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Mind-Wandering and Childhood ADHD: Experimental Manipulations across Laboratory and Naturalistic Settings

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Abstract

The conceptual overlap between mind-wandering and attention-deficit/hyperactivity disorder (ADHD)-related impairments is considerable, yet little experimental research examining this overlap among children is available. The current study aims to experimentally manipulate mind-wandering among children with and without ADHD and examine effects on task performance. Participants were 59 children with ADHD and 55 age-matched controls. Participants completed a novel mind-wandering sustained attention to response task (SART) that included non-self-referential and self-referential stimuli to experimentally increase self-referential mind-wandering, reflected by increases in reaction time variability (RTV) following self-referential stimuli. The ADHD group participated in a classroom study with analogue conditions aimed at encouraging self-referential future-oriented thinking (free play/movie before and after class work) compared to a control condition (newscast) and a cross-over methylphenidate trial. The significant interaction between ADHD status and self-referential stimuli on SART performance indicated that self-referential stimuli led to greater RTV among children with ADHD (within-subject $d = 1.29$) but not among controls. Methylphenidate significantly reduced RTV among youth with ADHD across self-referential ($d = 1.07$) and non-self-referential conditions ($d = 0.72$). In the ADHD classroom study, the significant interaction between mind-wandering condition and methylphenidate indicated that methylphenidate led to higher work completion (ds > 5.00), and the free-play mind-wandering condition had more consistent detrimental effects on productivity

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Conflicts of Interest The authors have declared that they have no competing or potential conflicts of interest.

Code Availability Data were analyzed in SAS 9.4 using PROC GLIMMIX.

Compliance with Ethical Standards

Ethics Approval All procedures were approved by the Florida International University Institutional Review Board (IRB-16–0217-CR03).

Consent to Participate Written informed consent was obtained from the parents and written informed assent was obtained from child participants.

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(*d*s ≥ 1.25) than the movie mind-wandering condition. This study is the first to manipulate mind-wandering and assess effects among children with ADHD using a behavioral task. Results provide evidence that children with ADHD are uniquely susceptible to mind-wandering interference.

Keywords

Attention-deficit/hyperactivity disorder; Mind-wandering; Psychostimulants; Attention

Childhood attention-deficit/hyperactivity disorder (ADHD) is a critical public health concern given the high prevalence rate (10%; Centers for Disease Control & Prevention, 2011), significant societal costs (Robb et al., 2011), and poor long-term outcomes (Barkley et al., 2010). Children with ADHD present with hyperactivity, impulsivity, and attention difficulties leading to impairment in peer relationships, academics, and family functioning (Nigg & Barkley, 2014). However, mechanisms of the attention deficit have been difficult to specify via translation to cognitive tasks. Despite the widespread belief that children with ADHD are distracted by external stimuli (e.g., sounds in the classroom), research indicates that children with ADHD are not differentially susceptible to distractors in their environment or on cognitive tasks (see Huang-Pollock et al., 2005). This raises the question of whether an alternative mechanism of *internal distraction* such as mind-wandering causes what parents and teachers ubiquitously report as high distractibility and inattentive behaviors that interfere with functioning in ADHD.

Mind-wandering is defined as perceptually decoupled thought or attending to internal thoughts rather than external stimuli (Smallwood & Schooler, 2006). Mind-wandering is a ubiquitous part of daily life (Seli et al., 2015) and can occur with or without intention or meta-awareness (Seli et al., 2016). There is clear overlap between the study of mind-wandering in cognitive psychology and that of childhood ADHD in clinical psychology. Mind-wandering is often measured by thought probes during attention tasks-participants are asked whether they were thinking about the task or something unrelated. Probe-caught mind-wandering is associated with the very same functional deficits implicated in ADHD such as sustained attention (Cheyne et al., 2009), excessive motor movements (Seli et al., 2014), and poor educational performance (Smallwood et al., 2007). In fact, parents and teachers narratively report that children with ADHD are often “mind-wandering” or “day-dreaming.” Similarities in research methods are also common as probe-caught mind-wandering is highly related to cognitive constructs implicated in ADHD such as reaction time variability (RTV; Epstein et al., 2011; Tamm et al., 2012). In fact, RTV has been used as a behavioral, objective indicator of mind-wandering independently or in conjunction with subjective, self-reported mind-wandering (Mrazek et al., 2012; Smallwood et al., 2008).

The theoretical relation between ADHD and mind-wandering has gained increasing attention in the literature (Becker & Barkley, 2021; Seli et al., 2015) though available experimental research is limited by population and methodology. Available research documents the positive relation between self-rated ADHD symptoms and mind-wandering among adults (Franklin et al., 2014) and adolescents (Fredrick & Becker, 2021). In fact, spontaneous mind-wandering has been found to relate to adult ADHD symptoms in clinical and nonclinical samples (Seli et al., 2015). Further, mind-wandering has been shown to contribute to impairment beyond ADHD symptoms (Mowlem et al., 2016). Importantly, these studies focused on adults with ADHD symptoms or diagnoses, though the literature is clear that individuals diagnosed with ADHD in adulthood are distinct from children with ADHD followed prospectively into adulthood (Barkley et al., 2010).

