indexes the speed of processing, and amplitude, which indexes the magnitude of processing (Sokhadze et al., 2017; Luck 2005). This method offers excellent temporal resolution, which is optimal for capturing sub-second cognitive processes, and is considerably more cost-effective than other neuroimaging techniques (e.g. fMRI).

To date, ERPs have been utilized to document differences in cognitive functions across numerous clinical conditions. Furthermore, it has been shown in clinical neuroscience studies to be able to differentiate between several clinical groups (Hajcak, Klawohn, & Meyer, 2019), including ADHD in particular. For example, Mueller and colleagues found that features of independent ERP components can be used to accurately discriminate adults with ADHD and control subjects (Mueller et al., 2010). Given the potential diagnostic utility of this method, I have chosen to utilize the ERP technique to investigate differences in distraction processing between adults with and without ADHD.

1.1.1External Distraction

External distraction processing has been shown to occur in distinct and serially occurring stages (Horváth, Winkler, & Bendixen, 2008), each of which is reflected in dissociable electrophysiological responses. The first stage in this chain is the novelty detection stage, i.e., the point at which an individual detects a discriminable deviance in stimuli. An unexpected change in auditory stimuli (as commonly characterized by a deviant tone embedded among a series of standard tones) has been shown to elicit a negative-going ERP component called the Mismatch Negativity (MMN) (Garrido, Kilner, Stephan, & Friston, 2009). The MMN is a negative potential maximal over the frontocentral scalp (Kujala et al., 2007; Näätänen, Paavilainen, Rinne, & Alho, 2007; Näätänen et al., 1993), typically peaking 150-250 ms after onset of the stimulus in healthy individuals. This component is thought to be a marker of involuntary orientation to a deviant stimulus (Garrido, Kilner, Stephan, & Friston, 2009). Importantly, the elicitation of the MMN does not depend on attention or motivation, making it particularly suitable for use in clinical groups. For example, the MMN has been shown to be elicited even in sleep and coma states. Clinical neuroscience data have shown that altered or impaired MMN responses are associated with a number of clinical conditions, including schizophrenia, dyslexia, and learning impairments (Garrido, Kilner, Stephan, & Friston, 2009). Thus, while it is not a specific marker, it is deserving of further investigation.

Evidence of altered MMN in children with ADHD is mixed (Oades et al., 1996; Ghanizadeh 2011; Horváth, Winkler, & Bendixen, 2008; Cheng, Chan, Hsieh, & Chen, 2016). I am aware of only one study examining the MMN in adults with ADHD: MMN latency and amplitude were not found to differ significantly between adults with and without ADHD (Negoro et al., 2005). Importantly, however, informant report was not utilized in the diagnosis of adult ADHD in this investigation, potentially yielding inaccurate diagnostic classification. The present study is the first to my knowledge to investigate differences in MMN latency and amplitude between adults with and without ADHD within a well-characterized and carefully diagnosed sample.

Following novelty detection, individuals enter the second stage of distraction processing, in which they orient attention to the deviant stimulus. The MMN has been shown to be followed by the P3a, or novelty P3 (Yamaguchi & Knight, 1991), which is a positive-going ERP component peaking around 250-300 ms after a novel stimulus in typically developing individuals. The P3a is maximal over the frontocentral scalp. It is believed to reflect an involuntary orienting of attention toward a novel or deviant stimulus. Repeated presentation of a novel stimulus leads to a decrease in the amplitude of the P3a component (Polich, 1989). This reduction is thought to reflect the process of habituating to consistent task-irrelevant stimulus (for example, the process of habituating to the sound of a loudly ticking clock).

Although findings are mixed, a number of clinical neuroscience studies have shown attenuated P3a responses in individuals diagnosed with ADHD (Gumenyuk et al., 2005; Liotti et al., 2005; Yang et al., 2015; Senderecka et al., 2012). For example, Gumenyuk and colleagues (2005) have reported altered P3a responses in children with ADHD. Specifically, such children demonstrated significantly reduced P3a amplitudes, suggesting abnormal involuntary attention processes/distraction processes (Gumenyuk et al., 2005). Authors suggest that these findings may be reflective of broader impaired control of involuntary attention in ADHD.

Additionally, clinical neuroscience studies have demonstrated reduced habituation in children with ADHD, suggesting possible neural underpinnings of enhanced distractibility in this population (Tegelbeckers et al., 2015). Investigation of P3a responses in adults with ADHD is needed, and the proposed study will be one of the first to examine habituation processes in adults with ADHD using EEG/ERPs.

In all, evidence for altered or enhanced external distractibility in ADHD, as well as proposed neural underpinnings of these impairments, have been reasonably well documented in children with ADHD. Still, both investigation and understanding in adults are sparse. The present study aims to address this issue.

1.1.2 Internal Distraction

In addition to distraction generated by external stimuli, individuals can also become distracted by (or shift their attention toward) internal thoughts. This state of internal distraction/attending toward internal thought is often referred to as mind wandering. Research has consistently shown that successful completion of cognitive tasks can be significantly and negatively influenced by mind wandering (Smallwood & Schooler, 2015).

Cognitive neuroscientists have sought to elucidate the neural underpinnings of moments of mind wandering, as well as to understand neurological explanations for impaired task-relevant processing during these periods. Several studies have demonstrated that when individuals engage in mind wandering, attentional processes are temporarily decoupled from perceptions of the external environment (Smallwood et al., 2007). This attenuation in the processing of external stimuli during periods of mind wandering is referred to as "perceptual decoupling," and it is thought that this process may explain why mind wandering can be detrimental to successful task-relevant performance.

While researchers have focused on understanding the process of perceptual decoupling in neurotypical individuals, much less focus has been placed on investigating the process of perceptual decoupling during periods of mind wandering in children or adults diagnosed with ADHD (Bozhilova et al., 2021). Given understanding of abnormal attentional functioning in this condition, further investigation into perceptual decoupling in ADHD in particular is warranted.

The proposed study seeks to examine the neural correlates of internal distraction, in the form of perceptual decoupling, in adults with and without ADHD.

To investigate differences in perceptual decoupling between adults with and without ADHD, I have chosen to investigate group differences in attenuation of the N1-P2 evoked potential during mind wandering, using an auditory oddball task. The N1 and P2 are a coupled set of ERP components that have each been shown to be modulated by attention (Näätänen & Picton, 1987; Hansen & Hillyard, 1980). The N1 is a negative-going ERP usually peaking between 80 and 120ms after stimulus onset, maximal over the frontocentral scalp, and believed to reflect perception of or shifting of attention toward an auditory stimulus (Knight, Hillyard, Woods, & Neville, 1980; Näätänen & Picton, 1987). The N1 is followed by the P2, a coupling referred to as the N1-P2 complex. The P2 is a positive-going ERP peaking around 200ms after stimulus onset, often maximal over the frontocentral region of the scalp, and believed to reflect subsequent processing of a perceived stimulus.

