

WORKING MEMORY AND INATTENTION IN COLLEGE STUDENTS

By

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A Thesis Submitted to The Honors College

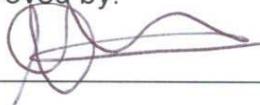
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STATEMENT BY AUTHOR

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A handwritten signature in blue ink, written over a horizontal line. The signature is cursive and appears to read "Ashley D. Gray".

Abstract

Attention-deficit/hyperactive disorder (ADHD), specifically the symptom domain of inattention, has been associated with deficits in working memory (Martinussen et al., 2005, 2006). This preliminary study further investigated this relationship by testing normally functioning college students ($n=41$) on a working memory (WM) task that distinguished between the maintenance and updating components of WM. Performance was compared to relative levels of inattention, hyperactivity, and impulsivity. We hypothesized that levels of inattention, and not hyperactivity/ impulsivity, would predict poor performance on the WM memory task. We were also interested in examining whether inattention was more closely related to performance on trials that measured maintenance versus updating of WM. No significant correlation was found between inattention and the trials for the separate components of WM. However, trials that required both maintenance and updating of WM were negatively correlated with inattention ($r = -.27^*$), hyperactivity ($r = -.29^*$), and impulsivity ($r = -.44^{**}$). These results suggest that in the normal population, relative levels of inattention, hyperactivity, and impulsivity hinder performance on the most cognitively demanding of WM tasks. This study will be repeated with a clinical population of adolescents to further explore the relationship between WM and symptom domains of ADHD.

Introduction

Attention-deficit hyperactivity disorder (ADHD) is “the most common neurobehavioral condition of childhood” (American Academy of Pediatrics, 2000), for which the causes are currently unknown. According to the 2000 Diagnostic and Statistical Manual of Mental Disorders Revised 4th ed. (*DSM-IV-TR*), ADHD is a disruptive behavior disorder characterized by the presence of a set of chronic and impairing behavior patterns that display abnormal levels of inattention, hyperactivity, or their combination. These core deficits lead to considerable problems with daily performance and affect children in multiple settings. Difficulties can manifest through academic struggles, trouble forming interpersonal relationships with family and peers, as well as low self-esteem (American Academy of Pediatrics, 2000). The *DSM-IV-TR* recognizes three subtypes (Primarily Inattentive, Primarily Hyperactive/ Impulsive, and Combined) of ADHD based on symptom clusters exhibited by the child, as long as symptoms are displayed to the extent that the behavior interferes with normal functioning (2000). Beyond the behavioral aspects of the disorder, there are several deficits in executive functions (Barkley, 1997; Willcutt et al., 2005) that are highly associated with the symptoms of ADHD. One of these cognitive impairments is working memory (Martinussen et al., 2005; Willcutt et al., 2005).

Working memory is the active mental system for temporarily holding limited amounts of information in a readily accessible form where it can be combined, manipulated and stored productively (Klingberg et al., 2002; Rapport et al., 2008). This neural system is essential for guiding behavior and directing complex cognitive tasks, such as problem solving, comprehension, and learning. Baddeley (1986) proposed a multi-component model of working memory, which included the central executive, the phonological loop, the visuospatial sketchpad, and, recently added, the episodic buffer (2000). This model is currently regarded as the most

accurate description of the working memory system, in which the central executive component oversees the visuospatial and phonological systems. The specific role of the central executive remains vague, but it likely serves to regulate and coordinate the other working memory components and to ensure efficient perception of the world immediately around us. There has been extensive research done on the phonological loop, which deals with storing and manipulating auditory information (Andersson, 2008; Buchsbaum & D'Esposito, 2008; Saeki, 2007); the visuospatial sketchpad, which deals with storing and manipulating visuospatial information, has been subject to significantly less research. This study is more concerned with the visuospatial sketchpad aspect of working memory. As proposed by Shah and Miyake (1996), there exists separate verbal and spatial working memory systems, rather than a single central executive serving various functions. Thus, the phonological loop and visuospatial sketchpad have both been sub-divided into two-component systems, one for storage and one for processing and manipulating information.

