Examining the Relations among Working Memory Capacity, Attention Deficit Hyperactivity Disorder Symptomology, and Conscious Experience

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Open Practices Statement

The data and analyses for this project are available here: https://osf.io/z3awm/. This study was preregistered. The preregistration is available here: https://aspredicted.org/6s7wm.pdf. The SART task used here is available at: https://osf.io/z3awm/. Shortened complex span tasks are available from Randy Engle's lab at Georgia Institute of Technology: https://englelab.gatech.edu/taskdownloads. The questionnaire used here is available from the original authors.

Abstract

Van den Driessche et al. (2017) found that children and young adults with more Attention Deficit Hyperactivity Disorder (ADHD) symptoms report more mind blanking than those with fewer ADHD symptoms and that non-medicated children with ADHD reported less mind wandering and more mind blanking than medicated children with ADHD. Van den Driessche et al. speculated that medication facilitated executive control and that executive resources support mind wandering (and on-task thought). Besides describing the conscious experience of those with ADHD symptomology, these findings bear on the theoretical debate of executive functions' role in conscious experience. Some argue that executive functions support mind wandering (Levinson, Smallwood, & Davidson, 2012; Smallwood, 2010, 2013), while others argue that mind wandering situationally results from a lack (or failure) of executive control (McVay & Kane, 2010; Meier, 2019). Here, we conducted a study like Van den Driessche et al.'s study with young adults (Experiment 2, 2017) and tested the associations between ADHD symptomology and conscious experience. Rather than speculating about the effects of medication, we directly measured executive functioning (via complex span tasks). Like Van den Driessche et al., we observed a positive association between mind blanking and ADHD, but we detected no evidence supporting the claims that executive functions support (or reduce) mind wandering. We also assessed the relative associations between task performance metrics and reports of mind blanking and mind wandering. We did not detect differential performance associations between those thought reports. [Preregistration, data, analysis scripts, and output are available via the Open Science Framework: https://osf.io/z3awm/].

Keywords: attention, consciousness, individual differences, mind blanking, replication

Examining the Relations among Working Memory Capacity, ADHD Symptomology and Conscious Experience

Using the operational definitions of mind wandering as “spontaneous self-generated thoughts that are independent of both the task and the environment,” and mind blanking as “no reportable mental content,” Van den Driessche et al. (2017) examined the role of executive functions in conscious experience. Functionally, Van den Driessche et al. used attention-deficit/hyperactivity disorder (a neurocognitive disorder marked by symptoms of impulsivity and hyperactivity ([American Psychiatric Association, 2013]; ADHD) as a proxy for executive functioning. Van den Driessche et al.’s results showed that children diagnosed with ADHD (Experiment 1) and young adults who report more ADHD symptomology (Experiment 2) reported more mind blanking than people without an ADHD diagnosis or who report less symptomology, and the use of medication in children with an ADHD diagnosis reduced reports of mind blanking and increased mind wandering. Van den Driessche et al. broadly speculated that medication recruited executive functions and mind wandering (and on-task thought) rely on these executive functions.

There is an active debate on the role of executive functions in mind wandering with some claiming that mind wandering requires executive resources. This view predicts mind wandering will be greater in situations that demand fewer resources and people who have more resources available will mind wander more than people with less available resources (Levinson et al., 2012; Smallwood, 2010, 2013). Others argue and provide evidence that in situations where someone is trying to concentrate, mind wandering occurs because executive functions fail to maintain control over attention (McVay & Kane, 2010; Meier, 2019). Smallwood and Andrews-Hanna’s (2013) context regulation hypothesis emphasizes that task context is an important consideration of when we should see associations between executive functions and mind wandering, with a negative association expected in more difficult (i.e., attentionally demanding) tasks. Because of this issue's theoretical importance, we sought to replicate the associations between ADHD and conscious experience from Van den Driessche et al. and to test directly (via measures of working memory capacity) if executive functions support mind wandering in the context of a sustained attention task.

Van den Driessche et al.'s 2017 Studies

Van den Driessche et al.'s Experiment 1 (2017) examined conscious experience in four groups of children (ages 6-12): children diagnosed with ADHD taking medication, children diagnosed with ADHD not taking medication, a control group with other psychiatric disorders, and a healthy control group. In their Experiment 2, Van Driessche et al. dichotomized a young adult sample (*M* age = 24) into a group that reported more ADHD symptoms (a score of five or higher on the DIVA [Kooij & Francken, 2010] ADHD self-report questionnaire) and a group that reported fewer ADHD symptoms (a score of less than five on the DIVA). In both experiments, subjects completed sustained attention to response tasks that had embedded thought probes with five response options: on-task focus, task-related interference (i.e., a lapse of attention due to thinking about something related to the task), distraction (interference caused by something in the environment), mind wandering, and mind blanking.

In Experiment 1, the non-medicated ADHD children reported increased mind blanking but not mind wandering compared to the medicated ADHD children and the two control groups, and the medicated ADHD children reported more mind wandering than the other three groups (i.e., non-medicated ADHD children, other psychiatric disorder children, healthy control children). Additionally, when combining thought reports speculated to rely on executive functioning (i.e., mind wandering and on-task), the non-medicated ADHD children had fewer reports than the medicated ADHD children and control groups. No statistically significant differences were found among these groups in the number of reports speculated not to require executive resources (i.e., a composite formed of task-related interference and distraction). In Experiment 2, the young adults who reported more ADHD symptoms reported more mind blanking than those who reported fewer ADHD symptoms. Reports of mind wandering did not differ between groups. Like in Experiment 1, the group with more ADHD symptoms had fewer reports in the composite made up of mind wandering and on-task reports than the group that reported less ADHD symptoms. There was no statistically significant difference between the two groups in the number of reports speculated not to require (or require little) executive resources (i.e., composite of task-related interference and distraction).