A major barrier to researching mind-wandering during childhood is children's limited ability to self-report their mental activity. As described above, available research often utilizes probe-caught and self-reported mind-wandering which is likely not valid among children with ADHD given their well-documented poor insight and invalid self-perceptions (Hoza et al., 2004; Owens et al., 2007). The only study to date experimentally examining mind-wandering among children with ADHD utilized self-reported thought content during attentional lapses while completing a go/no-go task (Van den Driessche et al., 2017), and it is not surprising that unmedicated children with ADHD most frequently reported that their minds were "blank" as opposed to reporting their thought content. Importantly, medicated children with ADHD were more likely than controls to report that their thoughts were off-task, providing preliminary support for the hypothesis that mind-wandering plays a role in ADHD-related attentional dysfunction in children. Qualitative research provides further evidence of mind-wandering among youth with ADHD. In a sample of middle-school age children with ADHD and sluggish cognitive tempo, parents narratively reported youth "daydreaming and getting lost in her thoughts" while children self-reported "listening and then just my brain stares off" and "think[ing] of random things, and just like imagine stuff" (Becker et al., 2021). This suggests the experience of mind-wandering in addition to some difficulty reporting even among 12- and 13-year-old children. In fact, one child stated when asked what they are thinking about, they "don't know how to say it." To quantitatively evaluate mind-wandering among children with ADHD, then, alternative methods of measurement and experimental manipulation are needed.

The extant mind-wandering literature provides an exemplary measurement tool for mind-wandering-reaction time variability (RTV). RTV has been used as a reliable, valid indicator of mind-wandering in various samples. RTV has been shown to be moderately correlated with probe-caught mind-wandering ($r = 0.66$; Seli et al., 2013). Further, variability in response time has been shown to significantly predict subsequent, probe-caught mind-wandering, and, in a second sample, results were replicated with medium to large effect sizes found for the relation between probe-caught mind-wandering and response variability (Seli et al., 2013). This aligns with previous work indicating RTV is positively associated with self-reported mind-wandering (Cheyne et al., 2009). Building upon this research, measures of intra-individual RTV have been used in real time to predict whether a participant may be on-task or off-task, triggering thought probes of self-reported attentional focus (e.g., Franklin et al., 2011). In a reading task using this method, the developed algorithm using RTV predicted on-task vs. off-task states with 72% accuracy, and participants more often reported that they were thinking about 'unrelated concerns' when their reaction time was more variable (in this case, when local reaction time was faster than individual, global average reaction time; Franklin et al., 2011). RTV is therefore a valid and reliable behavioral indicator of mind-wandering. However, available research has not linked RTV to mind-wandering in the ADHD literature via experimental manipulation.

Cognitive neuroscience research on the default mode network provides insight not only into potential neurobiological mechanisms underlying the mind-wandering hypothesis of ADHD dysfunction but also potentially effective experimental manipulations that systematically bias the likelihood of mind-wandering and our ability to objectively measure it. The default network is characterized by spontaneous correlations of neural activity during rest (Fox et al., 2005), suppression of activation during externally goal-directed tasks (Shulman et al., 1997), and activation during retrospective and prospective *self-referential* tasks (Andrews-Hanna et al., 2010; Buckner et al., 2008; Christoff et al., 2009). The default mode network and neural networks related to task performance are typically anticorrelated-when the default network is active, task positive networks are less active and vice versa-and this anti-correlation facilitates the ability to focus or sustain attention on a given external activity (Buckner et al., 2008; Weissman et al., 2006). Among individuals with heightened ADHD symptoms, however, default network activation is elevated (Cortese et al., 2012), and this hyperactivation correlates with RTV among children with ADHD (Querne et al., 2014). As self-referential stimuli have been used to elicit default network activity in past work (Buckner et al., 2008), default network hyperactivation found among youth with ADHD could reflect increases in self-referential thought interference with external tasks and therefore worsen sustained attention (i.e., mind-wandering interference leading to greater RTV). Cognitive neuroscience research suggests, therefore, that mind-wandering among individuals with ADHD is likely self-referential in nature. Based on this inference, the current study aims to experimentally manipulate and measure mind-wandering among children with ADHD by manipulating the presence of self-referential distractors during naturalistic and computer tasks and measuring outcomes associated with mind-wandering such as RTV.

Present Study

We developed a novel sustained attention to response task (SART) integrating self-referential stimuli to evaluate differences in mind-wandering susceptibility among children with and without ADHD. We hypothesize that RTV will be greater following self-referential stimuli—photos of participants themselves at parties, sports events, etc.—compared to non-self-referential stimuli—photos of other children/families—and that the increase will be significantly greater in the ADHD group compared to the control group. Further, psychostimulant medication is the most common treatment for childhood ADHD (Danielson et al., 2018), and effects of medication on SART performance will be evaluated.