The manipulation system is also referred to as the updating system (REF), while the storage system is also referred to as the maintenance component of working memory (REF). The updating component involves continuously adjusting the information being held in the working memory store with the presentation of new input. This process is active throughout the course of everyday activities, including learning and comprehension. The updating function is generally investigated using tasks that require the manipulation of information and multiple shifts in attention (Collette & Van der Linden, 2002). Alternately, the storage of information in working memory requires temporarily holding information in the memory store over the course of a delay until the information needs to be used, or while performing a separate cognitive task. These processes are important to study, since deficits in any of the systems lead to poor functioning in

everyday life. Specifically, weaknesses in visuospatial storage have been associated with low academic achievements in literacy, comprehension and arithmetic. (Martinussen, et.al., 2005).

Although numerous studies have focused on the relationship between symptoms of ADHD and clinical deficits in working memory capacity, few have thoroughly investigated the association between the separate components of working memory and the symptom domains of ADHD. Past research has not been entirely in agreement that individuals with ADHD suffer clinical deficits in working memory. However, several studies have failed to control the modality of working memory being tested (verbal versus visuospatial), the type of processing required (storage versus storage and manipulation), and/ or potentially confounding variables such as comorbidity with reading and language learning disorders. To account for these shortcomings in current research, Martinussen, et. al. (2005) conducted a meta-analysis to determine the validity of the relationship between ADHD and working memory deficits. 26 empirical research studies published from 1991 to 2003 met their inclusion criterion and were used in the analysis.

Researchers sorted the working memory measures based on the component being tested and type of processing required. They also controlled for comorbid disorders. Overall, children and adolescents with ADHD demonstrated impairments in working memory capacity that was not related to any comorbid disorders. Deficits in the spatial component of working memory were more profound than those in the verbal component, for both storage and manipulation. This inclusive study indicates not only that symptoms of ADHD correlate with weakness in working memory, but that the spatial component is more strongly associated. Therefore, this study focused on a task that measured visuospatial working memory capacity. Although this study had definite benefits, by determining a clear association between ADHD and working memory impairments, researchers were not able to examine the specific relationship between working

memory and inattention versus hyperactivity/ impulsivity. This distinction is important, and many studies suggest that ADHD-related deficits in working memory are primarily due to inattention. This hypothesis is based on preliminary studies described below.

An experiment conducted by Schweitzer et al. (2000) investigated regional cerebral blood flow (rCBF) in adults with ADHD during a working memory task in order to learn more about the pathophysiology of the disorder. Changes in rCBF, as seen through PET scans, were more widespread in adults with ADHD when compared to controls during the task. These results indicated the usage of compensatory cognitive strategies during tasks to make up for the inability to inhibit attention to distracting stimuli. The PET scans provided physiological evidence that working memory deficits in adult ADHD are specifically related to symptoms of inattention.

Furthermore, Kuntsi, Oosterlaan, & Stevenson (2001) found no difference between hyperactive children and controls on working memory tasks, which indirectly points to the relationship between inattention and working memory impairments.

More indirect evidence for the relationship between working memory impairments and inattention comes from studies that investigate working memory's relation with attentional processes and control.

Kane et al. (2001) conducted a study, where participants were presented with a cue that either validly (prosaccade trials) or invalidly (antisaccade trials) predicted the location of a target stimulus letter. In order for participants to direct their attention away from the incorrectly cued location to the correct location, they either had to deliberately move their eyes from the incorrectly cued location to the location of the target, or inhibit their attention from the cue entirely and only focus on the stimulus upon its appearance. Both of these strategies required that the goal remained actively accessible in the working memory store; otherwise distractors would

ultimately guide behavior. Researchers proposed a controlled attention view of working memory capacity, with higher working memory individuals being able to more effectively direct their attention to goal-specific locations and resist the interference of distractors. Importantly, results showed that high-span working memory participants performed significantly faster and with fewer errors on antisaccade trials than did low-span working memory individuals. This suggests that attention is highly implicated in effective working memory capacity. Thus, it would make sense that inattention would be correlated with working memory impairments. Furthermore, quick and correct responses required maintenance of the goal in working memory, which led to adjusting incorrect visual focus or inhibiting attention to the cue entirely. This indicates that the maintenance component of working memory capacity requires attentional control.