With respect to mind wandering and perceptual decoupling, findings in studies investigating attenuation of the N1-P2 during periods of mind wandering are mixed. It is hypothesized that differences in paradigm design and methods of identifying periods of mind wandering contribute to inconsistent findings (these differences are discussed further below). On one hand, Braboszcz and colleagues found an increase in P2 amplitude during moments of mind wandering. Given that the P2 component to auditory stimulus has also been associated with the disengagement of subjects' attention toward stimuli (Naatanen & Picton, 1987) and is also characteristic of the sleep onset period (Campbell &Colrain, 2002), authors propose that this finding suggests that periods of mind wandering may be similar to periods of sleep onset. On the other hand, other studies have reported attenuated N1 and P2 responses during periods of mind wandering, in line with the perceptual decoupling hypothesis (Martel et al., 2019, Conrad & Newman, 2021, Kam et al., 2011). Clearly, more research is required to resolve this discrepancy.

Findings from studies investigating the N1-P2 complex in individuals with ADHD are also mixed. In adults, several studies have demonstrated that adults with ADHD show reduced N1 and P2 amplitudes compared to controls (Sable et al., 2013; Missonnier et al., 2013), although other investigators have failed to replicate this finding. Some have found that those with ADHD show increased N1 and P2 amplitudes (Zhao et al., 2020; Prox et al., 2007), but other studies have found no significant difference in N1 and P2 amplitude or latency between individuals with and without ADHD (Tsai, Hung, & Lu, 2012). Investigations revealing reduced amplitudes in adults with ADHD suggest that this result may be reflective of impaired abilities to perceive and process relevant stimuli. On the other hand, investigations demonstrating the opposite propose that these increased amplitudes may reflect increased use of cognitive resources by individuals with ADHD when required to attend to particular stimuli. It is hypothesized that (a) task difficulty and (b) task modality (e.g. auditory vs. visual), as well as age differences across studies, may be a contributing factor regarding such mixed findings (Sable et al., 2013). This study will be the first to my knowledge to investigate the N1-P2 complex in adults with and without ADHD during mind wandering.

A particular challenge in studying mind wandering lies in accurately identifying periods of this attentional state (Smallwood & Schooler, 2006). In the laboratory setting, thought-sampling methodologies have become the most popular method for investigating mind wandering and internal distraction. In these procedures, an individual is asked to provide information about his or her internal state at certain points while completing a laboratory task. Furthermore, within thought-sampling methodologies, thought samples (and in turn measures of mind wandering) can be self-caught vs. probe-caught.

First, self-caught mind wandering methodologies ask participants to monitor their attentional state and indicate (e.g., via button press) when they engage or have engaged in periods of mind wandering. Self-caught methodologies require the individual to be aware of and take note of the internal content of their thoughts: a process called meta-awareness.

Research on mind wandering and meta-awareness in ADHD specifically has shown that individuals diagnosed with ADHD show poor meta-awareness, i.e., difficulty accurately catching and reporting moments of off-task thought (Franklin et al., 2017). These findings make self-caught techniques an ineffective methodology within the particular clinical group of interest for the current investigation—that is, individuals with ADHD. An alternative to self-caught methodologies, and a potential solution to this dilemma, lies in the so-called probe-caught technique.

Second, in probe-caught experiments, participants are periodically interrupted while completing a task and asked to respond to questions probing their current internal state. For example, participants indicate whether their thoughts just prior to the probe were on task, intentionally off-task, or unintentionally off-task. These may be more advantageous for research on ADHD populations, who many not be as “meta-aware” as needed to engage in accurate self-caught measurement of mind wandering. Furthermore, probe-caught methodologies have consistently demonstrated reliable neurocognitive differences between on-task and mind wandering attentional states (Franklin, Smallwood, & Schooler, 2011; Kam et al., 2011; Smallwood, Beach, Schooler, & Handy, 2007). With converging evidence from these objective measures, these findings suggest the probe-caught technique reliably captures one’s attentional state. As such, the present study utilized the probe-caught methodology to investigate neural correlates of internal distraction in adults with and without ADHD.

In addition to identifying differences in strategies for identifying periods of mind wandering, cognitive psychologists have identified two related though partially distinct forms of mind wandering. Specifically, researchers have found that mind wandering can be intentional/deliberate versus unintentional/spontaneous (Seli, Risko, Smilek, & Schacter, 2016). Intentional mind wandering has been shown to occur most frequently during tasks requiring low levels of cognitive engagement (for example, intentionally choosing to mentally rehearse a research talk while driving to work) (Seli, Konishi, Risko, & Smilek, 2018). Intentional mind wandering is characterized by an awareness of its initial occurrence. In contrast, unintentional mind wandering occurs spontaneously without deliberate attentional shift (Seli, Risko, & Smilek, 2016). Such unintentional/spontaneous mind wandering, compared to its intentional counterpart, has been shown to be associated with increased interruption of task-relevant processing. Furthermore, individuals reporting higher rates of unintentional mind wandering have been shown to experience increased impairment in their daily lives. These include the display of higher rates of injury while driving, impairment in educational settings, and affective dysregulation (Seli et al., 2016). Martel and colleagues have shown a greater P2 reduction during periods of unintentional, compared to intentional, mind wandering, potentially at least partially explaining the detrimental effects of unintentional mind wandering in particular (Martel et al., 2019). In short, there may well be neural correlates of these two core types of mind wandering.

Importantly, excessive unintentional mind wandering has been shown to be associated with the kinds of functional impairment most commonly seen in ADHD. Specifically, existing literature suggests that ADHD is associated with excessive unintentional (but not intentional) mind wandering (Franklin et al., 2017; Mowlem et al., 2019; Seli et al., 2015; Shaw & Giambra, 1993). For example, Seli and colleagues (2015) demonstrated that in a sample of college students who reported previously being diagnosed with ADHD, unintentional/spontaneous mind wandering, though not intentional/deliberate mind wandering, was independently associated with reported ADHD symptoms. Furthermore, ADHD has been shown to be associated in particular with more detrimental episodes of mind wandering—in other words, mind wandering that interferes with successful and efficient task performance.

Taken together, these findings support the theory that excessive internal distraction in the form of unintentional mind wandering may be a key driver (or at the very least correlate) of ADHD symptomatology. Although researchers have investigated the behavioral correlates and impacts of mind wandering in ADHD, much less attention has been placed on understanding the neural correlates of such mind wandering/internal distraction in this population (Bozhilova et al., 2020). In particular, I aim to investigate the impact on task-processing during mind wandering in adults with ADHD, using EEG/ERP and probe caught mind wandering methodologies. Additionally, because of their conceptual and empirical distinctiveness, I investigate both intentional and unintentional mind wandering in my design.