Mind-wandering may have its most detrimental impacts in the classroom – leading to more time off task and poorer performance. Therefore, we created a classroom analogue to evaluate the ecological validity of mind-wandering as a potential contributor to inattentive behavior. The ADHD group participated in this parallel second study within an analogue elementary classroom as part of an intensive summer day treatment program. Mind-wandering was manipulated in the classroom setting by introducing a salient stimulus—free play with toys and tablets or an engaging movie—prior to and after independent classwork to increase the probability that children would engage in task-unrelated thoughts. Children with ADHD also participated in a cross-over methylphenidate (MPH) trial. We hypothesize that children will complete less classwork in both mind-wandering conditions

—free play and movie—compared to the control condition (watching an ostensibly non-engaging newscast before and after classwork), reflecting an increase in internal thought interference. Based on decades of research documenting the salutary effects of stimulants on productivity (Pelham et al., 1993, 2001; Pliszka, 2007), we hypothesize that MPH will improve productivity. Additionally, we will examine the interaction between MPH and mind-wandering condition as well as the correlations between performance on the SART and classwork productivity. We hypothesize that RTV will be negatively and moderately correlated with productivity.

Methods

Participants

Fifty-nine children with ADHD and 55 control participants (ages 7–12 years) participated in the study[1]. Youth who had a diagnosis of Autism Spectrum Disorder of moderate or high severity (i.e., requiring substantial or very substantial supports) as determined via semi-structured clinical interview were excluded from either group. Inclusion criteria included a Full-Scale IQ above 70.

Children with ADHD were recruited from the Summer Treatment Program as part of a NIMH-funded trial (R01MH099030). Exclusion criteria for the ADHD group included currently or in the past 6 months receiving psychotropic medication for conditions other than ADHD, medical or psychiatric conditions that could be worsened by stimulants (e.g., seizures, pregnancy, mania), a documented intolerance or lack of response to MPH, or a severe comorbid disorder requiring emergent treatment (e.g., active suicidal ideation). ADHD diagnosis was established based on the Diagnostic and Statistical Manual of Mental Disorders – 5 (DSM-5; American Psychiatric Association, 2013), and symptoms were considered present if endorsed by the parent or teacher on the disruptive behavior disorders rating scale (DBD; Masetti et al., 2003) or parent semi-structured clinical interview (Pelham et al., 2005). Children in the ADHD group had an average of 8.22 (SD = 1.57) inattentive symptoms and 7.40 (SD = 2.20) hyperactive-impulsive symptoms endorsed. Two PhD level psychologists determined diagnoses independently, and if disagreement occurred, a third PhD level psychologist reviewed the diagnostic information and determined diagnosis. Among the children with ADHD, 19% had predominantly inattentive presentation, 7% predominantly hyperactive/impulsive presentation, and 74% combined presentation. Further, 63% of participants with ADHD met criteria for oppositional defiant disorder and 5% for conduct disorder.

Control participants were matched on age and as closely as possible on gender, ethnicity, and parent education status (see Table 1 for demographics). Control participants were recruited from public schools and the community via flyers and were excluded if they had a T-score > 60 on any externalizing subscale on the Child Behavior Checklist (CBCL;

[1]Three children in the ADHD group completed an incorrect version of the MW SART in error and one child did not submit SR photos required for the task. Of the 59 participants with ADHD, 55 completed the MW SART, and therefore 55 children without ADHD were recruited for the control group.

Achenbach & Rescorla, 2001). Participants were 79% boys, 21% girls, 86% white, and 87% Hispanic/Latinx.

Setting

Children with ADHD participated in a summer treatment program, an intensive, behavioral treatment program, from 8AM-5PM for 8 weeks. Children completed the mind-wandering SART individually in a private classroom at the summer treatment program. Children without ADHD completed the task individually in a private room at the university or a private office in their elementary school.

During the summer treatment program, children with ADHD attended a one-hour long analogue classroom twice per day. The classroom study took place in the morning class in which children were instructed to complete grade-level appropriate, independent classwork. The behavioral intervention in the morning classroom included point losses for breaking rules related to behavior (e.g., be respectful) but not for productivity (e.g., stay on task).

Procedure

Parents signed consent forms and completed the CBCL (Achenbach & Rescorla, 2001) to screen for emotional and behavioral problems, and children completed assent documentation prior to participation. The Wechsler Abbreviated Scale of Intelligence, second edition, (WASI-II; Wechsler, 2011) and subscales of the Wechsler Individual Achievement Test, third edition, (WIAT-II; Wechsler, 2009; Table 1) were administered. Parents in the control group received $20 for their child’s participation. All procedures were approved by the Florida International University Institutional Review Board.