Fockert et al. (2001) studied the association between selective attention and working memory. Selective attention is an important process that works to retain focus on the pertinent situation and block out distracting information. To selectively attend to relevant stimuli, individuals must actively maintain the different priorities of the stimuli in working memory. Fockert found that working memory load has a significant effect on distractor processing, indicating that selective attentional abilities diminish when working memory stores are less available. This is likely due to the reduced differentiation between high- and low- priority stimuli (targets versus distractors). Fockert's study provided evidence for the direct causal role of working memory capacity in controlling selective attention, as well as how the maintenance component is important in this process. Thus, we have incorporated the distractor trials in our Visuospatial Working Memory task so that participants actively maintain selective attention. In sum, the results of these studies suggest that working memory deficits are primarily associated with inattention and less or not to hyperactivity/impulsivity.

Although these studies have seemingly clearly identified a relationship between working memory deficits and symptoms of inattention, it is important to distinguish between the different working memory components (maintenance versus updating) and determine which of these deficits is most closely related with inattention.

Martinussen et. al. (2006) conducted a study that not only demonstrated the correlation between inattention and working memory impairments, but also examined how inattention is related to the different components of working memory. They predicted that children with Combined and Primarily Inattentive subtypes of ADHD would demonstrate weaknesses in working memory as compared with a control group of adolescents. Further, they hypothesized that central executive working memory deficits would be strongly correlated with inattention and not with hyperactivity/ impulsivity. Four groups of participants were used, to distinguish between deficits of ADHD and those of reading and language learning disorders. All participants completed a verbal and spatial working memory task, though verbal working memory was not considered in our study. Maintenance (or storage) was tested in a very similar manner as our study, with a test called Finger Windows. In the Finger Windows test, experimenters presented memory stimuli by pointing to increasingly longer sequences of locations (i.e. windows) on a card, and the participant was asked to reproduce the sequence exactly. Updating (or central executive/ CE) was tested in a different way; rather than incorporating distractor stimuli into the sequence, participants were asked to point to the just presented sequence in the reverse order. When a subsample of ADHD kids were matched to a control group for age, IQ, reading and language ability, and gender, the ADHD kids performed considerably worse than control kids on both components of CE working memory. Likewise inattention, and not hyperactivity/ impulsivity, was a significant predictor of weakness in both verbal and spatial CE components of

working memory. These results indicate that ADHD kids exhibit considerable deficits in CE domains of working memory compared to control kids. Furthermore, ADHD Combined and Inattentive kids performed far worse on CE working memory compared to controls, while hyperactivity did not predict poor performance on any working memory aspect.

Several studies have determined that working memory deficits are associated with symptoms of inattention. However, only one study has examined the relation between the various working memory components and the symptoms domains of ADHD (inattention and hyperactivity/impulsivity (Martinussen et al., 2006). One limitation of this study is that the task did not use a delay between stimulus presentation and the subjects' responses; hence this study seemed to measure storage rather than the maintenance of information over the course of a delay. Our study will further explore the specific relationship between inattention versus hyperactivity/impulsivity and working memory components within the visuospatial domain. Participants will complete a task that distinguishes between the components of working memory. Although the population is largely comprised of normally functioning college students, the symptoms of inattention and hyperactivity/impulsivity range from normal to clinically deficient values. Thus, this study will determine whether the relative symptoms of inattention and hyperactivity/impulsivity correlate with poor performance on the working memory task, and specifically whether their relative symptoms are more strongly correlated with poor performance on the updating or maintenance domain of working memory.