Based on their results and previous reports of ADHD-related deficits in executive functioning (Barkley, 1997), Van den Driessche et al. surmised that increased mind blanking in those who have (non-medicated) ADHD is due to a lack of (or ineffective use of) executive resources. More specifically, they conjectured that those who lack executive resources (indicated by ADHD symptomology) cannot maintain an internal train of thought that supports mind wandering or on-task thought and that medication enhances executive control, which in turn increases the ability to support these thought types. In their discussion, Van den Driessche et al. introduced the idea that medication could influence thought reports through motivation as well as executive functioning, based on claims that ADHD is associated with a motivation deficit (Volkow et al., 2011) and motivation can decrease mind wandering independent of executive control (Mrazek et al., 2012). Van den Driessche et al. (without much explication) dismissed motivation as a causal factor and favored the executive control account for their inferences regarding the effects of medication on thought reports. Van den Driessche et al.'s discussion implied a model where ADHD symptomology is caused by motivation and executive function deficits, but the executive function component (and not the motivation component) was affected by medication and largely determined conscious experience. Van den Driessche et al. surmised that increased mind blanking in those who have (non-medicated) ADHD is due to a lack of (or ineffective use of) executive resources. More specifically, they conjectured that those who lack executive resources (indicated by ADHD symptomology) cannot maintain an internal train of thought that supports mind wandering or on-task thought and that medication enhances executive control, which in turn increases the ability to support these thought types.

Connections with the Broader Literature

Van den Driessche et al.'s finding of elevated mind blanking in non-medicated ADHD is consistent with other reports of ADHD-related deficits of metacognition specifically related to mind wandering and cognition more generally. For example, Franklin et al. (2017) reported that ADHD scores were positively correlated with a lack of meta-awareness. That is, subjects who endorsed more ADHD symptomology were more likely to report that they were unaware that they were mind wandering when probed during a reading task. Vatansever et al. (2019) found that subjects with more ADHD symptoms reported less detailed thought experiences responding to a multidimensional thought probe (i.e., a series of questions about thought details) when completing a 1-back task (while finding no ADHD-related differences in details in a less demanding 0-back task). Regarding cognition more broadly, Antshel and Natasi (2008) have found that preschoolers with ADHD had metamemory skills behind preschoolers without ADHD, and Knouse et al. (2005) reported that adults with ADHD exhibited impaired metacognitive monitoring by overestimating their abilities in driving scenarios compared to control groups.

Van den Driessche et al.'s speculation on medication, executive functioning, and thought reports seems less consistent with other work. For instance, Robison and Unsworth (2018) found that a working memory capacity latent variable (composed of scores from three complex span tasks; the association between a latent variable of complex span tasks and a latent variable of executive function tasks [e.g., mental arithmetic, mental control, verbal fluency, and the Wisconsin Card Sorting Test] has been estimated at .97, McCabe et al., 2010) correlated (non-significantly) only at .07 with a mind blanking latent variable (from three cognitive tasks with embedded thought probes). This result (on the surface) is inconsistent with the claim of mind blanking propensity associating with executive functions. Also, from Robison and Unsworth (2018), there is some evidence that Van den Driessche et al. dismissed motivation prematurely. Robison and Unsworth (2018) reported a correlation of -.54 between a motivation latent variable and a mind blanking latent variable. However, Robison and Unsworth (2018) used a probe response “mind blanking” that subjects endorsed if they were feeling “not very alert” or “mind blanking” making the interpretation of this response ambiguous, thus limiting the strength of inferences that can be drawn. Very little lab work shows statistically significant positive associations between working memory capacity and mind wandering propensity that one would expect if working memory capacity (or executive functioning more broadly) supports mind wandering. Levinson et al. (2012) did report a positive correlation between working memory capacity and mind wandering in a low-demand breathing task, but a direct replication of this work (Meier, 2019) reported a negative association. The negative association from Meier (2019) is in line with many other findings (McVay & Kane, 2009, 2012a, 2012b; Robison & Unsworth, 2018; Unsworth & McMillan, 2013, 2014).

Moreover, some recent work reports null associations between complex span tasks and reports of ADHD symptomology. Unsworth et al. (2019) reported a correlation of .07 (N = 204) between ADHD and a latent variable formed from three complex span tasks, Franklin et al. (2017) reported a correlation of .05 (N = 100) between a reading complex span task and a composite of two ADHD self-report measures (CAARS-S:SV and ASRS-V1.1), and Jonklin et al., (2017) reported no significant differences in operation complex span scores between high (i.e., scores in the 80th and 90th population percentile) and low (i.e., scores in the 10th and 20^{h} population percentile) ADHD inattentive subtype groups. Some may be tempted to dismiss these null associations because ADHD-related working memory deficits have been reported as more pronounced in spatial measures (e.g., Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004). However, Meier (2021) reported null associations between two shortened complex span tasks, their composite, and an ADHD self-report measure. One of these measures was a spatial task, symmetry span task (*r*[223] = -.02), lending support to the notion that ADHD symptoms may be independent of executive functioning (at least in a young adult population). We are not aware of reports of statistically significant associations between complex span task performance and self-report measures of ADHD symptomology. The potential for executive functions (at least as measured by complex span tasks) to be independent from ADHD symptomology suggests an alternative model to the one implied by Van den Driessche et al. (2017) on how executive functions and ADHD affect thought content. In this alternate model, executive functions (operationalized as working memory capacity) uniquely contribute to or moderate the relation between ADHD and conscious experience (operationalized as thought reports).

Mind Blanking, Mind Wandering, and Task Performance

Across multiple studies, Ward and Wegner (2013) found that mind wandering was reported more frequently than mind blanking, and that mind wandering, but not mind blanking, was associated with decrements in reading comprehension when subjects controlled the in-the-moment display of reading material. But when the presentation of reading material was out of subjects' in-the-moment control, both mind wandering and mind blanking were associated with worse reading comprehension and did not differ from each other. The explanation offered for this difference between conditions (i.e., in-the-moment control vs. not in-the-moment control) was that when mind wandering, processes like eye movements continue close to as if one were reading. But when mind blanking, all processes associated with external attention are paused, and this maintains the subjects' place in the text. Although we consider the results from Ward and Wenger interesting, we think of them as having weak evidential value because of between-subjects analyses with small sample sizes (e.g., the experiments with reading comprehension had samples of 75, 56, and 27), and a self-catching probe methodology that resulted in very few endorsements of mind wandering and mind blanking.