Medication

During the first two weeks of the 8-week summer treatment program, children with ADHD underwent a double-masked, placebo-controlled evaluation of three doses of long-acting MPH (Concerta; 18 mg, 27 mg, or 36 mg). Each child’s lowest effective dose was determined by review of clinical data collected over this titration trial. Then children began a crossover trial in which they were randomized to receive placebo or their lowest effective dose of MPH for three weeks and crossed over to the other condition for the final three weeks of the summer treatment program. This resulted in 12–13 total days in each of the two conditions (i.e., placebo and lowest effective MPH dose) for each child. Children with ADHD completed the SART once when administered MPH and once when administered placebo, an average of 12.55 (SD = 4.70) days apart. Number of days between task administration did not vary by crossover order ($p = 0.43$). In sum, they completed the task once in each 12–13 day crossover period.

Control children were recruited after the summer treatment program and matched to a participant in the ADHD group. Control children’s SART performance was compared with the ADHD child’s performance on placebo, and crossover MPH order for the ADHD group was unmasked at this time. As such, control children completed the task 1–2 times depending on when the matched child with ADHD received placebo to control for practice effects. Put another way, if a control child was matched with a child with ADHD who received placebo in the second crossover phase (and therefore had completed the task once before completing it when receiving placebo), the control child completed the task twice, and the second task administration was used herein.

Mind-Wandering Sustained Attention to Response Task (SART)

The mind-wandering SART was based on a standard SART in which participants are instructed to respond to certain stimuli (non-target trials) by pressing a button and instructed to withhold the response for rarely occurring stimuli (target trials). Thus, a key press is the prepotent response given the high proportion of non-target to target trials. Reaction time variability (RTV), the key outcome of the current study, is measured during non-target trials. To allow for the examination of differences in RTV following self-referential stimuli, the mind-wandering SART modified the basic SART structure by including two types of non-target stimuli: 1) photos provided by the participant's family (self-referential trials) and 2) photos of people unknown to the child (non-self-referential trials). The mind-wandering SART, then, was aimed at eliciting self-referential internal distraction by displaying photos that were familiar to the participant and evaluating RTV immediately following self-referential stimuli presentation. Therefore, RTV was measured only on non-self-referential trials, and RTV after self-referential stimuli is compared to RTV following non-self-referential trials. To achieve this, the task was comprised of three Block Types: 1) Non-Self-Referential (NR) Block- NR *NR NR NR*, 2) Self-Referential (SR) Block- SR *NR NR NR*, and 3) Target Block- NR NR NR Target. The three non-self-referential (NR) trials emphasized with italics in the non-self-referential and self-referential blocks were the trials utilized to calculate outcome measures (i.e., RTV). The task included 8% self-referential trials, 84% non-self-referential trials, and 8% target trials. Target trials, which were pictures of animals (e.g., birds, bears) were not modified to be self-referential or non-self-referential. Each block was repeated 29 times, and participants took an average of 6.79 min (SD = 1.08 min) to complete the task. Real life color images were used for all pictures in the task. Stimuli were presented in the middle of the screen with a black background for 2000 ms followed by a white fixation cross for 500 ms between stimuli.

Classroom Mind-Wandering Manipulations

The classroom study included only children with ADHD. To manipulate the frequency of mind-wandering among children with ADHD and evaluate effects of classwork productivity, three conditions were randomized over days and present for the first 5 and last 10 min of class: 1) *free play* with preferred toys and tablets, 2) watching an excerpt from a children's *movie*, or 3) a watching a non-engaging news excerpt (i.e., CSPAN; *control*). To increase future-oriented self-referential thoughts, children were told they would have the same condition at the end of class—i.e., teachers told children they would have 10 min to continue playing with toys, watching the movie, or watching CSPAN at the end of class. Across conditions, there were no differences in the environment during classwork completion (i.e., toys were removed, media projector was turned off).

Measures

Reaction Time Variability (RTV)—Reaction time variability was the SART outcome variable. RTV was calculated as the reaction time standard deviation from the 3 non-self-referential trials that followed either self-referential or non-self-referential stimuli presentation representing the self-referential and non-self-referential blocks (i.e., Block Type), respectively. See above description of task for further detail. Responses to self-referential trials were not used to calculate outcome variables. Incorrect responses and reaction times below 200 ms were excluded from analyses consistent with past work (Kofler et al., 2014).

Classwork Completion—Using procedures documented as effective in studies of medication effects in the summer treatment program classroom (e.g., Fabiano et al., 2007; Pelham et al., 2011), children were instructed to complete grade-level classwork in math, reading, and language arts for 30 min. The number of problems completed was the dependent measure.