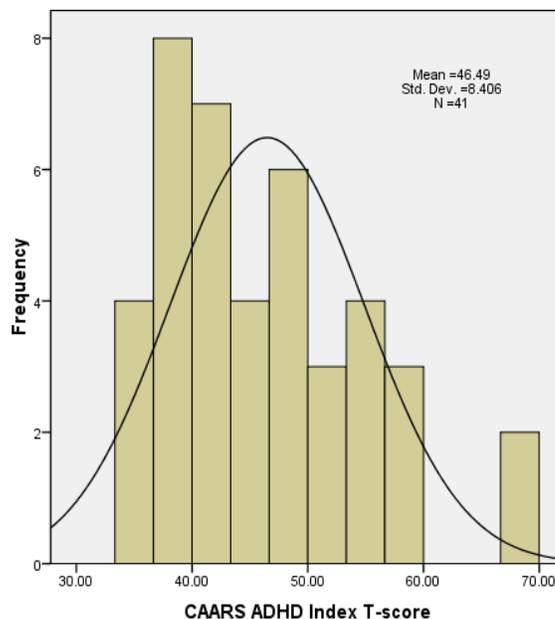
Based on this research, the following hypothesis has been formulated. Weakness in working memory will be associated with symptoms of inattention but not, or to a lesser extent, with symptoms of hyperactivity/impulsivity. Furthermore, we wish to examine the relationship between performance on the maintenance versus updating trials and symptoms of inattention.

Method

Participants

This study included 43 University of Arizona college students ranging in age from 18-22 years (mean= 19.05, sd= 1.0) and included 24 males and 19 females. However, 2 participants (one male, one female) did not complete the entire study, so their data has not been included in the analyses. Recruitment took place through the Introduction to Psychology course. Although three participants indicated that they had been previously diagnosed with ADHD, the large majority consisted of normally functioning college students who were free of any disorders or cognitive deficits. Scores on the Conners' Adult ADHD Rating Scale (CAARS) for inattention, hyperactivity, and impulsivity varied between participants. However, as illustrated in Figure 1 the t-scores for most appeared within normal limits (t-score < 65) on the CAARS ADHD Index (range= 35-69, mean= 46.49, sd= 8.41). Likewise, most scores for the Wender Utah Rating Scale (WURS) ADHD total were within normal limits (range= 2-47, mean=15.17, sd= 10.90).

Figure 1



Assessment Measures

Participants completed self-report questionnaires before the cognitive computer tasks, although a few completed the questionnaires after the tasks. They completed a demographic form, the Wender Utah Rating Scale (WURS), the Conners' Adult ADHD Rating Scale (CAARS), and the Behavioral Inhibition System and Behavioral Activation System (BIS/BAS) Scales. The BIS/ BAS questionnaire was administered as part of a bigger project that is not a focus of this study, so these results were not used in this study's analysis.

Wender Utah Rating Scale (WURS)

The Wender Utah Rating Scale can be used to assess the likelihood that adults over the age of 18 have ADHD. The scale consists of 61 items, with a WURS ADHD Total subscale of 25 items associated with the diagnosis of ADHD.

Conners' Adult ADHD Rating Scale (CAARS)

The CAARS is a 66-item scale that provides a multimodal assessment of symptoms and behaviors associated with ADHD in adults aged 18 and older. Specifically, the five different subscales of Inattention/ Memory Problems, Hyperactivity/ Restlessness, Impulsivity/ Emotional Lability, DSM-IV Inattentive, and DSM-IV Hyperactive/Impulsive were used to separately assess symptoms of inattention, hyperactivity, and impulsivity, and the ADHD Index subscale was used as a general indicator of ADHD symptoms.

Tasks

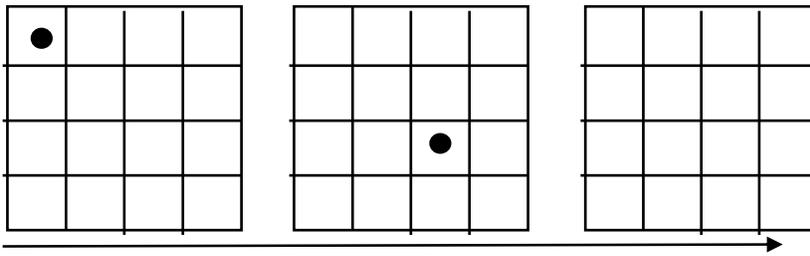
The participants completed four computerized cognitive tasks on a laptop. These included the Choice Delay Task, the Probabilistic Learning Task, the Visual-spatial Working Memory Task, and the Stop Task. Participants completed these four tasks in one of two balanced, randomized orders. Participants followed directions that appeared on the computer screen prior

to completing each of the tasks. All participants completed all four cognitive tasks in the context of a larger project; however, the focus of this study was on the Visual-spatial Working Memory task and not any of the others.

