

**Understanding the Associations Among Working Memory Capacity, Working Memory
Processes, and Symptoms of ADHD and Depression**

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Abstract

Working memory is a complex psychological construct. Using Edith Kaplan's Boston Process Approach (1988), the present study examines the extent to which working memory capacity (WMC) is associated with process-specific variables such as reaction time, accuracy on a distractor task, and task stimulus domain (tier 1). Additionally, while research documents significant associations between working memory and both depression and Attention-deficit/hyperactivity disorder (ADHD) symptoms, the underlying cognitive mechanisms are not completely understood. Therefore, the study examines the unique contribution of WMC to ADHD (tier 2) and depression (tier 3) symptom severity. Sixty-six college students completed symptom severity ratings and three working memory complex span tasks that were designed based on Engle's Executive Attention Model of Working Memory (Engle, et al., 1999). Results indicated that reaction time, distractor accuracy, and task stimulus domain contributed uniquely (i.e., accounted for a statically significant amount of variance) to WMC. WMC was not a significant predictor of ADHD symptomatology; however, there was a trending relation between WMC and depression symptomatology. Applied research implications including working memory assessment, potential psychotherapeutic intervention targets, and academic accommodation developments are discussed.

Keywords: Working Memory, Working Memory Processes, ADHD, Depression

Table of Contents

<i>Chapter One: Introduction</i>	1
<i>Chapter Two: Method</i>	13
Participants	13
Measures.....	13
Intellectual Functioning.....	13
Working Memory Processes.....	14
Clinical Symptoms	16
Procedure.....	18
<i>Chapter Three: Results</i>	19
Dependent Variables	19
Preliminary Results	20
Statistical Analyses.....	20
Tier I: Contributions of Working Memory Processing Variables to Working Memory Capacity.....	20
Tier II: Contributions of Working Memory Capacity to Attention-Deficit/Hyperactivity Disorder Symptoms	21
Tier III: Contributions of Working Memory Capacity to Depression Symptoms.....	22
<i>Chapter Four: Discussion</i>	23
<i>List of References</i>	31
<i>Appendices</i>	47
Appendix A: Figures	48
Appendix B: Tables.....	49
<i>Vita</i>	55

List of Tables

Table 1. Demographic Data.....	49
Table 2. Tier I Regression Analysis Summary: Reaction Time.....	50
Table 3. Tier I Regression Analysis Summary: Distractor Task Accuracy.....	51
Table 4. Tier I Regression Analysis Summary: Task Stimulus Domain.....	52
Table 5. Tier II Regression Analysis Summary: Contributions of WMC to Attention- Deficit/Hyperactivity Disorder Symptoms.....	53
Table 6. Tier III Regression Analysis Summary: Contributions of WMC to Depression Symptoms.....	54

Chapter One: Introduction

Mental disorders are a growing public health problem in the United States (American Psychiatric Association, 2013; Grant et al., 2005; Kessler et al., 2006; Kessler, Petukhova, Sampson, Zaslavsky, & Hans-Ullrich, 2012). According to the National Institute of Mental Health (2019), approximately 46 million adults are diagnosed with a mental health disorder every year in the United States based on the most recent census data (U.S. Census, 2011). Between 2007 and 2017, the percentage of young adults diagnosed with at least one mental disorder increased from 22% to 36% (Lipson, Lattie, & Eisenberg, 2019). To date, major depression and Attention-Deficit/Hyperactivity Disorder (ADHD) are two of the most commonly diagnosed mental disorders in the United States (American Psychiatric Association, 2013; Hoffman, Dudeks, & Wittchen, 2008; Kessler et al., 2006, 2012), with epidemiological studies documenting a 12-month prevalence rate of 4.4% for adult ADHD (Kessler et al., 2006) and a 12-month prevalence rate of 8.6% for major depression (Kessler et al., 2012). Collectively, mental disorders have a significant impact on public health with rising prevalence rates, particularly in young people, across the globe (Grant et al., 2005; Patel, Flisher, Hetrick, & McGorry, 2007).

Mental disorders are associated with significant individual and societal costs. For example, research suggests that depression and ADHD are associated with significant loss of workplace productivity, loss of wages, increased healthcare usage/cost, and increased comorbid medical disorders (Conti & Burton, 1994; Hoffman et al., 2008; Katon & Sullivan, 1990; Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007; Simon, 2003). Relatedly, treatment for depression is associated with an individual yearly medical cost of approximately \$3000 (\$4,428-

adjusted for inflation; Luber et al., 2000) and treatment for ADHD is associated with a \$5,651 yearly medical cost (\$7,283- adjusted for inflation; Matza, Paramore, & Prasad, 2005).

Understanding underlying cognitive mechanisms associated with anxiety and depression may inform the development of impairment-specific interventions (i.e., identification of promising treatment targets).

Mental Health and College Students

Research suggests that college students are significant consumers of mental health services (Breiter et al., 2015; Esienberg, Hunt, & Speer, 2012; Hunt & Esienberg, 2010). Epidemiological studies indicate that almost half of all college students meet criteria for a mental disorder in a given year (Auerbach et al., 2016; Eisenberg, Hunt, & Speer, 2012). Researchers attribute increasing prevalence rates among college students to changes in Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) criteria and an increase in help-seeking behaviors for mental disorders (American Psychiatric Association, 2013; Hunt & Eisenberg, 2010). Moreover, Beiter and colleagues (2015) report a 231% increase in yearly visits to a campus-based counseling center (Beiter et al., 2015). They noted the increase in help-seeking behaviors among college students is also attributed to improved early detection/screening efforts, decreased stigmatization, and greater education on mental health awareness (Eisenberg, Hunt, & Speer, 2012; Hunt & Eisenberg, 2010). Additionally, high school students are receiving academic accommodations for mental disorders at an increased rate and are more likely to enroll in post-secondary education (Wolf, 2006). The increased enrollment of college students with mental disorders has resulted in a greater need for psychological assessments, psychotherapy, academic accommodations, and psychoeducation (Chang &

D’Zurilla, 1996; Eisenberg et al., 2012; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999; Padron, 2006; Richards, Rosén, & Ramirez, 1999; Souma, Rickerson, & Burgstahler, 2002). Furthermore, research documents that the mean prevalence rate for ADHD is between 2 and 8% (DuPaul, Weyandt, O’Dell, & Varejao, 2009). The mean prevalence rate of depression symptomatology among college students is 30.6%, which is significantly higher than the general population (Ibrahim, Kelly, Adams, & Glazebrook, 2013).