Planned Analyses—Generalized linear mixed models (PROC GLIMMIX in SAS 9.4) were used for analyses to account for repeated measurement of outcomes. Analysis of RTV were fit to a lognormal distribution with between-subject (ADHD placebo vs. control), within-subject (non-self-referential vs. self-referential block), and interaction effects as predictors. Identical procedures were used to examine the effect of MPH (placebo vs. MPH), block type (non-self-referential vs. self-referential block), and their interaction in the ADHD group controlling for crossover order.

To analyze MPH and mind-wandering manipulation effects on classroom productivity in the ADHD group, a generalized mixed model was fit to a Poisson distribution with the outcome of number of seatwork problems completed. Analyses controlled for the child's medication crossover order (i.e., MPH or placebo first), assigned classroom (which methodologically controls for child age and teacher), their interaction, and interactions between these variables and MPH and mind-wandering condition, respectively. The relation between SART performance and classroom productivity was evaluated via Pearson correlation coefficients.

Results

Sustained Attention to Response Task

Initial analyses examined group effects (ADHD vs. control) and self-referential stimuli effects by including data from the ADHD group when receiving placebo and the matched control group. ADHD status significantly predicted RTV ($F(1,107) = 22.18$, $p < 0.001$), and block type (self-referential vs. non-self-referential) did not significantly predict RTV ($F(1,107) = 1.91$, $p = 0.17$). The interaction between ADHD and block type was significant ($F(1,107) = 5.09$, $p = 0.03$; Table 2, Fig. 1). Specifically, self-referential stimuli resulted in greater RTV relative to non-self-referential stimuli in the ADHD group ($t = -2.5$, $p = 0.01$, $d = 1.29$), but not in the control group ($t = 0.63$, $p = 0.53$, $d = 0.15$).

Given significant differences between the ADHD and control groups on RTV, the effect of MPH and self-referential stimuli on RTV were examined in the ADHD group only (Table

2). Block type significantly predicted RTV (F(1, 53) = 8.58, p = 0.005) such that RTV was greater following self-referential stimuli compared to non-self-referential stimuli among children with ADHD. MPH significantly predicted RTV (F(1, 51) = 11.39, p = 0.001) such that RTV was reduced by approximately 7–10 ms when children with ADHD received MPH. Within-subject effects of MPH were moderate to large across non-self-referential and self-referential blocks (d = 0.72 and d = 1.07, respectively). The interaction between block type and MPH was not significant (F(1, 52) = 0.24, p = 0.63).

Classroom Study

There were significant main effects of mind-wandering condition (F(2, 112) = 11.49, $p <$ 0.001) and MPH (F(1, 56) = 1943.28, $p < 0.001$) on classwork completion in the ADHD group (Table 3). Specifically, children with ADHD completed significantly less work in the Free Play condition compared to both the control ($p < 0.001$) and Movie (p = 0.008) mind-wandering conditions in the classroom. When children with ADHD received MPH, they completed significantly more work. The interaction between mind-wandering condition and MPH was significant (F(2, 112) = 4.35, p = 0.02; Table 3). As expected, MPH led to increased classroom productivity compared to placebo across mind-wandering and control conditions (ps < 0.001, ds > 5.00). Interaction effects indicate when administered placebo, children's work completion was lower in the Free Play mind-wandering condition compared to both the control (t = 3.71, $p < 0.001$) and the Movie conditions (t = 4.00, $p < 0.001$) which were not significantly different from each other (t = 0.24, p = 0.81). When receiving MPH, children completed less work in both mind-wandering conditions compared to the control condition (Free Play, t = 2.90, p = 0.005, and Movie, t = 2.63, p = 0.01). Within-subjects effect sizes indicate large detrimental effects of the mind-wandering conditions on classroom productivity when children received MPH (Free Play vs. control, d = 1.25; Movie vs. control, d = 1.02).

Correlations

In the ADHD group, average reaction time did not correlate significantly with work completion in any conditions (ps > 0.10). Classwork completion in the Free Play, placebo condition was correlated significantly with RTV during both self-referential (r = −0.304, p = 0.03) and non-self-referential blocks in the MPH condition (r = −0.312, p = 0.02). Correlations were moderate in the expected direction (i.e., greater RTV was associated with less work completion; Table S1).

Discussion

The current study is the first to experimentally manipulate and evaluate the impact of mind-wandering on task performance (i.e., RTV) and classwork completion among children with ADHD. Aims were to determine if children with ADHD are susceptible to and affected by mind-wandering compared to children without ADHD and whether increased mind-wandering results in impaired academic productivity. Results indicate that 1) children with ADHD are differentially susceptible to mind-wandering or internal distraction, 2) mind-wandering manipulations resulted in decreased classwork productivity among children with ADHD, and 3) MPH decreased RTV and increased productivity but did not reduce the effects of mind-wandering manipulations.