Using larger samples and probe-caught methodology, Unsworth and Robison (2016, 2018) tested for differences between mind wandering and mind blanking in behavioral indices (they also tested for differences in pupillometry, but we judged those as not germane to the current study). On the surface, the behavioral results from Unsworth and Robison's studies appear mixed. In Unsworth and Robison (2016) a response that included mind blanking was reported more than a mind wandering response, but in Unsworth and Robison (2018), and consistent with Van den Driessche et al. (and Ward & Wegner, 2013), mind wandering was more frequently reported than mind blanking. In addition, Unsworth and Robison (2018) found that mind wandering reports were associated with faster response times on the trials immediately preceding them than mind blanking reports while Unsworth and Robison (2016) did not detect a difference.

The differences in behavioral results between Unsworth and Robison's 2016 and 2018 studies were likely driven by differences in how the mind blanking thought probe response was worded. In 2016, Unsworth and Robison used "I am not very alert/my mind is blank or I'm drowsy" and, as previously mentioned, in 2018 they used a less broad response option of "I am not very alert/my mind is blank" which because of being less inclusive was endorsed less than the probe response from the 2016 study. Because Unsworth and Robison (2016, 2018) used response options that allowed subjects to respond based on more than mind blanking, it is not clear that the differences they note between mind wandering and mind blanking can be attributed to mind blanking.

The Current Study

The current study tested the claims of Van den Driessche et al.'s (2017) Experiments 1 and 2. Here, using a young adult sample (like Van den Driessche et al. Experiment 2), we attempted to replicate the associations between ADHD symptomology and thought reports (including thought report composites). Following Van den Driessche et al.'s speculation that medication recruited executive resources that in turn affected thought reports (i.e., conscious experience), we measured executive function directly by assessing working memory capacity with two shortened complex span tasks. We used these measures because the references in Van den Driessche et al. where they discussed executive function suggested working memory capacity (sometimes referred to as executive attention; Engle, 2001) as the most likely candidate

(Christoff et al., 2009, 2016; Smallwood, 2013; Smallwood, Brown, Baird, & Schooler, 2012). We tested the association among working memory capacity and thought reports.

In addition to testing these associations, we assessed an alternate model with working memory capacity and ADHD symptomology both allowed to predict unique variance in thought reports and a model term estimating the interaction between working memory capacity and ADHD symptomology. Considering the weaknesses of both Ward and Wegner (2013; i.e., small sample sizes) and Unsworth and Robison (2016, 2018; i.e., ambiguous probe response options) regarding the associations among mind blanking, mind wandering, and task performance, we tested for differences in the associations between these two thought reports and task performance with an adequate sample size, probe-caught methodology, and a focused mind blanking response option with in-the-moment behavioral measurements.

Methods

We preregistered this study on August 28th, 2019 (https://aspredicted.org/6s7wm.pdf). The data for this study was collected during the Fall 2019 semester. This study was approved by the Western Carolina University Institutional Review Board on August 8, 2019.

Subjects

Three hundred and two subjects from Western Carolina University completed the informed consent for this study (mean incoming student SAT scores range from 1116 to 1149 for cohorts entering Fall 2017 through Fall 2019). Of these 302 subjects, 59% were female. Subjects had a mean age of 19 (*SD* = 2); Of the subjects who gave ethnicity information (two subjects declined), 248 identified as white, 20 as black, 10 as multiracial, 10 as Asian, seven as Native American or Alaskan Native, and five as other. Subjects received partial credit for a course requirement as compensation for their participation. The stopping rule for data collection was the end of a semester in which we had at least data from 250 subjects. Data collection was completed during the 2019 fall semester. This sample size was chosen on the basis that correlations (ρs) as weak as .10 stabilize within a narrow window when approaching 250 subjects (Schönbrodt & Perugini, 2013), thus allowing precise estimates. The advertised eligibility criteria for participation in this study were being within the age range of 18-30, having no serious visual impairments, and being native English speakers. Subjects attended one session that lasted up to one hour.

Materials

All measures were programmed in E-Prime (Psychology Software Tools, Pittsburg, PA, 2012) on Windows computers, and subjects used a standard mouse, QWERTY keyboard, and liquid crystal display monitors.

Measures

Complex Span Tasks

We measured working memory capacity with two shortened complex span tasks (Foster et al., 2015). We used shortened complex span tasks to limit each experimental session's time and maximize the number of subjects. Subjects completed one block of each of the two shortened complex span tasks (compared to the usual 3 blocks). Using two one-block complex span tasks provides superior measurement properties over using one complete (three-block) span task (Foster et al., 2015). In these tasks, subjects memorized the identity and order of stimuli. Subjects completed an unrelated processing task in which they gave a true/false answer within a specific timeframe in between each to-be-remembered item. After each sequence, which had an unpredictable number of transitions between memorial and processing portions, subjects recalled the memory items. Subjects practiced both parts of the task individually as well as combined before beginning the scored trials. During the combined practice section, the average response time was calculated. If during the scored trials a subject's response time was 2.5 standard deviations (*SD*) away from their mean response time (from the combined practice), the computer counted that processing task trial as an error and moved to the next screen. A working memory composite was created by averaging the z-scores of both the symmetry and operation complex span tasks.

Operation Span (Unsworth et al., 2005). Subjects solved simple math problems (e.g., [3 * 4] +2 = ?) and verified if a presented answer was true or false. After the math problem, the computer presented a letter for one second to the subject, out of twelve possible letters, to be remembered. Each sequence had a random length of between 3 and 7 problem-letter pairs. One trial of each set size (i.e. 3-7) was presented, for a total of five trials. During the recall phase, subjects were presented with the 12 possible letters with boxes next to each of them. Subjects were instructed to click on the boxes with a computer mouse next to the letters they saw in a trial in the order that the letters were presented in. Scores on this task were computed by summing the total number of letters remembered in the correct serial order (Conway et al., 2005). There was a maximum score of 25 for this task and Cronbach's α for one block of this task has been reported as .69 (Foster et al., 2015). This task took approximately 15 minutes to complete.

Symmetry Span (Kane et al., 2004). Subjects indicated if a picture was vertically symmetrical and memorized the position and sequence of colored squares on a 4 x 4 grid. One cell filled in the 4 x 4 matrix would appear on the screen for 650ms. Each sequence had a random length between two and five trials. There was one of each set size (five total trials). During the recall phase, subjects clicked on cells in an empty matrix to show the location and sequence of the red squares they saw on the previous screens. There was a maximum score of 14 for this task. Cronbach's α for one block of this task has been reported as .61 (Foster et al., 2015). This task took approximately 10 minutes to complete.