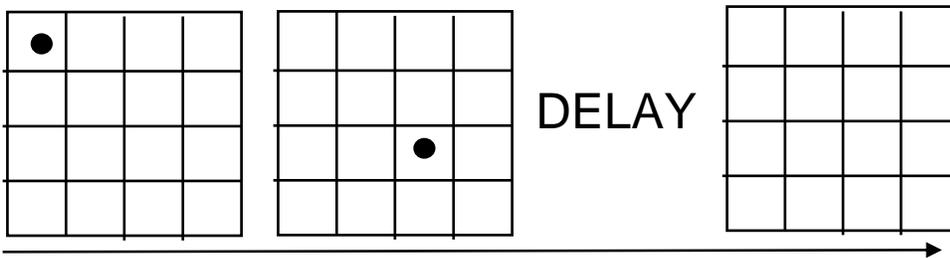
Visual-spatial Working Memory Task

In the Visual-spatial Working Memory Task, circles (memory stimuli) were presented one at a time in a 4 x 4 grid on the computer screen. After the series of memory stimuli, participants were presented with empty grids and asked to respond by pointing to the squares where the circles were located and in the same sequence. Working memory load was manipulated by including a series of 2-9 memory stimuli followed by empty grids. Participants were presented with 4 trials for each difficulty level: 1 control, 1 delay, 1 distracter, and 1 distracter and delay. For the delay trials, empty grids were shown after a delay period of 1500 ms. For the distracter trials, the circle stimuli appeared in the grids together with distracter triangles simultaneously present in another square on the grid. For the distracter and delay trials, the circle stimuli appeared in the grids together with distracter triangles simultaneously present in another square, and the empty grids were shown after a delay period of 1500 ms. For the control trials, triangles were not presented, nor was there a delay preceding the empty grid. We introduced the distracter and delay manipulations to distinguish between updating of working memory and maintenance of working memory. Poor performance on the distracter trials would indicate a deficit in updating of working memory, while poor performance on delay trials would indicate a deficit in maintenance.

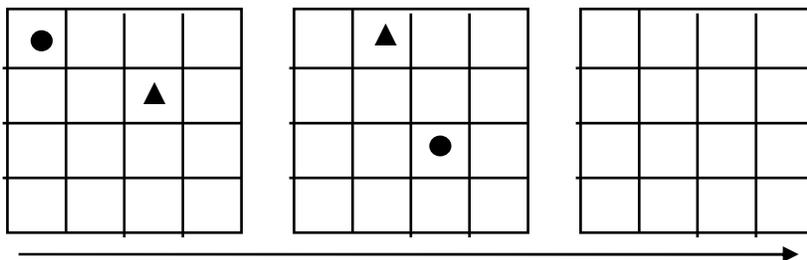
Figure 2. Examples of the four different Working Memory task trials with a load of 2 stimuli



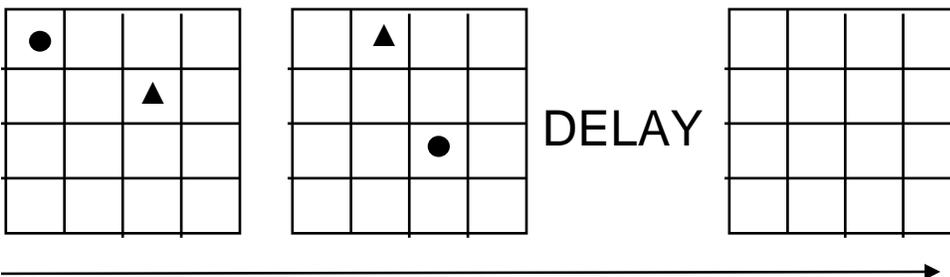
Example of a control trial (no distractor with no delay)