RTV was the primary outcome of interest as children with ADHD have greater variability in attentional performance than typically developing children (Epstein et al., 2011; Kofler et al., 2013; Tamm et al., 2012). Results from the SART confirm hypotheses with a significant interaction effect between ADHD and block type (non-self-referential vs. self-referential block). Self-referential stimuli led to increased RTV among children with ADHD but not among children without ADHD (Fig. 1). Children with ADHD were therefore differentially susceptible to mind-wandering interference and experienced impaired task performance after self-referential stimuli presentation. As this is the first study to experimentally evaluate mind-wandering among youth with ADHD, results provide much needed initial support for the theory that mind-wandering underlies the attention problems characteristic of childhood ADHD (Seli et al., 2015). Results align with qualitative research indicating that children with ADHD experience daydreaming and mind-wandering (Becker et al., 2021) though more work is needed to examine the alignment of inattentive symptoms and sluggish cognitive symptoms with mind-wandering both quantitatively and qualitatively. Results are also consistent with research utilizing self-reported mind-wandering among adults with ADHD symptoms (Franklin et al., 2014) while having the distinct advantage of not requiring children to self-report thought content.

The SART developed herein can therefore be adopted to further examine mind-wandering among youth with ADHD. As proof-of-concept, confirming hypotheses has validated the experimental manipulation of self-referential stimuli presentation in conjunction with RTV as an outcome. The relation between mind-wandering SART performance and other cognitive and behavioral constructs of interest, such as classroom productivity (see supporting information) or inattentive symptoms, among youth with ADHD should be examined. Future studies using the novel, mind-wandering SART and fMRI should examine the theory that DMN intrusion is related to elevated RTV among youth with ADHD (Querne et al., 2014) which would provide additional support for the validity of the mind-wandering SART.

In the classroom, mind-wandering was manipulated by introducing a salient stimulus (i.e., free play or a children’s movie) prior to and after independent work completion to increase the probability that children would engage in task-unrelated thought during classwork. Results indicated a significant interaction between mind-wandering conditions and MPH. When receiving placebo, children with ADHD completed less work in the Free Play condition compared to both the Movie and control (newscast) conditions. When receiving MPH, however, children with ADHD completed less work in both mind-wandering conditions (Free Play and Movie) compared to the control condition. Free Play, when children chose what they played with each day, was more consistently associated with impaired performance than the Movie condition. A potential explanation could be that the self-determined nature of free play was more likely to produce future-oriented, self-referential mentation than passively watching a movie.

Altogether, results indicate that children with ADHD had significantly lower productivity on mind-wandering condition days such that children completed about 3 fewer problems during the 30-min activity. Three problems may not appear clinically substantial; however, this study aimed to *increase* mind-wandering in a group of children that are likely already experiencing impairing mind-wandering prior to the introduction of any experimental manipulation. Findings therefore indicate that children with ADHD are susceptible to mind-wandering that negatively impacts their academic performance. In a child's daily life, these task-unrelated engaging stimuli are often present, and children's ability to focus on less-engaging stimuli (e.g., math worksheet) rather than thinking about entertaining activities may underlie academic productivity.

The effects of evidence-based treatments on mind-wandering are critical to assess, and most children with ADHD in the United States receive stimulant medication (61–69%; Danielson et al., 2018; Visser et al., 2014). Herein, MPH improved attentional performance (i.e., RTV) and classroom productivity, confirming hypotheses and replicating decades of research supporting stimulant efficacy (Pliszka, 2007). Children with ADHD completed about 20 more problems when they received MPH compared to placebo in the 30-min class period across mind-wandering conditions. However, when children with ADHD received MPH, they remained susceptible to mind-wandering interference in the classroom and cognitive task. In fact, children with ADHD were more consistently susceptible to mind-wandering in the classroom when receiving stimulant medication. One potential explanation could be that children with ADHD are engaging in task-unrelated thought at a high frequency throughout the day and increasing that rate requires a highly salient self-referential stimuli (i.e., playing their favorite game before and after classwork). When they receive MPH, however, the dynamic range of mind-wandering may be rescaled, unmasking mind-wandering in response to other activities (e.g., watching a movie). We would likely not expect the same effect when children with ADHD receive evidence-based behavioral treatment as the salience of preferred stimuli is directly and effectively capitalized upon to improve work productivity via setting the clear expectation that preferred activities will be available contingently upon work completion (Fabiano et al., 2021).

Importantly, the current experimental design was aimed at *increasing* mind-wandering, and therefore results do not indicate whether MPH reduces mind-wandering that is hypothesized to occur throughout the day among children with ADHD which warrants further investigation. More work is needed to quantify mind-wandering and internal distraction as it occurs. However, based on the literature, asking a child with ADHD if they are off-task or what they are thinking is unlikely to advance our understanding of this phenomenon. Given the consistent overlap between childhood ADHD-related deficits and mind-wandering research, there are multiple opportunities for further exploration of the ways in which mind-wandering may affect children with ADHD. For example, replicating work demonstrating the relation between mind-wandering and moment-by-moment reading comprehension errors (Franklin et al., 2011) among children with ADHD would advance our understanding of reading deficits and therefore reading interventions for this at-risk population (Sexton et al., 2012) allowing for the development of just-in-time adaptive interventions (Koch et al., 2021). Relatedly, establishing a clear relation between mind-wandering and DMN hyperactivation among children with ADHD may lead to advances in neurofeedback (e.g., Wang et al., 2021). The avenues for future research are vast, and much more work is needed to understand the dynamics and correlates of mind-wandering among children with ADHD prior to intervention development.