In summary, recent evidence in the fields of clinical psychology and electrophysiology has emerged to suggest that enhanced distractibility, both internal and external, may be a key feature of ADHD. Although several investigators have investigated these cognitive processes in children with the disorder, much less attention has been given to understanding these processes in adults. In this study I aim to contribute to the literature by examining differences in external and internal processing between adults with and without ADHD, using EEG/ERP.

1.2 Hypotheses

1.2.1 Objective I: Examine differences in external auditory distraction processing between adults with and without ADHD

Hypothesis 1: Evidence of MMN impairment in ADHD is mixed. Some studies have demonstrated shorter MMN latencies in ADHD (Oades et al., 1996), suggesting that individuals with ADHD may perceive deviance more quickly than typically developing peers. However, other researchers have found delayed MMN latencies (Winsberg, Javitt, Silipo, & Doneshka, 1993), suggesting that those with ADHD process distraction more slowly than their peers. These contradictory findings highlight the need to continue to investigate the MMN in ADHD, and particularly in adults with ADHD. With respect to amplitude, evidence currently converges to suggest an enhanced MMN amplitude in ADHD (Franken, Nijs, & Van Strien, 2005; Ghanizadeh, 2011; Lepistö et al., 2005). Given consistent evidence of slower information and cognitive processing speed in ADHD (Shanahan et al., 2006):

I hypothesize that adults with ADHD will demonstrate a delay in peak MMN, reflecting slower information/cognitive processing speed, as well as an enhanced MMN amplitude, reflecting a hypersensitivity to deviance/novel stimuli.

Hypothesis 2: Evidence regarding altered P3a responses in children and adults with ADHD is also mixed. Holcomb and colleagues revealed evidence suggesting that children with ADHD demonstrate longer P3a latency (Holcomb, Ackerman, & Dykman, 1985) than comparison children, reflecting a slowing in processing speed. However, contrasting literature has found that individuals with attention difficulties demonstrate a shorter P3a latency (Banaschewski et al., 2003; Keage et al., 2006) than comparisons, potentially revealing a faster orienting to distracting stimuli within the ADHD population. With respect to amplitude, clinical neuroscience studies in children with ADHD have demonstrated an increased P3a amplitude in response to deviant stimuli (van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007); this increase in amplitude has been proposed to reflect an increased orienting response to novel stimuli/increased distractibility as compared to controls (i.e., a stronger involuntary switching of attention). Given consistently documented difficulty in processing speed as well as behavioral evidence of increased involuntary attentional capture in individuals with ADHD:

I hypothesize increased P3a amplitude and increased latency, representing slowed processing speed and increased orienting response to novel stimuli (reflecting increased distractibility), in the ADHD sample as compared to controls.

Hypothesis 3: One model of ADHD impairment suggests that individuals suffering from ADHD are unable to efficiently habituate to irrelevant distractors (Jansiewicz, Newschaffer, Denckla, & Mostofsky, 2004). Research examining habituation to distractors in healthy populations shows that with repeated presentation, the P3 amplitude decreases. I know of no ERP studies examining habituation processes in adult ADHD.

I hypothesize that the P3a amplitude in response to distracting auditory stimuli will decrease across trials in the control population but not in the ADHD group, reflecting impaired habituation processes for the latter.

Hypothesis 4: In addition to neural measures of distraction, research has shown that behavioral measures, namely reaction time variability, are also reliable indicators of enhanced distractibility in ADHD (Kofler et al., 2013). More specifically, increased reaction time variability is thought to reflect lapses in attentional control/distractibility; it has also been shown to be associated with increased distraction in adults with ADHD (Adams, Roberts, Milich, & Fillmore, 2011). This study aims to replicate previous findings.

I hypothesize adults with ADHD will show increased reaction time variability, reflecting increased distractibility. I do not hypothesize that these groups will significantly differ in response time or overall response accuracy.

1.3.2 Objective II: Group differences in internal distraction processing

Hypothesis 5: During periods of mind wandering, studies have revealed a process known as perceptual decoupling. I know of no studies investigating this attentional/perceptual process in ADHD. Given behavioral evidence of enhanced disruption of task performance during periods of mind wandering in individuals diagnosed with ADHD, I hypothesize that EEG/ERP data will reflect this enhanced attenuation of perceptual processing. Specifically,

I hypothesize that adults with ADHD will show increased perceptual decoupling during periods of unintentional/spontaneous mind wandering.

Hypothesis 6: In line with prior findings, reviewed above:

I hypothesize that reaction time will be slower during periods of mind wandering across both groups. I also hypothesize that reaction time during periods of mind wandering will be more slowed in adults with ADHD. Related to Hypothesis 4, I additionally hypothesize that adults with ADHD will show increased reaction time variability compared to controls.

Hypothesis 7: This study will aim to replicate findings that individuals with ADHD report more frequent unintentional/spontaneous mind wandering than their typically developing peers (Seli et al., 2015). In line with prior findings:

I hypothesize that adults with ADHD will report more frequent unintentional/spontaneous mind wandering than peers without ADHD.

2. Methods

2.1 Participants

Participants were recruited from one of three larger studies of ADHD: The Berkeley Girls with ADHD Longitudinal Study (BGALS-Hinshaw, Owens, Sami, & Fargeon, 2006), the Multimodal Treatment Study of Children with ADHD (MTA-Molina et al., 2009), and the Neuropsychological Attention Test Research Study (NAT), all conducted at UC Berkeley. Baseline diagnostic procedures for each of these three studies are outlined below.

BGALS

BGALS is a broad longitudinal study investigating the developmental trajectory of girls/women with and without ADHD. At baseline (ages 6-12 years), ADHD diagnostic status was determined using the Diagnostic Interview Schedule for Children (DISC) 4.0 (fourth edition; Shaffer et al., 2000) and the Swanson, Nolan, and Pelham Rating Scale (fourth edition; SNAP-IV; Swanson et al., 2001). Both parent and teacher informants were emphasized. The diagnostic algorithm used is described in Hinshaw (2002).

MTA

The MTA is a large, longitudinal, multisite study examining the efficacy of psychosocial and medication treatments for ADHD (MTA Cooperative Group, 1999). At baseline (ages 7-10 years), ADHD diagnostic status was determined using DSM-IV criteria for ADHD Combined Type according to the Diagnostic Interview Schedule for Children (DISC), parent report, version 3.0 (Shaffer, Fisher, & Lucas, 2004). Again, parent and teacher informant report was emphasized (see Hinshaw et al. 1997, for details)

Note that for both BGALS and MTA, re-recruitment for this investigation was performed during early adulthood.

NAT

The NAT is a broader investigation of sustained attention in adults with ADHD conducted at UC Berkeley, in collaboration with ThinkNow, Inc.. ADHD diagnostic status was determined using structured clinical interview, the MINI International Neurospychiatric Interview (Sheehan et al., 1998), and corroborating information.