Understanding the cognitive mechanisms that are etiologically responsible for ADHD and depression in a college sample is particularly important. Extant research purports that most mental disorders are associated with cognitive dysfunction (Millan et al., 2012). ADHD, for example, is related to attention problems and underlying impairments in working memory and processing speed (Millan et al., 2012; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Similarly, working memory deficits are related to symptoms of depression including difficulty regulating emotions and managing negative ruminative thoughts (Christopher & MacDonald, 2005; Joormann & Gotlib, 2008; Rose & Ebmeier, 2006). Understanding the underlying cognitive deficits associated with ADHD and depression may lead to improved academic accommodations for college students. To date, academic accommodations focus largely on short-term compensatory strategies to improve academic functioning (e.g., providing a note-taker or isolated testing space; Souma, Rickerson, & Burgstahler, 2002). As such, it is important for researchers to assess the specific cognitive correlates of depression and ADHD symptom severity to develop impairment-specific interventions.

Working Memory

Working memory is defined as a limited-capacity cognitive system that stores and manipulates visuospatial and verbal information (Baddeley, 2003, 2012; Haberlant, 1997; Miyake & Shah, 1999). Working memory, described as “the most significant achievement of human mental evolution,” is the capstone of higher-order cognitive abilities that enables planning and problem-solving (Goldman-Rakic, 1992). Understanding working memory is important because working memory is associated with intelligence (Fukuda, Vogel, & Mayr, 2010; Kane, Hambrick, & Conway, 2005; Unsworth, Fukuda, Awh, & Vogel, 2014; Wongupparaj, Kumari, & Morris, 2015), academic achievement (Gropper & Tannock, 2009), mental disorders (Alloway, 2010; Brewer et al., 2005; Glahn et al., 2006; Spitzer, 1993), sleep (Bohning et al., 2017; Bolden, Gilmore-Kern, & Fillauer, 2019), and social behaviors. (Kofler, et al., 2011; Schmader, 2002; Schmader & Johns, 2003).

While multiple models of working memory exist (Baddeley, 2012; Cowan, 1999; Engle, Kane, & Tuholski, 1999; Miyake & Shah, 1999), Baddeley’s Multi-Component Working Memory Model (Baddeley, 2003, 2012) and Cowan’s Embedded Process Model (Cowan, 1988) are used frequently in cognitive and empirical studies (Brewer et al., 2005; Glahn et al., 2006; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010; MacLeod & Donnellan, 1993; Otto et al., 2016; Rose & Ebmeier, 2006). More recently, however, Engle and colleagues (Engle, Kane, & Tuholski, 1999; Kane, Bleckley, Conway, & Engle, 2001) introduced the Executive Attention Model of Working Memory, a process-oriented working memory model to further elucidate working memory’s relation with additional separate but related cognitive abilities (e.g., general intelligence vs. fluid intelligence; Engle et al., 1999; Kane et al., 2001).

Baddeley's Multi-Component Working Memory Model includes the central executive (CE) and two domain-specific subsystems for storing and processing both verbal and visuospatial information (Baddeley, 2003, 2012; Miyake & Shah, 1999). The domain-general CE (i.e., the attention controller) interacts with the two subsidiary subsystems (i.e., the phonological short-term store and visuospatial sketchpad) and is responsible for focusing attention, shifting attention between two or more tasks, and networking with long-term memory stores (Baddeley, 2003, 2012). The CE is associated with everyday problem-solving abilities and abstract reasoning while the subsidiary systems are associated with domain-specific information management and manipulation (Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005; Gropper & Tannock, 2009).

Comparatively, Cowan's Embedded Process Model of Working Memory posits that working memory consists of organized cognitive processes that are hierarchical in nature (Cowan, 1999). The hierarchy includes three embedded cognitive processes: (1) long-term memory store; (2) activated memory; and (3) the focus of attention (i.e., the spotlight/awareness; Cowan, 1988). Cowan's model posits that the three embedded cognitive processes have unique limits, functions, and activation requirements (Cowan, 1988, 2005). According to Cowan (1988, 2005), working memory broadly refers to the interaction between the current focus of attention and an activated long-term memory. Items stored in long-term memory move in and out of the focus of attention depending on current needs (Cowan, 1988; Dehn, 2008; Miyake & Shah, 1999). For example, when completing a math problem, one must focus on the current problem and simultaneously pull information about math (e.g., number sense) stored in long-term memory. Working memory relies on the ability to consciously decide on the current focus of

attention (i.e., what is important in the moment) in order to activate long-term memory (Dehn, 2008). Additionally, items that are frequently the focus of attention move to the long-term memory store for later activation (Dehn, 2008). Both the Multi-Component Working Memory Model (Baddeley, 2003, 2012) and the Embedded Process Model (Cowan, 1988, 2005) include a hierarchical system (i.e., attentional controller and subsidiary systems). Cowan's model (1988, 2005), however, is domain general and emphasizes the focus of attention. Comparatively, Baddeley's model (2003, 2012) focuses on the central executive's (i.e., attentional controller) ability to manage the two modality-specific subsystems (i.e., phonological and visuospatial).

More recently, Engle and colleagues proposed the Executive Attention Model of Working Memory (Engle, et al., 1999; Kane, et al. 2001). The Executive Attention Model of Working Memory integrates parts of Baddeley's Multi-Component Working Memory Model and Cowan's Embedded Process Model of Working Memory (Dehn, 2008; Engle, et al., 1999), namely a central executive and the interaction between multiple memory systems (e.g., long and short term). However, the Executive Attention Model of Working Memory (1999, 2001) also emphasizes the central executive/attentional controller component's role in blocking interference. The model proposes that blocking interference is required for maintaining working memory (Dehn, 2008; Engle, et al., 1999; Kane, et al., 2001; Miyake & Shah, 1999). Engle and colleagues' model purports that interference is usually generated by previously learned information that is no longer relevant (Dehn, 2008; Engle, et al. 1999). They posit that working memory deficits reflect difficulty blocking interference and maintaining attention (Engle, et al., 1999). In addition, they propose strategies/procedures (i.e., codes) for maintaining working memory activation. They note that these codes can be verbal, visual, auditory, and motor (Engle,

et al., 1999; Kane et al., 2001; Miyake & Shah, 1999). Research suggests that the visuospatial working memory code is related to fluid intelligence (Engle, et al., 1999; Unsworth et al., 2014) and the verbal working memory code is predictive of academic attainment and reading skills (Alloway & Alloway, 2010).