Limitations and Future Directions

The current study is novel in its methods and design, and as such, bears limitations. The manipulations used herein may not specifically target the cognitive phenomenon of mind-wandering but rather another aspect of off-task behavior. However, three different manipulations designed to increase mind-wandering based on the intersection between the extant mind-wandering and neuroscientific literatures were used, and each manipulation led to impaired attentional performance and productivity, as expected. As such, we hope the novel, mind-wandering SART will be utilized in future research to evaluate mind-wandering among children. The current study is limited in that a larger battery of cognitive tasks was not completed allowing for the explication of convergent and discriminate validity. Future research is needed to evaluate mind-wandering in relation to other cognitive functions known to be impaired among youth with ADHD such as inhibitory control and working memory (Rapport et al., 2001; Sonuga-Barke, 2002). Children with ADHD in the current study were treatment seeking and the majority had ADHD, combined presentation resulting in a restricted range of symptoms. This is an appropriate sample for foundational research and allowed for the investigation of classroom productivity and MPH effects. Future research should evaluate mind-wandering in a sample of children with a broader range of symptom presentations to evaluate individual differences and the dimensional relations between ADHD symptoms, internalizing symptoms, and mind-wandering susceptibility.

Future research would benefit from ensuring manipulations are sufficiently self-referential as the self-referential nature of stimuli may explain the stronger results for the Free Play compared to the Movie condition. Further, future research should systematically collect supplemental observational data in the classroom such as recording whether children make off-topic statements during the class period that relate to the manipulation (e.g., a child states they watch that movie every weekend) as this was observed to occur in the current study–though it was not consistently, systematically evaluated—and off-topic statements could be an observable indicator of internal distraction. Lastly, the amount of time that passed between stimuli in the classroom study (i.e., 30 min) may partially explain the comparatively weaker findings in the classroom setting compared to the controlled, laboratory manipulations of mind-wandering. Including controls in a replication of the classroom study is needed.

Conclusions

The current study developed and implemented novel methods to provide support for the hypothesis that children with ADHD are differentially susceptible to mind-wandering interference, and that increased mind-wandering negatively impacts attention and classroom productivity. The success of the specific, controlled, and thoughtful manipulations in reducing productivity and increasing RTV is clear initial evidence that children with ADHD are susceptible to mind-wandering and, more specifically, self-referential task-unrelated thought. This foundational work will allow researchers to continue exploring the phenomenon of mind-wandering among children, an area of study that has been markedly limited. We theorize that mind-wandering is an underlying dysfunction among individuals with ADHD, and future research could utilize and modify the mind-wandering task developed herein to examine the impacts of self-referential stimuli on a myriad of functional behaviors such as reading comprehension, driving simulation, or social interaction. Further explication of the ways in which mind-wandering negatively affects individuals with ADHD in the moment may lead to exciting advances in treatment development.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data Availability

Data are available upon reasonable request of the corresponding author.

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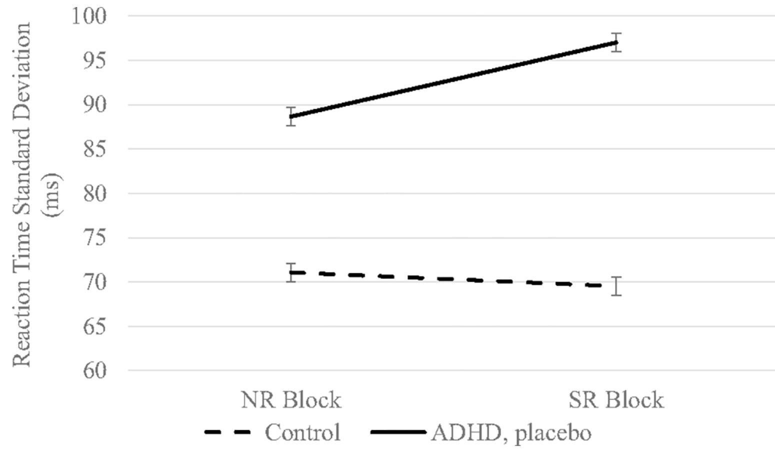

Fig. 1.
Effect of block type and ADHD status on reaction time variability. NR = non-self-referential, SR = self-referential. For between-group analyses of reaction time variability (RTV), the control group was compared to the ADHD group when receiving placebo. The interaction between block type and ADHD status on reaction time variability (RTV) was significant, $p < .03$. In the control group, block type did not significantly impact RTV, $p = .17$. In the ADHD group when receiving placebo, RTV was significantly greater in the SR block compared to the NR block, $p < .05$