Exclusion and Inclusion Criteria

Exclusion criteria for the present study included diagnosis of any psychiatric disorder other than an anxiety or depressive disorder, diagnosis of a substance use or abuse disorder, diagnosis of any hearing disorder, and history/diagnosis of neurological illness/disorder or brain injury (e.g. epilepsy, traumatic brain injury). For all participants, further exclusion criteria included current treatment with second-generation antidepressants, antipsychotics, sedative hypnotics, mood stabilizers/anticonvulsants, benzodiazepines-anxiolytics/hypnotics, or current treatment with any psychotropic medication that had not been stable for at least four weeks. For participants with ADHD, further exclusion criteria included current treatment for ADHD with non-stimulant medication. Participants with ADHD currently treated with stimulant medication were asked to refrain from taking medication for 24 hours prior to research visit; participants who were unwilling to refrain for 24 hours were excluded. All participants provided informed written consent, and all study procedures were approved by the Institutional Review Board at the University of California, Berkeley.

For all sources, inclusion criteria involved a diagnosis of ADHD from the measures described above—or the lack of an ADHD diagnosis, for the typically developing group.

A total of 26 adults (13 ADHD, 13 Typically Developing [TD]) participated in the present, ongoing study. Note study recruitment was limited by the COVID pandemic. 10 men and 16 women participated, ranging in age from 20 to 41 years (ADHD Group M_{age}=26.38, SD_{age}=5.36; TD Group M_{age}=25.38, SD_{age}=5.64). Further participant demographic information is included in Table 1. Of note, final sample size reported herein differs from the proposed sample size due to halted data collection as a result of COVID-19 restrictions on in-person testing. There is no means, of course, of conducting EEG evaluations other than in-person format.

2.2 Procedure

Participants were contacted and phone screened to ensure eligibility for the present study. Following phone screening, participants were scheduled for a 3-hour research visit that included completing two versions of auditory oddball tasks while their EEG data was being recorded, and completing self-report questionnaires.

2.3 Auditory Oddball Task Stimuli and Paradigm

2.3.1 External Distraction Task

Participants completed a three-stimulus auditory oddball external distraction task programmed in MATLAB using Psychtoolbox-3 extensions (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007) while their behavioral and EEG data were being recorded. Participants were presented with a series of standard sounds (500Hz tone, probability P = 0.80), target sounds (1000Hz tone, P = 0.10), and distractor sounds (e.g. bell, whistle, tone sweep, P =0.10) (Kiehl & Liddle, 2001). They were instructed to respond by button press to each sound as quickly and as accurately as possible (left arrow key for standard or distractor sounds and right arrow key for target sounds). Importantly, a button press for each tone, as opposed to for only target tones, was required in order to minimize motor-related ERP activity differences between target, distractor, and standard sounds (Luck 2005). Target and distractor sounds were always preceded by at least three standard tones. Each sound was presented for 200ms with a uniform stimulus onset asynchrony jittered between 1000ms and 1500ms (averaging 1250ms). Participants completed a total of six blocks lasting 5 minutes each. Figure 1 illustrates the task paradigm.

2.3.2 Internal Distraction Task

Participants completed a two-stimulus auditory oddball internal distraction task programmed in MATLAB using Psychtoolbox-3 (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007) while their behavioral and EEG data were recorded. Participants were presented with a series of standard sounds (500Hz tone, probability P = .80) and target sounds (1000Hz tone, probability P= 0.20). They were instructed to respond by button press to each sound as quickly and as accurately as possible (left arrow key for standard sounds, and right arrow key for target sounds). Each sound was presented for 200ms with a uniform stimulus onset asynchrony jittered between 1000ms and 1500ms. Participants completed a total of 30 blocks. Block duration was randomly distributed between 45 and 75 seconds at ten second intervals (with an average block length of 60 seconds) in order to reduce predictability of block completion and maximize variability of attention state at time of block completion.

At the end of each block, participants received a thought probe in which they were instructed to indicate, by button press, whether they were “on-task,” intentionally mind wandering, or unintentionally mind wandering, over the past 10 seconds. At least one, and no more than two targets occurred per block. Additionally, a target tone was never the first or last tone of the block, and never occurred within the last 12 seconds of the block. Analyses considered data 12 seconds before each attention report (Kam et al., 2011). This decision was made in order to maximize available data and to ensure that data accurately reflected assigned attention state. Studies of mind wandering suggest that states of mind wandering fluctuate approximately over this time window (Christoff et al., 2009; Sonuga-Burke & Castellanos, 2007). As such, these analyses assume that 12 seconds prior to each probe should reliably capture the reported attentional state. Figure 2 illustrates the task paradigm.

2.4 EEG Acquisition and Preprocessing

EEG data were recorded at the University of California, Berkeley, using a 64-channel BioSemi ActiveTwo system with a sampling rate of 512 Hz. Two additional electrodes located over the medial-parietal cortex (Common Mode Sense and Driven Right Leg) were used as ground electrodes. EEG data were recorded using a high-pass filter of 0.05 Hz. They were referenced offline to the average of two mastoid electrodes. Additionally, vertical and horizontal electrooculograms (EOGs) were recorded in order to allow for removal of events associated with eye movement artifacts.

EEG data were band-pass filtered between 1 and 60 Hz. Muscular and ocular muscle artifacts were corrected for using independent component analysis. Data decomposition was performed using the fastica algorithm in FieldTrip, and artifactual components were manually detected. Electrodes with excessively noisy signals were interpolated from neighboring electrodes using spherical spline interpolation.

Continuous EEG data were segmented into 3,000 ms epochs, beginning at 1,000 ms prior to stimulus onset. Each trial was visually inspected for remaining artifacts, and these were removed from subsequent analyses. Common average reference was then applied to the data. EEG data preprocessing and analysis were performed using FieldTrip (Oostenveld et al., 2011) within Matlab (The MathWorks Inc.).

2.5 EEG Data Quantification

For ERP analysis, EEG signals were bandpass filtered at 1–30 Hz and baseline-corrected using the 200ms pre-stimulus window. Only correct and artifact free trials were used for analysis. In the external distraction task, target, standard, and distractor trials were averaged separately within subjects. MMN and P3a amplitudes were measured over frontal sites (FC1, FCz, FC2). Peak amplitude was determined for each individual subject across a post-stimulus time window determined based on visual inspection of grand average waveforms.

In the internal distraction task, trials for which participants reported being on task, intentionally mind wandering, or unintentionally mind wandering were averaged separately within subjects. ERPs were measured over sites where they are typically maximal, as was the case in our data; N1 and P2 amplitudes were measured over frontal sites FC1, FCz, and FC2 (Yuan et al., 2007; Zhang et al., 2018). Peak amplitudes were again determined for each individual subject across a post-stimulus time window determined based on visual inspection of grand average waveforms.