Engle's Executive Attention Model of Working Memory (Engle, et al. 1999; Kane, et al. 2001) is rooted in Edith Kaplan's (1988) Boston Process Approach which emphasizes the importance of understanding basic cognitive processes that underlie higher-level cognitive abilities, like working memory. (Delis, Kaplan, & Kramer, 2001; Kaplan, 1988). These basic processes include processing speed, reaction time, and task-specific sensory information. (Delis, Kaplan, & Kramer, 2001; Kaplan, 1988) and must be considered when I attempt to interpret an overall score. Kaplan's research suggests that working memory deficits reflect process-specific errors. Kaplan's research highlights the importance of understanding how, when, and under what conditions working memory errors occur. This information is essential for developing targeted working memory interventions. Based on Kaplan's work researchers have started to examine the association between specific cognitive processes and working memory (Unsworth, Redick, Heitz, Broadway, & Engle, 2009). For example, researchers have examined the relation between reaction time (Bolden, Rapport, Raiker, Sarver, & Kofler, 2012; Meiran & Shahar, 2018; Schmiedek, Oberauer, Wilhelm, Süß, & Wittmann, 2007), response accuracy (Klink, Jeurissen, Theeuwes, Denys, & Roelfsema, 2017; Unsworth et al., 2009; Williams & Drew, 2018), and task stimulus modality/domain (i.e., visuospatial or phonological; Constantinidou, Danos, Nelson, & Baker, 2011; Fougne & Marois, 2011) and working memory. While multiple studies have examined the connection between specific cognitive processes and working memory, to my

knowledge no study to date has examined this relation in college students using Engle's Executive Attention Model.

Working Memory and Mental Disorders

Researchers have consistently documented a significant relation between working memory and mental disorders. For example, deficits in working memory are linked to ADHD (Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003; Valera, Faraone, Biederman, Poldrack, & Seidman, 2005; Willcutt et al., 2005), anxiety (Darke, 1988; Otto et al., 2016), depression (Joormann & Gotlib, 2008; Levens & Gotlib, 2010; Rose & Ebmeier, 2006), psychosis (Brewer et al., 2005; Wood et al., 2003), and bipolar disorder (Adler, Holland, Schmithorst, Tuchfarber, & Strakowski, 2004; Glahn et al., 2006). ADHD and depression have generally demonstrated the strongest association with working memory (Christopher & MacDonald, 2005; Kofler et al., 2010; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Rapport et al., 2008; Rose & Ebmeier, 2006). Research on mental disorders and working memory focus largely on the role of the storage and rehearsal components of working memory (Brewer et al., 2005; Glahn et al., 2006; Otto et al., 2016; Spitzer, 1993; Wood et al., 2003). However, the contribution of working memory capacity to mental disorder symptoms, primarily ADHD and depression symptoms requires further research. Working memory capacity is the sum total of the amount of information an individual can attend to, store, and manipulate within a given amount of time (Cowan, 2005; Wilhelm, Hildebrandt, and Oberauer, 2013). With this knowledge, researchers and clinicians alike can inform the development of impairment-specific interventions for psychopathologies most affected by working memory impairments.

Extant research documents an association between ADHD and working memory. A meta-analysis conducted by Alderson, Kaspar, Hudec, and Patros (2013) examined 38 studies and documented moderate effect sizes for both the phonological (Cohen's $d=.47$) and visuospatial (Cohen's $d=.50$) working memory domains for an ADHD group compared to a control group. Moreover, studies examining reading abilities and ADHD have consistently found a secondary deficit in working memory (Alloway & Alloway, 2010; Weyandt, Rice, Linterman, Mitzlaff, & Emert, 1998). Researchers have also demonstrated that individuals with ADHD often struggle with listening comprehension and have related verbal working memory dysfunction (McInnes et al., 2003). Working memory models posit that reading, listening, and comprehension abilities are associated with an individual's capability to store information in short-term memory and then use verbal and/or visuospatial skills to produce a desired response (Baddeley, 2003, 2012; Engle et al., 1999). To my knowledge, no study to date has attempted to isolate and examine the extent to which working memory capacity contributes to specific ADHD symptom domains (i.e., inattention, impulsivity, hyperactivity, and sluggish cognitive tempo).

Similarly, researchers document a bi-directional relation between working memory and depression. That is, research suggests that working memory affects depression and depression affects working memory (Christopher & MacDonald, 2005; Joormann & Gotlib, 2008; Rose & Ebmeier, 2006). For example, Joorman & Gotlib (2008) found that ruminating on irrelevant negative emotional material, which is often associated with depression, interferes with the ability to continuously update stored information. Working memory deficits are also associated with the inability to regulate emotions and affect (Levens & Gotlib, 2010). Moreover, individuals with depression and working memory deficits demonstrate a slower disengagement from negative

emotional material (Levens & Gotlib, 2010). Essentially, they hold on to negative feelings for a longer length of time. At least two meta-analytic reviews have investigated working memory and major depressive disorder (Lee, Hermens, Porter, & Redoblado-Hodge, 2012; Rock, Roiser, Riedel, & Blackwell, 2014). While Lee and colleagues (2012) found that working memory is not significantly different in depressed patients compared to healthy individuals (Hedges's $g = .16$), Rock, et. al. (2014) found significant working memory deficits (moderate effect sizes, Cohen's d ranging from -0.41 to $-.050$) in depressed patients compared to healthy controls. It is important to note that Rock and colleagues (2014) examined 24 studies that used the Cambridge Neuropsychological Test Automated Battery (CANTAB), which includes seven working memory measures. In contrast, Lee and colleagues (2012) examined 13 studies that only used simple span tasks. These methodological issues may be related to the discrepant findings. Collectively, additional research on the relation between working memory and depression is needed.

Methodological Concerns

Traditionally, working memory is assessed using simple span tasks (e.g., recalling digits and/or pictures; Dehn, 2008). Simple span tasks are administered quickly, are relatively inexpensive, and are easy to administer and score. However, simple span tasks are associated with a number of disadvantages. First, they target short-term storage of the domain-specific subsidiary systems (i.e. phonological loop and visuospatial sketchpad) based on Baddeley's Multi-Component working memory model (Baddeley, 2003, 2012). Simple span tasks are usually discontinued after two to three consecutive errors (Dehn, 2008). Simple span tasks do not account for individual differences in related processes (Dehn, 2008. Redick et al., 2012).

Moreover, simple span tasks do not consistently and reliably predict higher-level cognition such as reading, listening comprehension, visual construction skills, and/or working memory capacity as a reliable construct (Miyake & Shah, 1999; Perfetti & Lesgold, 1977; Redick et al., 2012).