Table 1

Participant Demographics, *M* (*SD*)

	Control, *n* = 55	**ADHD, *n* = 59**
Age (years)	9.24 (1.56)	8.7 (1.44)
Gender, *n* (%)[a]		
Male	43 (78.2%)	47 (79.7%)
Female	12 (21.8%)	12 (20.3%)
Hispanic/Latinx, *n* (%)[a]	47 (85.5%)	51 (87.9%)
Race, *n* (%)[a]		
Asian	2 (3.6%)	2 (3.4%)
Black	5 (9.1%)	7 (11.9%)
White	48 (87.3%)	50 (84.7%)
Parent Marital Status, *n* (%)[a]		
Single, not living with partner	15 (27.8%)	20 (34.5%)
Married or living with partner	39 (72.2%)	38 (65.5%)
Highest Parent Education, *n* (%)		***
Some Highschool	0 (0%)	1 (1.7%)
Highschool Diploma	1 (1.8%)	11 (18.6%)
Some College	8 (14.5%)	12 (20.3%)
Associates Degree or Technical School	8 (14.5%)	8 (13.6%)
Bachelor's Degree	18 (32.71%)	17 (28.8%)
Graduate Training	20 (36.4%)	10 (16.9%)
Grade	3.29 (1.57)	2.83 (1.49)
FSIQ	106.94 (11.80)	96.47 (12.47)***
Achievement Scores		
Word Reading	108.38 (13.77)	98.75 (16.18)**
Numerical Operations	110.31 (13.81)	102.47 (11.89)**
Spelling	111.54 (16.17)	98.11 (16.46)***
CBCL T-Scores		
Anxious/Depressed	54.20 (6.17)	60.45 (9.03)***
Withdrawn/Depressed	53.50 (5.20)	58.33 (8.60)**
Attention Problems	52.46 (3.67)	70.91 (9.55)***
Internalizing Problems	47.94 (10.23)	59.66 (10.01)***
Externalizing Problems	44.89 (9.12)	61.72 (9.06)***

CBCL = Child Behavior Checklist. FSIQ = full-scale IQ. T-tests were used to compare control and ADHD groups on continuous outcomes including highest parent education.

[a] Binary logistic regression was used to compare groups.

** $p < .01$

*** $p < .001$

Table 2

Mind-wandering sustained attention to response task (SART) performance. Model estimated means, 95% confidence intervals, and effect sizes for reaction time variability across groups and conditions

Block type	Control, *n* = 55 *M* [95% CI]	ADHD placebo, *n* = 54 *M* [95% CI]	ADHD MPH, *n* = 55 *M* [95% CI]	Cohen's *d* effect size, Control vs. ADHD placebo	Within-subject effect size, ADHD placebo vs. ADHD MPH
Non-self-referential	71.06 [69.01, 73.11]	88.15 [86.10, 90.19][b]	81.74 [79.70, 83.78][c]	3.14***	0.72*
Self-referential	69.53 [67.48, 71.58]	96.29 [94.24, 98.34][a,b]	87.07 [85.02, 89.11][c]	2.19***	1.07**
Within-subject effect sizes of block type					
Non-self-referential vs. self-referential	0.15	1.29*	1.01		

MPH = methylphenidate. Within-subjects effect sizes were calculated accounting for the correlation between scores (Morris & DeShon, 2002), $d = \frac{|m_1 - m_2|}{\sqrt{S_1^2 + S_2^2 - (2rs_1s_2)}}$. At $p < .05$

[a]Significant effect of block type (vs. non-self-referential)

[b]Significant effect of ADHD status

[c]Significant effect of MPH.

* $p < .05$

** $p < .01$

*** $p < .001$

Table 3

Classroom work completion among children with ADHD, $n = 59$

	MW Condition *M* [95% CI]			Within-subject effect size compared to Control condition	
	Control	**Free Play**	**Movie**	**Free Play**	**Movie**
Placebo	75.95 [66.00, 85.89]	72.74 [63.21, 82.26][a]	76.16 [66.19, 86.13]	1.61***	0.10
MPH	100.26 [87.16, 113.36][b]	97.51 [84.78, 110.25][a,b]	97.74 [84.97, 110.51][a,b]	1.25**	1.02**
Within-subject effect sizes					
MPH vs. Placebo	5.08***	5.59***	5.31***		

CI = confident interval, MW = mind-wandering, MPH = methylphenidate. Within-subjects effect sizes were calculated accounting for the correlation between scores (Morris & DeShon, 2002), $d = \frac{|m_1 - m_2|}{\sqrt{S_1^2 + S_2^2 - (2rs_1s_2)}}$. At $p < .05$

[a] significant effect of MW condition (Free Play or Movie) compared to Control condition

[b] significant effect of MPH compared to placebo