2.6 Measures

Mind Excessively Wandering Scale (MEWS; Mowlem 2019)

The MEWS is a brief 12-item screening measure used to assess severity of excessive mind wandering, specifically in adult ADHD. Items are scored on a 4-point Likert-type scale: 0 = not at all or rarely to 3 = nearly all of the time or constantly. The MEWS has demonstrated good internal consistency (α > .9), along with high sensitivity (.9) and specificity (.9) for the diagnosis of ADHD in adulthood.

Spontaneous and Deliberate Mind Wandering Scale (SDMWS; Carriere, Seli, &

Smilek, 2013)

The SDMWS is an 8-item scale that includes items specifically related to the frequency of deliberate/intentional mind wandering (e.g., “I allow my thoughts to wander on purpose”), and differentiates these from items specifically related to spontaneous/unintentional mind wandering (e.g., “I find my thoughts wandering spontaneously”). Items are scored on a 7-point Likert scale from 1 - rarely to 7 - a lot. The scale produces two scores probing frequency of deliberate/intentional and spontaneous/unintentional mind wandering respectively, and both subscales have shown good internal consistency, validity, and test-retest reliability (Marcusson-Clavertz & Kjell, 2019).

3. Statistical analyses

3.1 External Distraction

3.1.1 Behavioral Data

To examine group differences in behavioral responses to target, distractor, and standard tones, independent samples t-tests were used to compare mean reaction time, reaction time variability, and response accuracy. All data were analyzed using SPSS Statistics, version 27 (IBM Inc., Somers, NY, USA). All statistical tests were two-tailed; $p < 0.05$ were considered statistically significant.

3.1.2 ERP Data

MMN

Based on visual inspection of grand-average waves, the MMN ERP component was identified as a negative wave occurring within the 125–260 ms interval following stimulus onset. Peak amplitude was determined for each individual subject across this identified time windows. One-factor analyses of variance (ANOVAs) were computed to investigate the effect of group on ERP amplitudes and latencies.

P3a

P3a responses to standard, target, and distractor stimuli were measured across a post-stimulus time window of 240ms to 300ms after visual inspection of grand-average waveforms. Given a smaller than anticipated sample size and therefore insufficient power to detect interaction effects between diagnostic group (ADHD vs. TD) and condition, I chose to first examine patterns in P3a responses to standard, target, and distractor tones in the typically developing group, and then investigate whether similar patterns existed within the ADHD group. Paired samples t-tests were conducted to examine within group differences in P3a response (latency and amplitude) to standard, target, and distractor tones.

To examine P3a habituation within groups, the P3a amplitude to distractor tones in the first block of the task were compared to the P3a amplitude to distractor tones in the last (6th) block of the task via paired samples t-tests.

3.2 Internal Distraction

3.2.1

To examine group differences in the frequency of the three attentional states, the proportion of on task, unintentionally off-task, and intentionally off-task responses were calculated for each individual, and independent samples t-tests were conducted to examine group differences. To examine within group differences in reaction time to standard tones during on task vs. mind wandering states, paired samples t-tests were used. All data were analyzed using SPSS Statistics, version 27 (IBM Inc., Somers, NY, USA). All tests were two-tailed; tests with $p < 0.05$ were considered statistically significant.

3.2.2 ERP Data

N1

Based on visual inspection of grand-average waves, the N1 component was identified as a negative wave in the 80–120 ms interval following stimulus onset. Peak amplitude was determined for each individual subject across the identified time windows. Given the small sample size, and the high proportion of subjects not reporting intentional mind wandering, responses to both unintentional and intentional mind wandering were placed together in one category. Paired samples t-tests were conducted to examine within group differences in N1 response (latency and amplitude) to standard tones while on task vs while mind wandering.

P2

The P2 response was measured across a post-stimulus time window of 160ms to 200ms after visual inspection of grand-average waveforms. Peak amplitude was again determined for each individual subject across the identified time window. Responses to both unintentional and intentional mind wandering were again placed together in one category, and paired samples t-tests were conducted to examine within group differences in the P2 amplitude and latency.

3.3.3 Self-Report Measures in Questionnaires

Independent samples t-tests were used to investigate group differences in self-reported frequency of mind wandering in daily life, as assessed by the MEWS and SDMWS.

4. Results

4.1 External Distraction

4.1.1 Behavioral Data

When compared to adults without ADHD, adults with ADHD showed marginally significant differences in reaction time variability in response to distractor tones. Specifically, the ADHD sample showed greater reaction time variability. These findings held for both correct distractor responses ($M_{\text{ADHD-Correct Distractor}}$=120ms, $SD_{\text{ADHD-Correct Distractor}}$ =60ms; $M_{\text{TD-Correct Distractor}}$ = 90ms , $SD_{\text{TD-Correct Distractor}}$ =40ms; p=0.07) and false alarm distractor responses ($M_{\text{ADHD-FA Distractor}}$=80ms, $SD_{\text{ADHD-FA Distractor}}$ =40ms; $M_{\text{TD-FA Distractor}}$ =190ms , $SD_{\text{TD-FA Distractor}}$ =50ms; p=0.08). No significant differences in reaction time, accuracy, or reaction time variability in standard or target tones were observed. External distraction task behavioral results can be found in Table 2.

4.1.2 ERP Data

MMN

MMN amplitude did not differ significantly between adults with ADHD (M=-3.85, SD=2.31) and adults without ADHD (M=-4.01, SD=1.84) [F(1,24) = 0.41, *p* = .84]. Adults with ADHD showed a near-significant shortened MMN latency (M=163, SD=12) compared to adults without ADHD (M=172, SD=14) [F(1,24) = 3.57, *p* = .07] (See figure 3).

P3a

In adults with ADHD, P3a amplitude to distractor tones (M = 3.27, SD = 2.20) was significantly larger than P3a amplitude to standard tones (M = 0.87, SD = .76) [t(12) = -4.60, *p* < 0.001, Cohen's d = -1.27]. This finding was also true for adults without ADHD: distractor tones (M = 3.26, SD = 1.96), standard tones (M = .75, SD = 41) [t(12) = -4.82, *p* < 0.01, Cohen's d = -1.33].

Visualization of data revealed a main difference between groups—not in responses to standard and distractor tones, but instead in responses to target and distractor tones. As such, within-group differences in responses to target and distractor tones were also investigated, as reported next.

In adults without ADHD, the P3a amplitude to target tones (M = 2.74, SD = 2.07) did not significantly differ from P3a amplitude to distractor tones (M = 3.26, SD = 1.96) [t(12) = -1.40, *p* = .19]. In adults with ADHD, the P3a amplitude to target tones (M = 2.13, SD = 1.81) was significantly smaller than P3a amplitude to distractor tones (M = 3.27, SD = 2.20) [t(12) = -3.10, *p* = .009]. This finding suggests that in adults with ADHD, orienting to task relevant stimuli may be impaired.