Engle and colleagues have developed a method of evaluating working memory capacity using complex span tasks, which address some of the disadvantages associated with simple span tasks (Oswald, McAbee, Redick, & Hambrick, 2015; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Redick et al., 2012). The complex span tasks incorporate a distractor (i.e., interference) task to tax working memory capacity (Oswald, McAbee, Redick, & Hambrick, 2015; Redick et al., 2012). For example, the operation span task is used frequently to measure working memory capacity. In this task, participants are shown a set of mathematical operations (e.g., $6+3=9$) and asked to decide whether each equation is true or false. A letter or word is generally presented after each equation is shown on the computer screen, and the participants are instructed to recall the letters or words in order. (Dehn, 2008; Oswald, McAbee, Redick, & Hambrick, 2015). Complex span tasks allow researchers to examine multiple working memory processes (e.g., response accuracy, reaction time, and task domain/stimuli presentation; Oswald, McAbee, Redick, & Hambrick, 2015; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Redick et al., 2012). Conway and colleagues (2005) argue that complex span tasks are superior to simple span tasks when aiming to understand working memory capacity.

Study Aims

In the present study, I aimed to examine the unique contribution of working memory processes to working memory capacity in college students. Additionally, I examined whether working memory capacity predicts ADHD and depression symptomology. The study aims to

expand our knowledge of working memory by examining the unique contribution of specific working memory processes (i.e., reaction time, response accuracy, and task domain). Based on previous research, I hypothesize that reaction time (Meiran & Shahar, 2018; Schmiedek et al., 2007; Unsworth et al., 2009), distractor task response accuracy (Klink et al., 2017; Unsworth et al., 2009; Williams & Drew, 2018) and task stimulus domain (Constantinidou et al., 2011; Fougne & Marois, 2011) will be related to working memory capacity. In addition, the present study aims to expand our understanding of the relation between working memory capacity and both ADHD and depression symptomatology. Consistent with research connecting working memory deficits to ADHD (Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003; Valera, Faraone, Biederman, Poldrack, & Seidman, 2005; Willcutt et al., 2005) and depression (Joormann & Gotlib, 2008; Levens & Gotlib, 2010; Rose & Ebmeier, 2006), I hypothesize that impaired working memory capacity will be related to ADHD and depression symptomatology.

Chapter Two: Method

Participants

The present study used archival data (Fillauer et al., 2020) collected in the Behavior and Learning Lab at the University of Tennessee. Eighty-one participants (at least 18 years of age) were recruited with the university's Research Participant Recruitment System (SONA). Students participated in a 2.5-hour lab-based research appointment and received 2.5 research participation credits for their course grade. Individuals with a Full-Scale IQ-2 (FISQ-2) score of less than 85 on the WASI-II and individuals with gross sensory, neurological, serious motor impairment, a history of seizure disorder, or psychosis were excluded due to the task demands of the study. Participants were excluded if they were prescribed or using medication that might affect physiological data collection (e.g., antipsychotics, benzodiazepines, beta blockers). Participants who endorsed suicidal ideation over the past two weeks on the BDI-II were excluded in order to ensure participant safety and were provided with mental health resources.

Measures

Participants completed a questionnaire to assess basic demographic information including age, handedness, sex assigned at birth, gender identity, educational history, ethnic category, health (physical and psychological) history, and socioeconomic status.

Intellectual Functioning

Wechsler Abbreviated Scale of Intelligence (WASI-II). Given time constraints of the study and the comparable psychometric properties to the full Wechsler Adult Intelligence Scale, 4th edition (WAIS-IV), the WASI-II was used to estimate intellectual functioning. The WASI-II is an abbreviated intelligence battery consisting of subtests similar to those on the WAIS-IV. The

2-subtest format (vocabulary and matrix reasoning) was selected as it has good internal consistency ($\alpha = .94$) and is correlated with the WAIS-IV (McCrimmon & Smith, 2013). Higher Full-Scale IQ-2 (FSIQ-2) scores indicate greater intellectual functioning.

Working Memory Processes

Three abbreviated complex working memory span tasks were used in the present study.

Developed by Oswald and collaborators (2015) and based on Engle's Executive Attention Model, the following three tasks were used to assess working memory capacity and isolate specific working memory process variables:

Operation Span Task (Ospan). Ospan uses numerical stimuli to assess verbal working memory. Individuals were shown a set of mathematical operations (e.g., $4+4=2$) and asked to determine whether each equation is true or false (note: about half of the problems were true). A letter was presented after each equation was shown on the computer screen; participants were instructed to remember the letters in order. After the presentation of all operations within a set, participants were asked to recall the letters in order (Oswald, McAbee, Redick, & Hambrick, 2015). A longer version of this task has demonstrated good internal consistency ($\alpha = .80$; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004) and test-retest reliability ($r = .77-.83$; Redick et al., 2012). The version used in the current study also has demonstrated good internal consistency ($\alpha = .86$; Oswald et al., 2015). Individuals completed 3-7 sets across 3 blocks. This task generates working memory variables including working memory span in a verbal domain, time errors, response time, latency to first response, and accuracy errors.

Reading Span (Rspan). Rspan is a measure of verbal working memory. Participants were presented a set of sentences between 10-15 words long (e.g., "We were fifty lawns out at sea

before we lost sight of land”) and were asked to determine whether the sentence is semantically sensible (note: about half were sensible). Following each sentence, participants were shown a single letter, which they were asked to remember. After the presentation of all sentences within a set, participants were asked to recall the letters in order (Kane et al., 2004; Oswald et al., 2015). A longer version of this task has demonstrated good internal consistency ($\alpha = .78$; Engle, Tuholski, et al., 1999; Kane et al., 2004) and test-retest reliability ($r = .76-.82$; Redick et al., 2012). The version used in the current study also has demonstrated good internal consistency ($\alpha = .89$; Oswald et al., 2015). Participants completed three blocks of 3-7 sets. This task generates several working memory variables including working memory span in a verbal domain, time errors, response time, latency to first response, and accuracy errors.

Symmetry Span (Symspan). Symspan is a measure of visuospatial working memory. Participants were presented with a set of 8x8 matrices of black and white squares and asked to judge whether the matrices are symmetrical down a vertical axis (note: about half were symmetrical). After each matrix participants were shown a red square positioned in a 4x4 matrix for recall at the end of the set (Oswald et al., 2015). A longer version of this task has demonstrated good internal consistency ($\alpha = .86$; Engle, Tuholski, et al., 1999; Kane et al., 2004) and test-retest reliability ($r = .62-.77$; Redick et al., 2012). The version used in the current study also has demonstrated good internal consistency ($\alpha = .80$; Oswald et al., 2015). Participants completed three blocks of 2-5 sets of this task. This task generates several working memory variables including working memory span in a visuospatial domain, time errors, response time, latency to first response, and accuracy errors.