Sustained Attention to Response Task (SART) (Kane et al., 2016)

Subjects completed a Sustained Attention to Response Task (SART). This was a no/no-go task in which subjects pressed the space bar every time they saw a member from the non-target category and withheld response when they saw words from the target category. Subjects first practiced trials where they pressed the space bar for boy's names and withheld response for girl's names. The SART task was divided into four blocks, each of which had three miniblocks of 45 trials accumulating to a total of 540 total trials. During each miniblock, subjects were presented with five target stimuli (vegetable names) and 45 nontarget stimuli (animal names). Each word was presented on-screen for 300ms and then was immediately covered by a string of "X"'s for 1500ms. This task took approximately 20 minutes to complete. The dependent variable for this part of the task was *d'* (i.e., hit rate to animals minus false alarm rate to vegetables) and the *SD* of response times to "go" (animal) trials.

Within the SART, subjects were presented with thought probes. There were nine probes per block for a total of 36 probes. The probes asked subjects to evaluate their thoughts with the prompt, "What were you just thinking about?" and to press a number that best matched their thoughts. Response options included: "1: On task," "2: Task/Task performance," "3: Distraction," "4: Mind wandering," and "5: Mind blanking." Subjects were briefed on what each of these responses meant after finishing the practice trials at the beginning of the task. We summed how many times each thought response was indicated and created proportions (the denominator was the total number of thought probes presented). Following Van den Driessche et al. (2017), we created composites of thought responses conjectured to require executive resources (mind wandering and on-task thinking) and thought responses conjectured to not depend on executive resources (task-related interference and distraction).

ADHD Symptoms

Subjects completed a self-report questionnaire from the ADHD IV-Self-Report Version (Dupaul et al., 1998). Subjects answered 18 questions about ADHD symptoms within the past six months. Response options for all the questions were: never or rarely, sometimes, often, and very often. Nine items in the questionnaire assessed the inattention symptoms and nine items assessed hyperactive-impulsive symptoms. Scores were summed for these subtypes and for an overall score (never or rarely = 0; sometimes = 1; often = 2; very often = 3). The maximum score for the total was 54, and the maximum for each subtype was 27. This task took approximately 5 minutes to complete.

Procedure

Subjects started the session by reading and signing an informed consent form. Following Van den Driessche et al. (2017), the session's first two tasks were the SART and the ADHD questionnaire (and these were counterbalanced as in Van den Driessche et al.). Following these first two tasks, subjects completed the operation and the symmetry span task (all subjects completed these tasks in the same order). Finally, subjects completed a demographics questionnaire. These testing sessions took up to 1 hour to complete. At the end of the session, subjects read a debrief form and were given an opportunity to ask questions of the experimenter.

Data Analysis

Any analyses performed in this manuscript that are not included in the preregistration were made in response to the data and should be judged as such. We performed analyses in the R system for statistical analysis (R Core Team, 2019). Data, analysis code, and outputs are available at the following link: https://osf.io/z3awm/.

Data Loss

We made all data exclusions per the preregistration. We excluded from analyses eight subjects who did not meet the SART response time *SD* inclusion criterion, and two subjects who were deemed by experimenters as noncompliant with instructions across tasks. These decisions were made without consulting the subjects' data. Because of computer or experimenter error, we are missing data from two subjects in the symmetry span, and one subject on the ADHD-IV. Thus, we included data from 292 subjects from the SART and operation span tasks, data from 291 subjects for the ADHD-IV, and 290 subjects from the symmetry span. Descriptive statistics for all dependent variables can be seen in Table 1. Intercorrelations for measures can be seen in Table 2.

Results

Table. 1 Descriptive Statistics

Measure	Mean	SD	Min	Max	Skew	Kurtosis	N
SART Response Time SD (ms)	179	73	69	450	1.43	2.19	292
SART d'	1.55	1.12	-0.46	4.51	0.19	-0.85	292
On-task Report Proportion	0.30	0.20	0	0.97	0.69	0.07	292
Task-related Interference Report Proportion	0.30	0.19	0.00	0.92	0.63	-0.09	292
Distraction Report Proportion	0.10	0.10	0.00	0.86	2.80	15.2	292
Mind Wandering Report Proportion	0.19	0.13	0.00	0.69	0.61	0.06	292
Mind Blanking Report Proportion	0.11	0.13	0.00	0.69	1.85	4.07	292
Operation Complex Span (raw score)	15.43	5.73	2	25	-0.18	-0.84	292
Symmetry Complex Span (raw score)	8.62	3.03	1	14	-0.12	-0.71	290
Working Memory Capacity (z score)	0.00	0.82	-1.84	1.72	-0.09	-0.49	290
ADHD Total (raw score)	15.61	7.62	1	50	0.90	1.41	291
ADHD Hyperactivity (raw score)	7.73	3.96	0	24	0.86	0.93	291
ADHD Inattentive (raw score)	7.89	4.69	0	26	0.90	0.89	291

Note. ADHD = Attention-Deficit/Hyperactivity Disorder

Table 2. Correlations Among Measures (With Reliability Point-estimates for Appropriate Measures on the Diagonal)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. SART Response Time SD	.95												
2. SART d'	-0.35	.95											
3. On-task Report Proportion	-0.20	0.45	-										
4. Task-related Interference Report Proportion	-0.16	-0.16	-0.42	-									
5. Distraction Report Proportion	0.14	-0.06	-0.16	-0.28	-								
6. Mind Wandering Report Proportion	0.14	-0.07	-0.42	-0.31	-0.01	-							
7. Mind Blanking Report Proportion	0.30	-0.33	-0.38	-0.29	-0.09	0.09	-						
8. Operation Complex Span	-0.02	0.10	-0.01	0.11	-0.12	-0.06	0.00	.66					
9. Symmetry Complex Span	-0.09	0.18	0.05	-0.03	-0.09	0.09	-0.06	0.33	.52				
10. Working Memory Capacity	-0.06	0.17	0.03	0.05	-0.13	0.02	-0.04	0.81	0.81	-			
11. ADHD Total	0.13	-0.15	-0.15	-0.09	0.08	0.11	0.19	0.01	0.04	0.03	-		
12. ADHD Hyperactivity	0.09	-0.11	-0.08	-0.12	0.13	0.07	0.12	0.00	0.01	0.01	0.86	.72	
13. ADHD Inattentive	0.13	-0.15	-0.18	-0.04	0.01	0.11	0.21	0.01	0.06	0.04	0.90	0.55	.84