In adults without ADHD, P3a latency to target tones (M = 286, SD = 20) did not significantly differ from P3a latency to distractor tones (M = 278, SD = 23) [t(12) = -1.38, *p* = .192]. In adults with ADHD, P3a latency to target tones (M = 290, SD = 21) was significantly delayed compared to P3a latency to distractor tones (M = 264, SD = 27) [t(12) = -3.24, *p* = .007], suggesting that adults with ADHD process distracting stimuli more quickly than task relevant stimuli. (Figure 4).

P3a Habituation

In both adults with and without ADHD, P3a amplitude to distracting stimuli in the first block of the task did not significantly differ from P3a amplitude to distracting stimuli in the last block of the task. Specifically, ADHD Block 1 P3a Amplitude (M = 3.35, SD = 2.17), ADHD Block 6 P3a Amplitude (M = 3.35, SD = 2.71) [t(11) = -5.66, *p* = .58]. Control Block 1 P3a Amplitude (M = 3.53, SD = 1.74), Control Block 6 P3a Amplitude (M = 3.52, SD = 1.84) [t(12) = 0.01, *p* = .99].

4.1.3 External Distraction Results Summary

Behaviorally, adults with ADHD showed a trend to greater reaction time variability in response to distractor tones, compared to adults without ADHD. Regarding electrophysiological findings, adults with ADHD showed a trend to near-significant shortened MMN latency compared to adults without. Adults with ADHD also showed a significantly greater (with respect to amplitude) and earlier P3a response to distracting tones, compared to target tones. This difference was not observed in adults without ADHD. In both groups, P3a amplitude in response to distracting stimuli did not attenuate/habituate over time, suggesting that in this task participants did not become less pulled by the distracting stimuli over time.

4.2 Internal Distraction

4.2.1 Behavioral Data

Adults with ADHD showed a trend to slowing in response time when mind wandering (M = 350ms, SD =100ms) vs. when on task (M = 330ms, SD = 100ms) [t(11) = 1.95, *p* = 0.07]. Adults without ADHD did not differ in response time between attention states, Mind Wandering (M = 300ms, SD = 80ms), On-Task (M = 290ms, SD = .80ms), [t(9) = 0.84, *p* = .421]. No significant differences in reaction time variability between groups were found. Additionally, no group differences in frequency of reported mind wandering were found, regardless of mind wandering type during the task. Participants with ADHD reported being on task for 45% of probe responses on average, reported deliberately mind wandering for 12% of probe responses on average, and reported spontaneously mind wandering for 43% of probe responses on average. TD group reported 43%, 18%, and 39%, respectively.

4.2.2 ERP Data

A total of four subjects were excluded from analyses due to incomplete EEG data. Final sample size was as follows: 12 adults with ADHD, 10 controls.

N1

No significant differences in N1 amplitude or latency between responses in on task or mind wandering states were found in either group.

P2

No significant differences in P2 amplitude or latency between responses in on task or mind wandering states were found in either group.

4.2.3 Self-Report Measures

MEWS

Adults with ADHD scored significantly higher on the MEWS (M = 17.08, SD = 7.9) than adults without ADHD (M = 4.92, SD = 3.5), [t(24) = -5.07, *p* < 0.001]. This result signifies that adults with ADHD reported significantly more impairing mind wandering in daily life.

SDMWS

Adults with ADHD scored significantly higher on the unintentional/spontaneous mind wandering subscale of the SDMWS (M = 22.69, SD = 2.8) than adults without ADHD (M = 14.31, SD = 3.18) [t(24) = -7.17, *p* < 0.001]. No difference in score between adults with ADHD (M = 17.92, SD = 6.7) and adult without ADHD (M = 19.62, SD = 3.7) [t(24) = .79, *p* = .43] were observed on the deliberate/intentional mind wandering subscale.

4.2.4 Internal Distraction Results Summary

Adults with ADHD showed a near-significant slowing in response time when mind wandering, not observed in adults without ADHD. On self-report questionnaires, adults with ADHD reported engaging in spontaneous/unintentional mind wandering—in particular, with more frequency in daily life than adults without ADHD. Adults with ADHD also reported more severe episodes of excessive mind wandering overall. No differences in N1-P2 response while mind wandering (compared to while on task) was observed in either group.

5. Discussion

This set of studies aimed to investigate the differences in external and internal distraction processing between adults diagnosed with and adults without ADHD. Specifically, I aimed to contribute to the existing literature by examining differences in behavioral and neural responses to external and internal distracting stimuli. As conceptual frameworks of ADHD continue to evolve and include enhanced distractibility as a key feature, it is important that clinical neuroscientists improve understanding of the neural underpinnings of this core impairment. Further, given historically limited focus on adults with this disorder and current understanding of its lifelong nature, I chose in this work to examine these neural correlates in adults in particular.

External Distraction

With respect to external distraction, my hypothesis surrounding behavioral performance of adults with ADHD (i.e., adults with ADHD will show greater reaction time variability than adults without), was partially supported. Specifically, I found that adults with ADHD showed increased reaction time variability in response to distractor tones (both correct and false alarm distractor responses) in a three-stimulus auditory oddball task. Reaction time variability in response to standard and target tones did not significantly differ between groups. As hypothesized, these groups did not significantly differ with respect to overall response time or overall response accuracy.

This finding contributes to a growing body of literature highlighting response time variability, above and beyond response time or response accuracy, as a hallmark of ADHD (Tamm et al., 2012; Kofler et al., 2013). The finding that children and adults with ADHD show increased variability in reaction time has been interpreted as the outcome of variable sustained attention to tasks. However, more sophisticated investigations that take task specific manipulations into account (e.g. motivation/reward, stimulus type and presentation speed) have found that increasing task difficulty or reward for completion can eliminate or attenuate these differences (Tamm et al., 2012; Epstein et al., 2011). Importantly, Saville and colleagues using event-related potentials to investigate increased reaction time variability in ADHD found group differences in variability in response-locked, but not in stimulus-locked, event-related potential latencies (Saville et al., 2015). This finding suggests that behavioral reaction time variability may reflect inefficiencies in responding rather than stimulus processing. Taken together these results suggest that response time variability may in fact reflect more subtle inefficiencies in cognitive processing. My finding that adults with ADHD show near-significant increased reaction time variability to distracting stimuli suggests that individuals with ADHD respond more inefficiently to distracting stimuli in particular. Future work will examine whether this pattern holds in a larger sample size.

Regarding neural responses to externally distracting stimuli, contrary to my hypothesis, adults with ADHD showed no difference in MMN amplitude, and near-significant decrease in MMN latency, compared to controls. This parallels findings in which children with ADHD showed shortened MMN latencies (Oades et al., 1996) and suggests that adults with ADHD may process distracting stimuli more quickly than peers. Authors have interpreted these findings as a reflection of enhanced capture by such stimuli. With respect to orienting, in adults without ADHD P3a response to target and distractor tones did not differ in amplitude or in latency. However, in adults with ADHD P3a responses to distracting tones were significantly larger in amplitude and significantly shortened in latency than to target tones. In other words, adults with ADHD showed an increased orienting response to distractor stimuli, and oriented more quickly to distracting stimuli compared to task relevant stimuli. Taken together these findings suggest that adults with ADHD may show an increased orienting response to distracting stimuli that adults without ADHD do not show.