Working Memory Capacity Composite (WMC). A principal components factor analysis was conducted to measure the shared variance among the three Working Memory Capacity (WMC) tasks. Pioneered by Conway and colleagues (2005), this procedure creates a composite score by factoring the partial-span score on the three tasks. Conway and colleagues (2005) posit that the composite score represents the shared variance of the tasks and serves as a measure of “true working memory capacity” (Conway, et. al., 2005).

Working Memory Processes. Three working memory processes were examined in the present study: reaction time, accuracy, and task stimulus modality/domain. In the present study reaction time is defined as the average time taken (in milliseconds) to respond to a stimulus on the working memory tasks (i.e., Ospan, Rspan, and SymSpan). Accuracy is defined as the average percentage of correct responses for the distractor tasks. Finally, task modality is a measurement of correct responses (i.e., total score) an individual gives to different types of stimuli (i.e., numeric for Ospan, verbal for Rspan, and visuospatial for Symspan; Conway, et al., 2005). A latent variable statistical approach (i.e., identifying the shared variance; Conway, et. al., 2005) was used to isolate and examine reaction time and accuracy.

Clinical Symptoms

Barkley Adult ADHD Rating Scale-Fourth Edition: Current Symptoms (BAARS-IV: Current). The BAARS-IV assesses current ADHD symptoms and functioning. The scale uses a 4-point Likert scale that ranges from 1 (*Never or Rarely*) to 4 (*Very Often*). The BAARS-IV assesses five symptom domains of ADHD: inattention, hyperactivity, impulsivity, sluggish cognitive tempo, and frequency/onset of symptoms. Established Cronbach’s alpha is acceptable for all subscales: ADHD inattention = .902; ADHD hyperactivity = .776; ADHD impulsivity =

.807; ADHD total score = .914 (All F -tests significant at $p < .001$). The measure has satisfactory test-retest reliability: ADHD inattention = .66; ADHD hyperactivity = .72; ADHD impulsivity = .76; and ADHD total score = .75. Elevated BAARS-IV scores indicate greater inattention and hyperactive-impulsive problems (Barkley, 2011).

BAARS-IV Current Symptoms Interview (BAARS-IV: Interview). The BAARS-IV: Interview is a structured clinical interview that evaluates the following four elements: inattention, hyperactivity, impulsivity, and sluggish cognitive tempo. Individuals were instructed to answer questions by indicating that a symptom does not occur often, or the symptom occurs often. The BAARS-IV Current Symptom Interview is a companion to the BAARS-IV rating scale. Normative data is not available for the interview; however, there are high correlations between the interview scores and the current symptoms rating scale: Inattention = .87, Impulsivity/Hyperactivity = .85, and total number of symptoms = .89. Positive endorsements indicate greater impairments (Barkley, 2011).

Beck Depression Inventory-Second Edition (BDI-II). The BDI-II is a self-report assessment of depression symptoms over the past two weeks (Sundberg, 1987). The measure contains 21 items and uses a 4-point Likert scale. The BDI-II has strong internal consistency (i.e., Cronbach's alpha of .92; Beck, Steer, Ball, & Ranieri, 1996). The BDI-II has robust test-retest reliability with clinical samples of .96 (Sprinkle et al., 2002). Higher scores on the BDI-II indicate increased depression severity (Steer, Ball, & Ranieri, 1999). The BDI-II has the following two subscales: the cognitive-affective scale (items 1-13) and the somatic-performance (items 14-21; Smarr, 2003). The current study used a participant's total score as an approximation of current depression severity. The two proposed BDI-II subscales (somatic-

performance and cognitive-affective) were used to isolate and evaluate specific symptoms of depression.

Procedure

Individuals signed up for an available timeslot for the 2.5-hour research appointment on the university's SONA Research Participant Recruitment website. Participants were assessed individually. Once in the research lab, the research assistants reviewed the consent form which provided information on the purpose of the study, procedures, time involvement, benefits of participation, potential risks of participating, limits of confidentiality, and the right to cease participating in the study at any time without consequence or penalty. Participants were provided opportunities ask questions regarding the study. Individuals were asked to review and sign the consent form. Participants then completed the following questionnaires on a computer:

Demographics Questionnaire, BDI-II BAARS-IV: Current Rating Scale. Participants were then administered the WASI-II Two-Subtest Form and BAARS-IV: Interview (i.e., Vocabulary and Matrix Reasoning subtests). Next, all participants completed the following three computerized tasks (using E-Prime 2 psychological research software) in counterbalanced order to evaluate their working memory capacity: Ospan, Rspan, and Symspan tasks. Individuals received a debriefing document at the end of the study. The document reviewed the intent and goals of the study, finally the research assistants answered questions about the study.

Chapter Three: Results

Dependent Variables

Principal components factor analyses were used to compute a latent variable score that was used to assess working memory capacity, reaction time, and distractor task accuracy. The BAARS-IV: Current score was used to measure ADHD symptom severity. The total scores from the following four BAARS-IV: Current subscales were used to examine ADHD subtype symptom severity: inattention, hyperactivity, impulsivity, and sluggish cognitive tempo. The BDI-II total score were used as a measure of current depression severity. The total scores on the BDI-II subscales (i.e., cognitive-affective and somatic-performance) were used to examine total depression subtype symptom severity.

Participant Exclusion

Fourteen of the eighty-one participants recruited for the study met exclusion criteria. Two participants were excluded for having FSIQ-2 scores below 85 on the WASI-II. Two participants were excluded after indicating they were taking medications that could interfere with task demands (i.e., beta blockers and benzodiazepines). Nine participants were excluded for reporting past suicidal ideations on the BDI-II and were provided with a list of mental health services. Finally, a technological difficulty during the administration of the Rspan task (i.e., computer program ended mid-administration) resulted in the exclusion of one participant. Refer to Figure 1 (in appendix A) for a visual schematic of the participant exclusion process.

Preliminary Results

Power Analysis. An 80% *a priori* power analysis was conducted using a medium effect size as suggested by Kazdin (2015) and indicated that 64 participants would be necessary to detect an effect when using a linear regression. This sample contains 66 participants.

Distribution Analysis. When examining data for outliers, one participant was detected as an outlier due to age and excluded; this did not significantly affect results. Skewness and kurtosis analysis indicated elevated kurtosis for age (Skewness=1.89, Kurtosis=4.035; Kim, 2013). There were no distributional concerns regarding other measures.

Demographic Analyses. Analyses conducted on the sample's demographic data indicated a mean age of 19.09. Participant ethnic identification was mixed with 80.3% Caucasian (n=53), 2.9% Hispanic (n=2), 13.6% African American (n=9), 2.9% Asian (n=1), and 1.4% Other/Multiracial (n=1). Sex identification of the sample was 33.3% male (n=22) and 66.7% female (n=44). The sample had a mean intellectual functioning score on the FSIQ-2 of 102.06 (SD=8.21). Demographic data are displayed in Table 1 (in appendix B).