Note. ADHD = Attention-Deficit/Hyperactivity Disorder

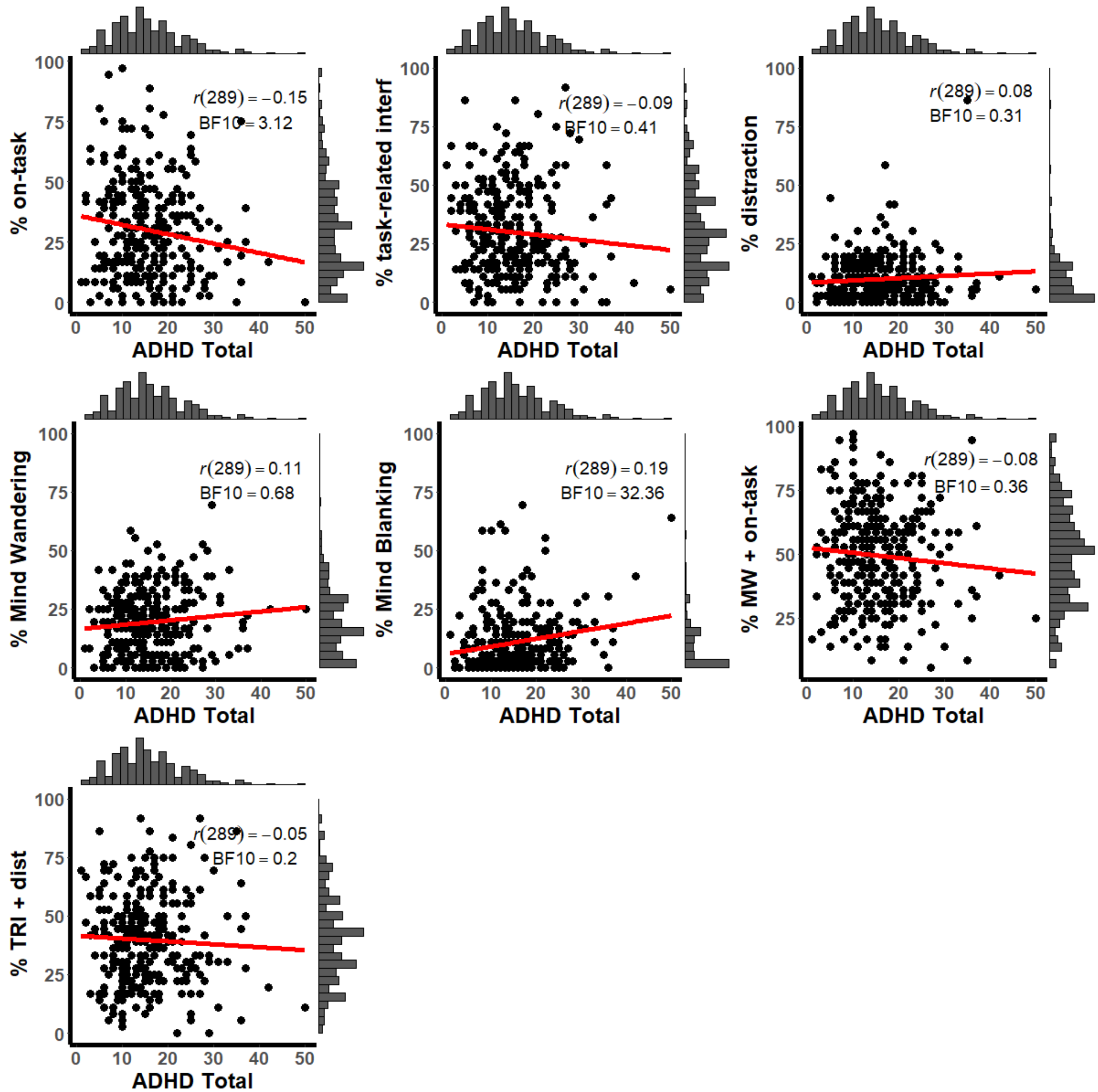

Figure 1. Scatterplots (with best-fitting regression lines in red) show the associations between the ADHD total score and each thought report's percentages. Histograms for each variable are presented across from each axis. Note. ADHD = Attention-Deficit/Hyperactivity Disorder; BF10 = Bayes Factor with numbers less than one favoring the null hypothesis and numbers greater than one favoring the alternative hypothesis; interf = interference; MW = mind wandering; TRI = task-related interference; dist = distraction.

Associations between ADHD Symptomology and Thought Reports

For all correlations, in addition to examining them with a frequentist interpretation, we also examined them using Bayes Factors (BF) using the BayesFactor package (Morey & Rouder, 2018). The BF indicates if the correlations are more likely from a point-null distribution (the null hypothesis) or if it came from a Cauchy distribution where 50% of the distribution lies between -.33 and .33 (alternative hypothesis). Here, numbers greater than one support the alternative hypothesis, and numbers less than one support the null hypothesis that the correlation is more likely from the point-null distribution ($r = 0$).

Our first goal was to replicate the associations between ADHD symptomology and thought reports provided by Van den Driessche et al. (2017; focusing on their Experiment 2 with young adults). For on-task thought, Van den Driessche et al. reported that ADHD subjects reported a non-statistically significant reduction in on-task thought compared to non-ADHD subjects. Here, we detected a statistically significant negative association between ADHD symptoms and on-task thought, $r(289) = -.15$, $p = .01$, *95%* confidence interval (*CI*) [-.26, -.03], $BF_{10} = 3.12$. Consistent with Van den Driessche et al., we found no statistically significant associations with ADHD and task-related interference, $r(289) = -.09$, $p = .14$, *CI* [-.20, .03], $BF_{10} = .41$, or distraction, $r(289) = .08$, $p = .19$, *CI* [-.04, .19], $BF_{10} = .31$. Regarding mind wandering, Van den Driessche et al. reported a non-significant difference with the higher ADHD symptomology group reporting less mind wandering than their group with less ADHD symptom reports. Here, we found a non-statistically significant association in the opposite direction, $r(289) = .11$, $p = .07$, *CI* [-.01, .22], $BF_{10} = .68$. Critically, the pattern of association between mind blanking and ADHD symptomology found here was consistent with results from Van den Driessche et al. with a statistically significant positive association between ADHD symptomology and mind blanking detected, *r*(289) = .19, *p* < .001, *CI* [.08, .30], BF_{10} = 32.36. As can be seen in Figure 1, in the scatterplot for the mind blanking and ADHD association there is an outlying data point in the upper right of the graph. When we removed that subject the association remained statistically significant, *r*(288) = .14, *p* = .02, *CI* [.02, .25], BF_{10} = 2.17, but the relative evidence for the alternative over the null hypothesis is substantially weaker.