Contrary to my hypothesis, P3a amplitude did not habituate/decrease across trials in either group. It is possible that the task paradigm used in this study contributes to this finding. Studies examining P3a habituation often investigate response to a target or a singular consistent stimulus deemed ‘distractor’ (Romero & Polich, 1996; Fjell et al., 2007). I hypothesize that the structure of the present task in which distracting tones themselves varied (i.e., no two distractor tones were the same) may have prevented habituation from occurring. Future work may aim to investigate habituation across trials in a task with a singular consistent distractor tone.

Internal Distraction

Behaviorally, adults with ADHD showed a near-significant slowing in response time during periods of mind wandering; this finding was not present in the control group. It is possible that this finding reflects increased capture by internal distraction in the ADHD group. Studies examining the impact of externally distracting stimuli on task performance in children with ADHD have found that children with ADHD perform slower than children without in comparable distraction settings (Rizzo et al., 2009). These findings were hypothesized to reflect increased capture by distraction; I hypothesize this rationale may also explain behavioral findings in my own work as well.

Surprisingly, and contrary to hypotheses, adults with ADHD did not report engaging in unintentional/spontaneous mind wandering more frequently during lab task performance. However, it is important to qualitatively note that 5 participants in the ADHD group reported not engaging in intentional mind wandering at any time during task performance, compared to only 1 participant in the control group. Self-report measures revealed that adults with ADHD reported more impairing mind wandering (e.g., “I find it hard to switch my thoughts off nearly all of the time”) than adults without ADHD. Importantly, adults with ADHD reported engaging in unintentional mind wandering more frequently in daily life than adults without ADHD. This finding is particularly important given evidence that unintentional mind wandering is uniquely associated with not only impaired task processing but also with increased rates of affective dysfunction such as depression (Seli et al., 2019). No significant differences between groups in self-reported frequency of intentional mind wandering was observed. This finding contributes to literature that spontaneous/unintentional mind wandering in particular may be a key feature in ADHD, and further, may contribute to comorbid affective dysfunction.

Also contrary to hypotheses, no significant differences in N1-P2 amplitude or latency between responses in on task or mind wandering states were found in either group. Given existing literature documenting effects of mind wandering on these components (Braboszcz & Delorme, 2011), I hypothesize that these null findings may be driven largely by small sample size (only a total of 12/13 adults with ADHD and 10/13 controls had EEG data able to be included in analyses). Additionally, given current findings of slowing in reaction time, future work may consider investigating group differences in both response-locked and stimulus-locked ERPs.

Concluding Remarks

In all, preliminary results suggest that adults with ADHD may indeed be more captured than adults without ADHD by both external and internal distraction (though findings focused on internal distraction processing were less robust, possibly due to smaller sample size/more data excluded compared to external distraction analyses). These findings indicate that interventions focused on reducing distractibility, rather than simply extending or enhancing attention, may well be in order. A promising contender in meeting this need can be found in mindfulness based and meditation-based interventions.

In recent years mindfulness based and meditation-based interventions for ADHD have grown in popularity (Mitchell, Zylowska, & Kollins, 2015), largely in response to a need for non-pharmacological intervention for those who do not respond to, experience aversive side effects from, or simply do not want to take psychotropic medications (Zylowska et al., 2008). Importantly, research has shown that adults with ADHD discontinue medications due to side effects or nonresponse at notably higher rates than children; studies investigating discontinue rates in children have found that 21% of children initiated on ADHD medication discontinued due to these concerns (Toomey et al., 2012), while studies investigating this phenomenon in adults have found that up to 42% of adults with ADHD discontinue medication for these same reasons (Michielsen et al., 2020). In adults with ADHD who are over the age of 65 safe pharmacological intervention becomes particularly challenging, despite persisting symptoms (Torgersen et al., 2016). As our understanding of the persistence of ADHD across the lifespan improves, so too must our arsenal of appropriate interventions.

To date, the majority of research investigating efficacy of mindfulness-based interventions for ADHD have focused on attention, emotion regulation, stress, and self-reported ADHD symptoms as outcome measures of interest (Zylowska et al., 2008; Janssen et al., 2019; Xue, Zhang, & Huang, 2019). Given that mindfulness training consists of, at its core, training the individual to return to a task (e.g. breath, counting, mantra repetition) after distraction, investigation into reduction in distractibility or improvement in meta-awareness in particular is warranted. I know of no studies examining the effect on mindfulness training on distractibility (self-reported or neural measures) in adults or children with ADHD. Given mounting evidence that enhanced distractibility is indeed a key and impairing symptom of ADHD, improving our understanding of interventions that may ameliorate this symptom is important work.

Findings in this study should be interpreted in the context of an important limitation; due to pause in data collection as a result of the COVID-19 pandemic/precautions surrounding in person testing, the sample size of the present study is smaller than anticipated. It will be important to examine whether current findings hold in a larger sample size. Small sample size also led to an examination of unintentional and intentional mind wandering together as one phenomenon. This folding together of these mind wandering types, though necessary due to current small sample size limitations, may conceal and weaken group differences that may be present in a larger sample/with separate analyses.

Importantly, mind wandering has been shown to affect processing of both external task relevant and externally distracting stimuli. While adults with ADHD did not report more frequent mind wandering in the present lab task examining internal distraction, this group did report engaging in more unintentional mind wandering in daily life and did show differences in behavioral performance suggesting possible increase in attentional capture by internal distraction, compared to adults without ADHD. It is important to note that differences in internal distraction processes may affect not only how an individual responds to internal distraction, but also how an individual processes external distraction. For example, Barron and colleagues found that participants who reported higher mind wandering during task performance also demonstrated reduced orienting to and processing of both target and distractor stimuli, as indexed by a reduction in P3a and Pb3 amplitude (Barron et al., 2011). As such, the effect that mind wandering may have on processing of externally distracting stimuli, and the ways in which this may differ between adults with and without ADHD, is a question that is unable to be addressed using the task paradigm employed in this study, and is as such an additional limitation of the present work. Additionally, all participants in this study completed tasks examining mind wandering last during their research visit. As such, it is possible that fatigue effects may drive some current findings.

The task paradigm utilized in the external distraction investigation in this study poses one additional and important limitation. The task used utilizes a variety of randomized distracting stimuli (e.g. whistle tone, car horn), as opposed to a single and consistent ‘distractor,’ as often utilized in studies examining habituation to distracting stimuli. This design may have prevented expected habituation from occurring in both ADHD and typically developing groups, and limited ability to examine differences in habituation processes between groups.