Statistical Analyses

Tier I: Contributions of Working Memory Processing Variables to Working Memory Capacity

Reaction Time. A linear regression was conducted to examine the contribution of reaction time to working memory capacity. Results indicated that reaction time was significantly related to working memory capacity. The reaction time latent variable score accounted for 7.2% of the variance ($p < .05$) in the WMC latent variable score. Tier I: Reaction time data are presented in Table 2 (in appendix B).

Distractor Task Accuracy. A linear regression was conducted to examine the contribution of distractor task accuracy (i.e., math problems, sentence sensibility, symmetry evaluation) to working memory capacity. Results suggested that accuracy was significantly related to WMC. The accuracy score accounted for 26% of the variance ($p < .001$) in WMC. Data are presented in Table 3 (in appendix B).

Task Stimulus Domain. Finally, three linear regressions were conducted examining the relation of the total scores on the Rspan, Ospan, and Symspan tasks and the latent variable working memory capacity score to examine the relation between domain and WMC. Results suggest that Ospan significantly predicted WMC and accounted for approximately 26% of the variance in WMC ($p < .001$). Rspan also significantly predicted WMC and accounted for approximately 38% of the variance in WMC ($p < .001$). Finally, Symspan also significantly predicted WMC and accounted for approximately 61% of the variance in WMC ($p < .001$). Data are presented in Table 4 (in appendix B).

Tier II: Contributions of Working Memory Capacity to Attention-Deficit/Hyperactivity Disorder Symptoms

A linear regression was conducted to evaluate the unique contribution of working memory capacity to ADHD symptoms (i.e., total score on the BAARS-IV: Current). Results indicated that WMC was not significantly related to ADHD symptomology ($p = .81$). Subsequently, four linear regressions were conducted as exploratory analyses to evaluate the unique contribution of working memory capacity (i.e., latent variable score from the factoring of the Ospan, Rspan, and SymSpan tasks) to ADHD subtypes (i.e., inattention, hyperactivity, impulsivity, and sluggish cognitive tempo). WMC was not significantly related to ADHD

subtypes (inattention: $p=.837$; hyperactivity: $p=.221$; impulsivity: $p=.554$; sluggish cognitive tempo: $p=.821$). Data are presented in Table 5 (in appendix B).

Tier III: Contributions of Working Memory Capacity to Depression Symptoms

A linear regression was conducted to evaluate the unique contribution of working memory capacity to depression symptoms. While results indicated that WMC was not significantly related to the the BDI-II ($p=.063$), a trend was documented. Subsequently, two exploratory linear regressions were conducted to evaluate the unique contribution of working memory capacity to the BDI-II subtypes (i.e., the cognitive-affective and somatic-performance subscales). Results indicated that WMC was not significantly related to the cognitive-affective subscale ($p=.083$) or the somatic-performance subscale score ($p=.073$). Data are presented in Table 6 (in appendix B).

Chapter Four: Discussion

Working memory is a higher-order cognitive construct that is associated with mental disorders (Alloway, 2010; Barkley, 1997; Brewer et al., 2005; Glahn et al., 2006; Lee, Hermens, Porter, & Redoblado-Hodge, 2012; Rock, Roiser, Riedel, & Blackwell, 2014; Spitzer, 1993), intelligence (Awh, Vogel, & Oh, 2006; Fukuda, Vogel, & Mayr, 2010; M. J. Kane et al., 2005; Unsworth, Fukuda, Awh, & Vogel, 2014), social behaviors (Kofler et al., 2011; Schmader, 2002; Schmader & Johns, 2003), and academic achievement (Gropper & Tannock, 2009). Based on seminal research conducted by Edith Kaplan (1988), the present study sought to enhance our understanding of WMC by examining the unique contributions of specific working memory processes (i.e., reaction time, accuracy, and task domain) to WMC in college students. Moreover, given the significant association between WMC and clinical symptomatology (Alloway, 2010; Barkley, 1997; Brewer et al., 2005; Glahn et al., 2006; Lee et al., 2012; Rock et al., 2014), the study examined the relation between WMC and both ADHD and depression symptom severity. Implications of this work include identifying evidence-based academic accommodations interventions to support college students with impaired WMC. Moreover, I am interested in enhancing evidence-based interventions for individuals with impairing ADHD and depression symptoms by identifying potential treatment targets. To my understanding, this is the first study to examine the relation between specific working memory processes and WMC using Oswald et al.'s (2015) abbreviated complex span tasks.

A regression framework was used to examine the relation between WMC and reaction time. Consistent with my hypothesis, I found that reaction time contributes uniquely to WMC and accounts for approximately 7% of the variance. Specifically, my finding suggests that slower

processing speed is associated with lower WMC. This finding is consistent with Baddeley's Multi-Component Model of Working Memory which posits that reaction time is related to how quickly individuals can rehearse verbal and/or visual information (Baddeley, 2003).

Additionally, Baddeley's Multi-Component Model of Working Memory theorizes that information stored in the short-term store fades quickly (i.e., after 2-3 seconds) if it is not rehearsed/refreshed (Baddeley, 2003). Whereas, Engle's Executive Attention Model posits that reaction time reflects how quickly individuals can process/manage interference. Moreover, based on Engle's Executive Attention Model, slower processing/reaction time is associated with difficulty blocking interference while maintaining attention (Engle, et al., 1999).

The finding that reaction time contributes to WMC is related to at least two theoretical models of working memory (Baddeley, 2003; Engle, 1999) and is consistent with extant research (Merian & Shahr, 2018; Unsworth et. al, 2009, and Schmiedek et al., 2007) studies. This finding is not consistent, however, with several empirical studies examining the relation between reaction time and working memory (Rapport et al., 2008; Valera, Faraone, Biederman, Poldrack, & Seidman, 2005). Rapport and colleagues (2008), for example, did not document a relation between reaction time and a working memory functioning when reading speed was used to control for reaction/processing time in a pediatric clinical sample. Additionally, Valera and colleagues (2008) did not find a significant relation between reaction time and performance on working memory span task in a clinical sample. While my findings highlight the importance of isolating and examining task-specific reaction time, future research should examine the unique contribution of reaction time to WMC in a clinical sample. Additionally, it would be beneficial to examine the utility of controlling for reaction time in widely used measures of working

memory functioning (e.g., the Working Memory Index on the WAIS-IV). This would allow us to examine whether slowed reaction time is related to impaired working memory functioning. as reaction time could be considered an important process score to improve our understanding of individual differences in working memory functioning. This understanding may inform our approach to assisting individuals with working memory impairments in the classroom and in an applied clinical context. For example, my finding suggests that individuals with slower processing abilities may experience difficulty in situations requiring complex information processing. Finally, future research should investigate whether training/improving processing abilities is related to improved WMC.