Following Van den Driessche et al. (2017), we created composites of thought types suggested to be reliant on executive functions (i.e., mind wandering and on-task) and those that are not (i.e., task-related interference and distraction). Inconsistent with a key result from Van den Driessche et al., we did not find a statistically significant negative association between ADHD and speculated-executive-function-reliant thoughts, *r*(289) = -.08, *p* = .16, *CI* [-.20, .03], BF_{10} =.36, with the null hypothesis favored by almost a factor of 3. Consistent with Van den Driessche et al., we found no evidence for an association between ADHD and speculated non-executive-functioning-reliant thoughts, *r*(289) = -.05, *p* = .40, *CI* [-.16, .07], BF_{10} = .19.

Associations between Working Memory Capacity and Thought Reports

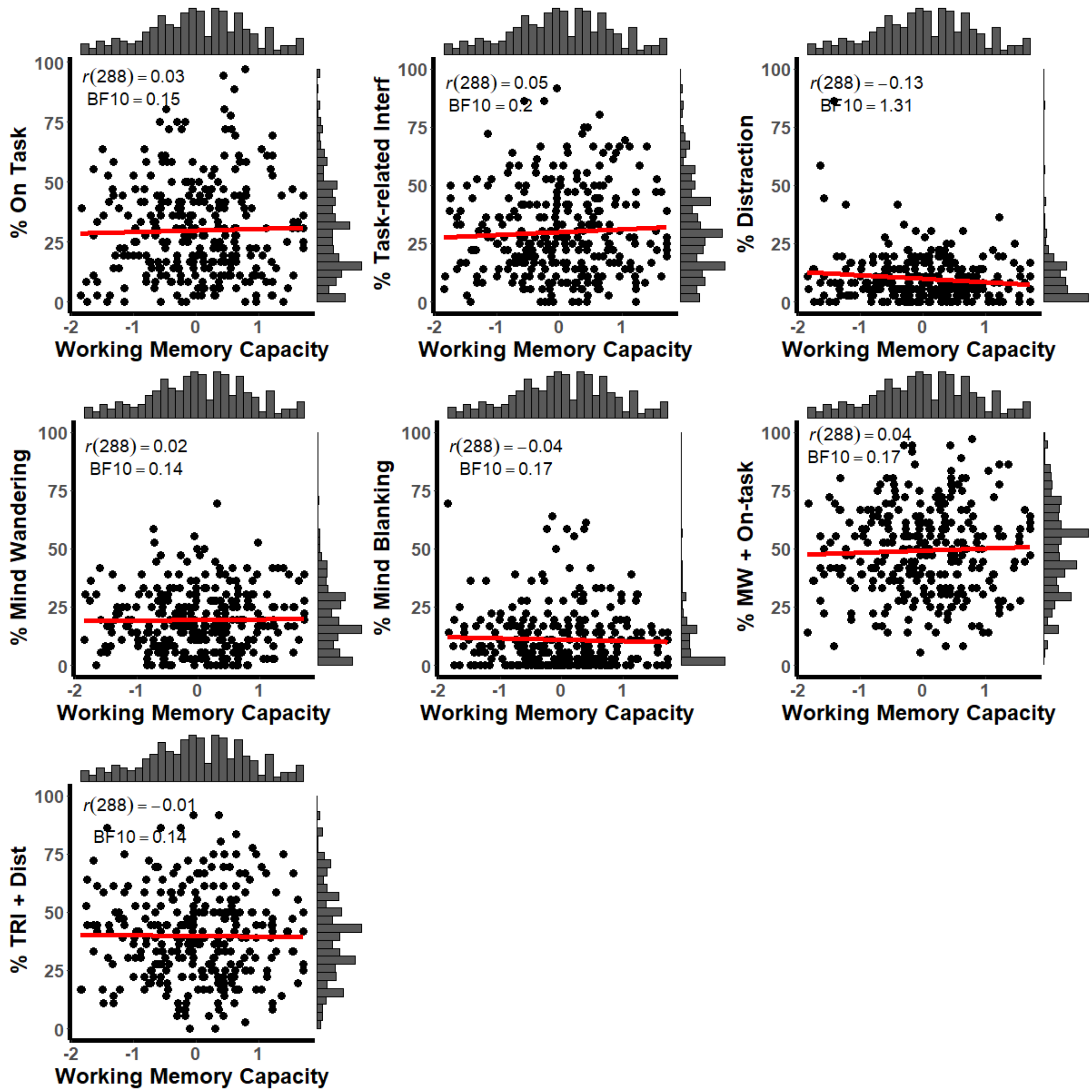

Figure 2. Scatterplots (with best-fitting regression lines in red) show the associations between the working memory capacity and each thought report's percentages. Histograms for each variable are presented across from each axis. Note. BF10 = Bayes Factor with numbers less than one favoring the null hypothesis and numbers greater than one favoring the alternative hypothesis; Interf = interference; MW = mind wandering; TRI = task-related interference; Dist = distraction.

Working memory capacity was only statistically significantly related to the proportion of distracted thought reports, *r*(288) = -.13, *p* = .03, *CI* [-.24, -.01], BF_{10} =1.31. Visual inspection of the corresponding scatter plot revealed an outlying data point in the upper left corner of the graph. When we removed that outlying subject, the estimate of association was no longer statistically significant, *r*(287) = -.09, *p* = .13, *CI* [-.20, .03], BF_{10} = .42. Most importantly, working memory capacity was not associated with mind wandering, *r*(288) = .02, *p* = .79, *CI* [-.10, .13], BF_{10} = .14, or the composite of on-task thought and mind wandering, *r*(288) = .04, *p* = .51, *CI* [-.08, .15], BF_{10} = .17, with both the BFs favoring the null hypothesis by factors of 7 and 6 respectively. As can be seen in Figure 2, working memory capacity was not associated with on-task thought, *r*(288) = .03, *p* = .65, *CI* [-.09, .14], BF_{10} = .15, task-related interference, *r*(288) = .05, *p* = .38, *CI* [-.06, .17], BF_{10} =.20, mind blanking, *r*(288) = -.04, *p* = .38, *CI* [-.15, .08], BF_{10} = .17, or the composite formed from task-related interference and distraction, *r*(288) = -.01, *p* = .84, *CI* [-.13, .10], BF_{10} = .14.