Despite these limitations, this study provides important insight into external and internal distraction processes in adults with ADHD. Improved understanding of the neural mechanisms underpinning enhanced distractibility in this disorder may allow for improved diagnostic reliability, sensitivity, and specificity moving forward, especially in adult populations. Future work should continue to examine the utility of measures of enhanced distractibility, in addition to impaired sustained attention, in treatment efficacy investigation and in diagnostic procedures.

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Table 1 - Sample Demographic characteristics

	ADHD	TD
Age (SD)	26.38 (5.36)	25.38 (5.64)
Gender, n(%)		
Men	4 (30.8)	6 (46.2)
Women	9 (69.2)	7 (53.8)
Race/Ethnicity, n(%)		
White, non Hispanic	9 (69.2)	3 (23.1)
African American or Black	1 (7.7)	1 (7.7)
Hispanic	1 (7.7)	1 (7.7)
AAPI	2 (15.4)	7 (53.8)
Biracial	0 (0)	0 (0)
Native American/Alaskan Native	0 (0)	0 (0)
Education, n(%)		
High School or GED	2 (15.4)	4 (30.8)
Some College	3 (23.1)	3 (23.1)
BA or Associates	8 (61.5)	3 (23.1)
Advanced Degree	0 (0)	3 (23.1)

Table 2 - Behavioral Performance; External Distraction Task

	ADHD		TD Control				
	M	SD	M	SD	*t*	*p*	Cohen’s d
Standard Mean RT	.37	.10	.32	.07	1.60	0.12	.63
Standard RT-SD	.11	.04	.09	.03	1.65	0.11	.65
Standard Accuracy	.93	.09	.97	.06	-1.482	0.15	-.58
Target Mean RT	.49	.08	.45	.08	1.32	0.18	.52
Target RT-SD	.08	.01	.07	.02	0.56	0.58	.22
Target Accuracy	.83	.12	.86	.19	-0.34	0.74	-.13
Corr Dist Mean RT	.50	.06	.44	.12	1.62	0.12	.64
Corr Dist RT-SD	.12	.06	.09	.04	1.87	0.07	.74
Dist Accuracy	.83	.19	.82	.28	0.05	0.96	.02
FA Dist Mean RT	.47	.09	.42	.12	1.23	0.23	.52
FA Dist RT-SD	.08	.04	.19	.05	1.81	0.08	.76

Note: TD = Typically Developing, RT = Response Time, RT-SD = standard deviation of response time, Corr Dist = Correct Response to Distractor, FA Dist = False Alarm Distractor Response

Figure 1: Three-stimulus external auditory oddball task. Calhoun et al., 2006

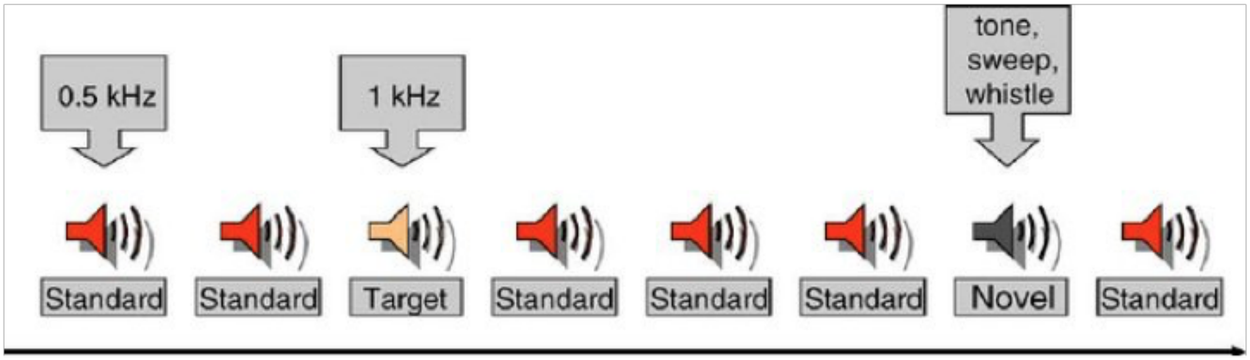

Figure 2: Two-stimulus auditory oddball task with thought probe. Adapted from Calhoun et al., 2006

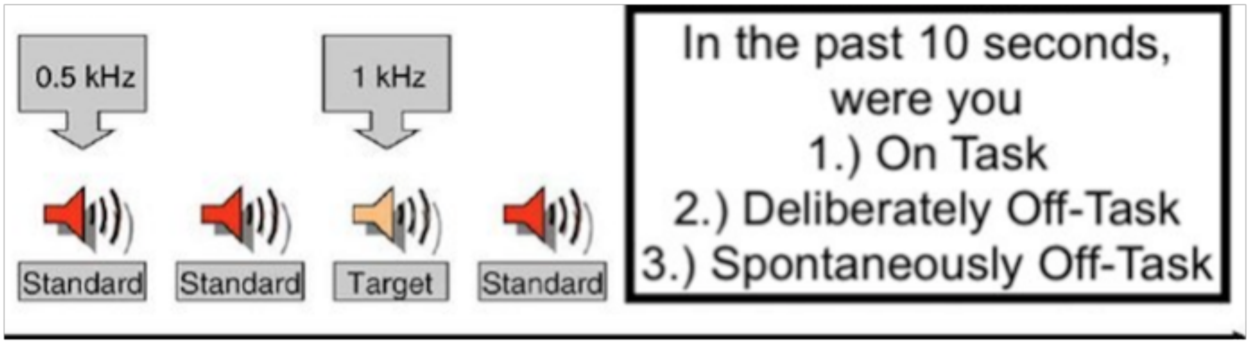

Figure 3: MMN - Grand-average event-related potentials waveforms, measured at FCz

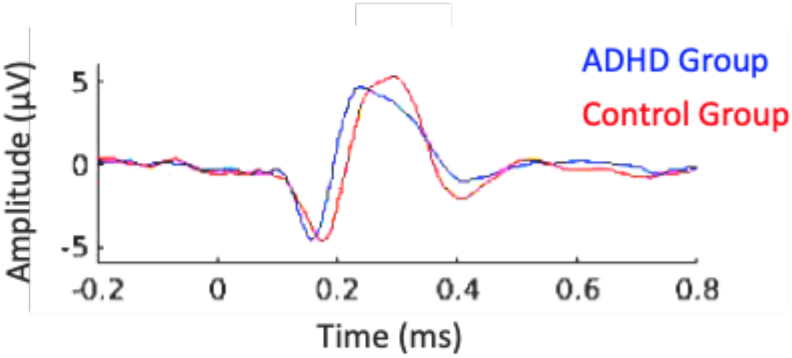

Figure 4: P3a responses to standard, target and distractor tones, by group