Based on the emphasis placed on interference blocking in the Executive Attention Working Memory Model (Engle, et al., 1999; Kane, et al. 2001; Miyake & Shah 1999), I examined the relation between accuracy on the distractor task and working memory capacity. The hypothesis that distractor task accuracy was related to WMC was supported. While the participants were instructed to not “focus on the letters presented” and not the distractor tasks (i.e., reading sentences, doing math problems, and evaluating symmetrical images), I found that participant accuracy to the distractor tasks (i.e., ratio of correct responses to incorrect responses) contributes to WMC and accounted for 26% of the variance. Specifically, the negative relation between accuracy on the distractor task and WMC suggests that lower WMC is associated with allocating attention and cognitive resources to the distractor task. This finding is consistent with both my hypothesis and previous researchers documenting that WMC is significantly related to response accuracy to a specific task (Unsworth et al., 2009; Williams & Drew, 2018). Specifically, Unsworth and colleagues (2009) found a potential mediating effect of accuracy and

Williams and Drew (2018) found that when distracted with novel stimuli, individuals failed to encode and recall information as well. Failure to recall stored information was not observed when individuals were presented with recurrent stimuli. My result indicates that focusing on the distractor task interferes with the ability to recruit working memory abilities. Future research should examine whether focusing on the distractor task impairs the encoding, storage, manipulation, and/or mechanism responsible for spoken/motor output. My result also supports work by Engle and colleagues (1999 & 2001) who posit that working memory requires the ability to block interfering information (i.e., distractors), as distractors impair our ability to maintain attention toward relevant information. Future applied research on the relation between working memory capacity and academic impairments should examine whether task interference is related to working memory-related academic impairments (e.g., ineffective studying, poor test taking skills, and/or in-class distractions).

To inform our understanding of the unique contribution of both visual and verbal information processing to working memory capacity, I examined whether the three complex span tasks (i.e., Rspan, Ospan, Symspan) contribute equally to WMC. While my three complex span tasks are related to WMC, I found that performance on the Symspan task accounted for most variance in WMC (accounting for approximately 61%). The hypothesis that task stimulus domain would be related to total WMC was supported. Interestingly, research suggests that the average score on the Symspan task is generally lower than the averages scores for both the Rspan and Ospan tasks (Oswald et al., 2015). Comparatively, the Rspan task is associated with higher average scores relative to both the Symspan and Ospan tasks (Oswald et. al., 2015). My results indicated that Rspan accounted for 38% of the variance. The Rspan task requires the

manipulation of letters while concurrently evaluating sentence semantics. My findings suggest that performance on the Ospan task is associated with approximately 21% of the variance in WMC. The Ospan task requires encoding, storage, and manipulation of letters while simultaneously evaluating math problems. It is important to note that the Ospan and Rspan tasks tap a different working memory subsidiary system than the Symspan task (Oswald et al., 2015). While performance on the Ospan and Rspan tasks require rapid encoding and storage of verbal information, performance on the Symspan task requires the manipulation of visual information while simultaneously evaluating symmetry in complex visual images. It should be noted that my results suggested that Ospan explained the least amount of WMC variance, which conflicts with Oswald and colleagues' (2015) results. Specifically, they found that the Rspan explained the least amount of variance. I believe there are hallmark differences between the participants in the present study and those included in the study conducted by Oswald and colleagues (2015), which may account for differences in amount of WMC variance explained by each task. Most notably, Oswald et. al. (2015) used community members in addition to college students in their large (N=4,885). My smaller sample (N=66) included college students only. Based on my finding, future research could examine if the Symspan task alone can provide important information about WMC (e.g., the effects of overwhelming the working memory system).

Based on previous research examining the connection between impaired working memory and ADHD I aimed to examine the influence of WMC to the level of ADHD symptomatology (Alderson, Kaspar, Hudec & Patros, 2013; Alloway & Alloway, 2010; McInnes et al., 2003; Weyandt, Rice, Linterman, Mitzlaff & Emert, 1998). Contrary to my hypothesis, I found that WMC did not uniquely contribute to ADHD symptom severity. It is important to note

at least two possible methodological concerns that are related to my finding. First, only 11.6% of participants reported having a diagnosed mental health concern. In contrast, Alderson and colleagues compared a sample of college students with ADHD to a clinical control sample (c.f., Alderson, Kaspar, Hudec & Patros, 2013). Another notable methodological concern is that the present study included a relatively high functioning sample based on my assessment of intellectual functioning. In contrast, Jarrett (2015) compared a community sample of individuals with and without ADHD. Additionally, I explored the relation between ADHD subtypes and WMC. Similarly, to the total BAARS-IV score, WMC did not significantly contribute to any of the ADHD subtypes. This surprising, particularly when it comes to inattention, based on previous literature citing a relation between WMC and inattention (Tillman, Eninger, Forssman, & Bohlin, 2011). Given my conflicting results with previous research and the growing number of college students with ADHD (DuPaul, Weyandt, O'Dell, & Varejao, 2009), future researcher should continue examining this relation to aid in the development of impairment specific ADHD interventions and accommodations.

Guided by previous research examining the associations between impaired working memory and depression I examined the influence of WMC to depression symptom severity (Lee, Hermens, Porter, & Redoblado-Hodge, 2012; Rock, Rosier, Riedel, & Blackwell, 2014). Consistent with my hypothesis I found a notable trend for an association between WMC and depression symptom severity (total BDI-II score). My results indicate that as WMC decreases depression severity increases. Clinically, this relationship is relevant as it may manifest in such places as the psychotherapy room. For example, if an individual has limited WMC they may struggle to both simultaneously manage their distress and encode the intervention for future use.

To inform future research, I also attempted to isolate and examine BDI-II subscales (e.g., cognitive-affective and somatic-performance symptoms). Whereas the cognitive-affective scale examines the psychological experience of depression (e.g., decreased mood), the somatic-performance scale examines physiological symptoms (e.g., increased need for sleep) of depression. These trends are consistent with findings from a meta-analytic review of working memory and major depressive disorder conducted by Lee and colleagues (2012), but inconsistent with a meta-analytic review conducted by Rock and colleagues (2014). Specifically, Lee and colleagues (2012) found that working memory was not significantly different in those with and without major depressive disorder. However, Rock and colleagues (2014) found a significant difference in working memory functioning for individuals with major depressive disorder. Given the trend, it is possible that I did not have enough statistical power to detect this effect. Future research should consider replicating this finding with a larger sample to further clarify the relation between WMC and depression. Furthermore, my sample was not a pure clinical sample, therefore further exploration of this question with a clinical sample would be a strong next step. Finally, if depression symptoms contribute uniquely to WMC or vice versa, future research should examine the reliability of the potential diagnostic criteria over time.