Model with Both Working Memory Capacity and ADHD Symptomology

We created linear models[1] predicting each thought report's proportion and the two thought report composites to test an alternate model where working memory capacity, ADHD symptomology, and their interaction could predict unique variance in thought reports. Table 3 contains the parameter estimates for these seven models. As can be seen in Table 3, only two of the 21 parameter estimates were statistically significant. Consistent with the zero-order correlations, ADHD symptomology was negatively associated with on-task reports, *b* = -.39, *SE* = .15, *t* = -2.53, *p* =.01, and positively associated with mind blanking reports, *b* = .33, *SE* = .10, *t* = 3.40, *p* < .001. Working memory capacity and the working memory capacity by ADHD interaction did not predict unique variance in any outcome measures.

Table 3. Linear Model Parameter Estimates

DV	Predictor	*B*	t value	*p*
On-task	WMC	2.69	0.80	.43
	ADHD Total	-0.39	-2.53	.01
	WMC × ADHD Total	-0.13	-0.66	.51
Task-related Interference	WMC	-1.08	-0.34	.74
	ADHD Total	-0.22	-1.48	.14
	WMC × ADHD Total	0.15	0.82	.41
Distraction	WMC	0.41	0.25	.80
	ADHD Total	0.10	1.30	.19
	WMC × ADHD Total	-0.12	-1.30	.19
Mind Wandering	WMC	0.86	0.38	.70
	ADHD Total	0.18	1.75	.08
	WMC × ADHD Total	-0.04	-0.34	.74
Mind Blanking	WMC	-2.72	-1.27	.21
	ADHD Total	0.33	3.40	< .001
	WMC × ADHD Total	0.13	1.08	.28
MW + On-task	WMC	3.55	1.12	.27
	ADHD Total	-0.21	-1.44	.15
	WMC × ADHD Total	-0.17	-0.94	.35
TRI + Distraction	WMC	-0.68	-0.21	.83
	ADHD Total	-0.12	-0.83	.41
	WMC × ADHD Total	0.03	0.17	.87

Note. WMC = working memory capacity; ADHD = attention deficit hyperactivity disorder; MW = mind wandering; TRI = task-related interference.

Mind Wandering Versus Mind Blanking Reports and Task Performance

We conducted linear mixed models predicting SART accuracy and response time *SD* (separately) to test for differential associations between task performance and mind wandering and mind blanking reports. These models used both random intercepts and slopes. In these analyses, we only included probe responses of mind wandering and mind blanking. In the model predicting response time *SD*, we included all mind wandering or mind blanking probe responses preceded by four consecutive nontarget trials where a response time was recorded. The response time *SD* in these models is the *SD* of these four trials. The model predicting accuracy (also restricted to trials where a mind wandering or mind blanking response was given) was a generalized linear mixed model to account for the dichotomous outcome variable (i.e., accurate or not). In both of these models, mind wandering was the reference level that mind blanking was tested against.

In the model predicting response time *SD* (N = 268; this smaller n is the result of the filtering conditions described in the previous paragraph), the estimate for mind blanking did not significantly differ from mind wandering, b = 4.9, SE = 5.8, t = .85, p =.40. In the model predicting accuracy (N = 278), mind blanking also did not differ from mind wandering in predicting the outcome, b = -0.02, SE = .11, z = -.19, p =.85.

At the request of an anonymous reviewer, we ran these same models but also included trials with on-task reports (as the reference level) to demonstrate that both mind wandering and mind blanking relate to performance in ways anticipated relative to on-task reports. In the model predicting response time *SD* (N = 292), we had to simplify the random effects structure and use random intercepts only because when using both random slopes and intercepts, the model failed to converge suggesting that the data were overfit. Parameter estimates for both mind wandering and mind blanking indicated that, as expected, these reports were associated with greater response time *SD* than on-task reports, $b = 7.8$, $SE = 3.3$, $t = 2.36$, $p = .02$, $b = 12.4$, $SE = 4.3$, $t = 2.87$, $p = .004$, respectively. The model predicting accuracy ($N = 292$) also met expectations with mind wandering, $b = -1.86$, $SE = .11$, $z = -16.35$, $p < .001$, and mind blanking, $b = -1.85$, $SE = .13$, $z = -13.76$, $p < .001$, both associated with lower accuracy than on-task thought reports.

Discussion

Van den Driessche et al.'s (2017) findings of positive associations between ADHD symptomology and mind blanking propensity and their speculation about the effects of ADHD medication on thought reports were the primary motivating factors for this study. The data from our study corroborated the positive association between ADHD symptomology and mind blanking reported by Van den Driessche et al. However, we did not find the negative association between ADHD symptomology and the composite of mind wandering and on-task thought (reports speculated by Van de Driessche et al. to rely on executive functioning). Van den Driessche et al. used this negative association as partial support for the claim of executive functioning being a common cause of on-task thought and mind wandering.

The data did not support van den Driessche et al.'s supposition that medication enabled better executive functioning, thus reducing mind blanking and increasing mind wandering reports. More specifically, we found no evidence consistent with the claim that executive functions support mind wandering. In addition to the lack of a statistically significant negative association between ADHD and the presumed executive functioning reliant composite, estimates of associations between working memory capacity scores (our measure of executive functioning), mind wandering, and this same executive functioning reliant composite were nonsignificant. BFs for these correlations indicated the data were more consistent with a null hypothesis of no association rather than the alternative hypothesis of a moderate-to-small association by factors of seven and six, respectively.

As a secondary goal of the study, we assessed the relative impact of mind wandering versus mind blanking on task performance. This goal was motivated by the methodological shortcomings of previous attempts addressing this question (Unsworth & Robison, 2016, 2018; Ward & Wegner, 2013). Here, consistent with the majority of previous reports (Van den Driessche et al., 2017; Unsworth & Robison, 2018; Ward & Wegner, 2013), we found that mind wandering was reported more than mind blanking and that in the SART task, there were no statistically significant dissociations between these reports and SART response time *SD* and SART target accuracy. That is, in this study with our preregistered performance criteria, we detected no functional difference in task performance between when someone reported mind wandering and mind blanking. This finding is consistent with Ward and Wegner's reports of no differences in reading comprehension when the task's pace is not under the subjects' control (as the SART task was here) and Robison and Unsworth's 2016 results (but inconsistent with Robison and Unsworth's 2018 results).

The corroboration of the ADHD-mind blanking association augments confidence in Van den Driessche et al.'s (2017) report that young adults with more ADHD symptomology are more likely to report mind blanking than those with less ADHD symptomology. But because we detected no relation between a measure of executive functioning and thought reports or between executive functioning and ADHD symptomology, the assertion that the ADHD-mind blanking association is due to executive functioning deficits in those with more ADHD symptomology is called into question. Given prior work suggesting metacognitive deficits in ADHD (Franklin et al., 2017; Vatansever et al., 2019) and the inability to report mental contents reflected by a mind blanking response, it seems likely that a relatively executive-function (as classically conceived) independent meta-awareness may be responsible for the association. That is, a meta-awareness deficit (in young adults at least) may cause (some) ADHD symptoms and mind blanking.

Perhaps a more distal causal process such as a motivational deficit, as suggested by Van den Driessche et al. (2017) and consistent with Robison and Unsworth's (2018) work, is responsible for the ADHD-mind blanking association. This motivational deficit could result in impaired meta-awareness downstream in the cognitive system. Another explanation of the ADHD-mind blanking association (mentioned in Van den Driessche et al.) that we cannot rule out is that mind blanking reports are meta-cognitively accurate. That is, people with more ADHD symptomology accurately report blank states of mind, and this blank mind state could result from the motivational deficit.

Given the results of this study and their coherence with most past laboratory studies (e.g., Kane et al., 2016; McVay & Kane, 2012a; McVay & Kane, 2012b; Meier, 2019; Robison et al., 2017; Robison & Unsworth, 2017; Unsworth & McMillan, 2013, 2014), we contend that no substantial evidence has been produced in the lab supporting the claim that greater executive functioning is associated with more mind wandering at the aggregate level (the current results are also not in favor of a general negative association between mind wandering and executive functions, but contrary to the claim of a positive association between executive function and mind wandering, there are many published reports of a negative association lending credence to the claim). To be clear, we are making a constrained claim that focuses on laboratory work with young adults (from WEIRD societies; Henrich et al., 2010) and aggregated measures of mind wandering propensity and executive functioning (or more specifically working memory capacity). Consistent with the context regulation hypothesis (Smallwood & Andrews-Hanna, 2013), other laboratory work suggests that young adults with greater working memory capacity can more flexibly adjust their rates of off-task thought in response to task context than people with lower working memory capacity (Ju & Lein, 2018; Rummel & Boywitt, 2014; for work showing a similar pattern but with fluid intelligence rather than working memory capacity, see Turnbull et al., 2019). Outside the lab, Kane et al. (2007, 2017) have provided evidence that when young adults try less than usual to concentrate in daily life, higher-working-memory-capacity people mind wander more than people with lower working memory capacity. The claim made in this paper is, in the lab, there is no compelling evidence (regardless of subjects' age range) that working memory capacity supports mind wandering. Preserving these distinctions between claims and contexts in which they occur may ultimately prove crucial for our understanding of cognitive abilities and conscious experience.

Our working memory composite formed from two complex span tasks performed in ways consistent with past work providing confidence in our measurement. For example, as can be seen in Table 2, the measures composing the working memory composite correlated positively with one another (r = .33, p < .001, BF_{10} = 961,371), and the composite correlated positively with SART d` (r = .17, p = .004, BF_{10} = 8.5). We acknowledge that multiple measures that do not share method variance may better measure working memory capacity (or executive control). In particular, longer complex span tasks may better correlate with mind wandering measured in another task because longer tasks promote more mind wandering (e.g., McVay & Kane, 2012a; Teasdale et al., 1995). However, given our resources, the potential gains in measurement quality would have been diminished (or nullified) by the tradeoff of longer testing times and reduced sample size. Nonetheless, this study advanced the investigation of executive functions and mind blanking by using putative measures of executive function/control rather than relying on further removed ambiguous indicators such as self-reported medication consumption.

One potential explanation for the different inferences in Van den Driessche et al. (2017) and the current manuscript about the role of executive functions in conscious experience is Van den Driessche et al. Experiment 1 used children as subjects. Their Experiment 1 was the study with medicated and non-medicated ADHD groups that were the primary basis for executive functions/control claims. Here (and in Van den Driessche et al. Experiment 2), young adults were subjects. Recent evidence suggests that ADHD in children and adults are distinct syndromes (Agnew-Blais et al., 2016; Caye et al., 2016; Moffitt et al., 2015). Van den Driessche et al. made broad claims about the role of executive functions based on the results across their two studies where more constrained claims limited to the populations represented by their samples seem more appropriate.

Conclusion

ADHD symptomology is positively associated with mind blanking, but the causal link of this association is undetermined. We tested the claim that executive function underlies both on-task thought and mind wandering and found no evidence for it. Future work should test competing explanations in multiple contexts (using tasks that vary in attentional demands) to better understand the causes of the ADHD and mind blanking association (i.e., strong inference [Platt, 1964]) and make constrained claims. Additionally, we assessed if mind blanking and mind wandering had differential associations with indexes of task performance. Here, in an experimenter-paced task, they did not.

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Footnotes

1. This is a departure from the preregistration. In the preregistration, the plan for this analysis was to use linear mixed models. After further consideration of the data, using linear mixed models here does not make sense because subjects will each have only one row of data for these analyses, thus linear mixed models are unnecessary and would yield the same results as the simpler linear model.

Author Note

As noted in the preregistration, a subset of the analyses presented here was done on the for a thesis project by the first author of this paper. That thesis can be found here: https://thesiscommons.org/yrbjt. We appreciate the input of thesis committee members David de Jong and David Solomon. For assistance in data collection, we thank Allyson Jones, Rebecca Daniel, and Lauren Testerman.