A number of limiting factors should be considered. Primarily, this study relied on several regression analyses which may have increased the error rate. If this occurred, it is possible that my results may not fully account for the studied associations. The sample was relatively homogenous, contained twice as many women than men, and had relatively low levels of reported clinical symptoms. As a result, this limits generalizability to the diverse population of college students. Additionally, the assessment of clinical symptoms relied on self-report data.

While this data collection methods offers the advantages of a quick evaluation of subjective experiences, to further generalize these results more in depth assessment (i.e., structured clinical interviews) would be a good next step. Finally, ADHD and depression are often comorbid and share some symptoms (e.g., inattention and sluggish cognitive tempo) as such my results may be influenced in the overlap of reported symptoms. Despite these limitations the current study offers an advancement in the research on not only working memory capacity, working memory process related variables, and working memory's connection to mental disorders. Specifically results suggesting a significant relationship between reaction time, inhibition of distractors, and the importance of stimulus domain in determining working memory capacity is noteworthy. The current study can serve as a guide for future research in terms of the importance of understanding working memory capacity in developing academic accommodations and clinical interventions. Based on this study researchers may consider continuing to examine how working memory capacity and depressive are connected as well as if working memory processes in and of themselves are significantly related to mental disorders.

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Appendices

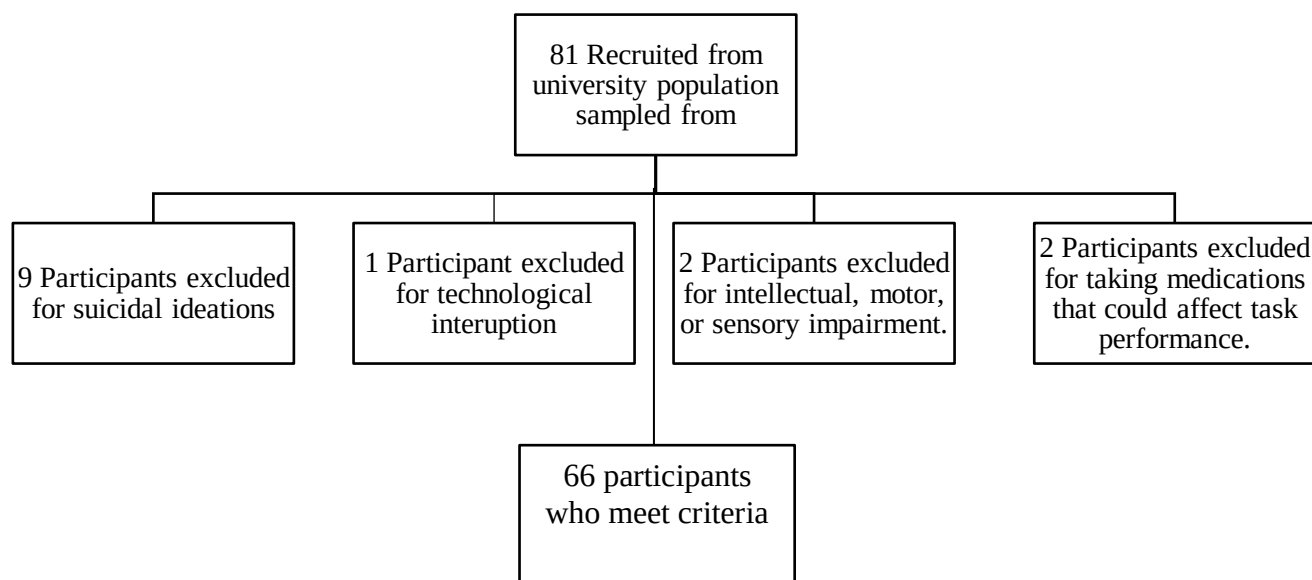
Appendix A: Figures

Figure 1. Participant Exclusion Schematic.

Appendix B: Tables

Table 1. Demographic Data

Variable		
	$\bar{X}$	<i>SD</i>
Age	18.70	1.067
FSIQ-2	102.06	8.21
	N	%
Sex		
Male	22	33.3
Female	44	66.7
Ethnic Category		
Caucasian	53	80.3
Hispanic	2	2.9
African American	9	13.6
Asian	1	1.4
Other	1	1.4

FSIQ-2 = Full Scale IQ-2

Table 2. Tier I Regression Analysis Summary: Reaction Time

Model	Variable	Reaction Time			β	t	p
		R	R Square	Std. Error			
1.		.294	.087	.963			
	(Constant)					.000	1.000
	WMC				.294	2.465	.016

WMC=Working Memory Capacity

Table 3. Tier I Regression Analysis Summary: Distractor Task Accuracy

Model	Variable	Accuracy			β	t	p
		R	R Square	Std. Error			
1.		.516	.266	.863			
	(Constant)					.000	1.000
	WMC				-.516	-4.818	<.001

WMC=Working Memory Capacity

Table 4. Tier I Regression Analysis Summary: Task Stimulus Domain

Model	Variable	Stimulus Domain			β	t	p
		R	R Square	Std. Error			
1.a		.783	.613	.626			
	(Constant)					-9.50	<.001
	WMC				.783	10.0	<.001
2.b		.513	.263	.864			
	(Constant)					.683	.497
	WMC				.513	-4.78	<.001
3.c		.622	.387	.789			
	(Constant)					-.901	.371
	WMC				.622	.635	<.001

a. Symspan = Symmetry Span

b. Ospan = Operation Span

c. Rspan = Reading Span

Table 5. Tier II Regression Analysis Summary: Contributions of WMC to ADHD Symptoms

Model	Variable	WMC			β	t	p
		R	R Square	Std. Error			
1.		.019	.000	11.7			
	(Constant)					31.0	<.001
	BAARS-IV				.019	.150	.881

BAARS-IV = Barkley Adult ADHD Rating Scale, fourth edition

Table 6. Tier III Regression Analysis Summary: Contributions of WMC to Depression Symptoms

Model	Variable	WMC			β	t	p
		R	R Square	Std. Error			
1.		.230	.053	8.06			
	(Constant)					8.25	<.001
	BDI-II				.230	1.89	.063

BDI-II = Beck Depression Inventory, second edition

Vita

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