Example of a maintenance trial (No distractor with a delay)



Example of an updating trial (distractor with no delay)



Example of a maintenance + updating trail (distractor and delay)

Procedure

This study was approved by the Institutional Review Board of the University of Arizona. All participants signed informed consent forms before taking part in the experiment. Researchers then administered a series of brief self-report questionnaires. Once these were completed, the experimenter explained the basic procedure of the computerized tasks. The participant completed the tasks in a private room on a laptop. Specific directions appeared on the screen before each task, with the researcher present to explain further directions if needed. All data was collected through participant responses by the laptop, except for the Working Memory task.

For this task, the participants responded by pointing with their index finger to the location in the empty grid that was presented on the computer screen following the sequence of memory stimuli. The researcher held an answer key and manually recorded the participants' responses. Due to the nature of the Working Memory task, in which participants pointed to the computer screen, a video camera was used to record the participants' responses to ensure correct scoring on the task. Experimenters explained the purpose of the camera to participants before starting to record, and ensured them that it was positioned to capture only their response on the computer screen and not their faces.

Following completion of the study, participants received four credits for class, as well as monetary compensation for their participation, ranging in value from \$11-\$20. Participants were then debriefed.

Statistical Analyses

Although the correlation between inattention and performance on the maintenance of working memory trials was of primary interest, we also looked at the relationship between hyperactivity/ impulsivity and performance on the working memory task. Therefore, we

performed correlations between the 4 subscales of the CAARS that measure inattention and hyperactivity/ impulsivity, the CAARS ADHD Index subscale, and the WURS ADHD total subscale on the one hand, and the sum totals of performance on the 4 trial levels of the Working Memory task on the other.

Results

As shown in Table 1, the predicted negative correlation between inattention and performance on the maintenance trials was not demonstrated. However, there were significant negative correlations between performance on trials that required maintenance *and* updating of working memory and levels of inattention ($r = -.27; p < .05$), hyperactivity ($r = -.29; p < .05$), and impulsivity ($r = -.44; p < .01$). Additionally, strong negative correlations between the maintenance and updating trials and both ADHD indexes (as measured by the CAARS and WURS) were observed ($r = -.42, p < .01$; $r = -.45, p < .01$ respectively).

Likewise, there were significant negative correlations between levels of impulsivity and performance on the control trials ($r = -.32, p < .05$), as well as between levels of hyperactivity and performance on the maintenance trials ($r = -.30, p < .05$).

Table 1. Correlations between the CAARS scales and the sum scores on the working memory task for each of the 4 trial types.

	Sum Scores			
	<i>Control</i> No Delay No Distractor	<i>Maintenance</i> Delay No Distractor	<i>Updating</i> No Delay Distractor	<i>Maintenance+Updating</i> Delay Distractor
CAARS ^a Scales				
Inattention-Memory	-.10	.06	-.13	-.27*
Hyperactive/Restless	-.23	-.08	-.30*	-.29*
Imp/Emotional Lability	-.32*	-.16	-.16	-.44**
DSM-IV ^b Inattentive	-.10	.02	-.16	-.12
DSM-IV Hyper/Imp ^c	-.12	-.12	-.17	-.15
ADHD ^d Index	-.23	-.07	-.18	-.42**
WURS ^e ADHD Total	-.08	-.16	-.16	-.45**

^a CAARS: Conners' Adult ADHD Rating Scale.

^b Diagnostic and Statistical Manual of Mental Disorders IV

^c Hyperactivity/ Impulsivity

^d Attention Deficit/ Hyperactivity Disorder

^e Wender Utah Rating Scale

* p<.05; ** p<.01

Discussion

The present study investigated the effects of varying levels of AD/HD-related behaviors (inattention, hyperactivity, and impulsivity) on visuospatial working memory capacity in normally functioning college students. We hypothesized that relatively high levels of inattention, and not hyperactivity/ impulsivity, would predict poor performance on the working memory task. We also wanted to examine the relation between deficits in the components of working memory (maintenance versus updating) and symptoms of inattention, hyperactivity, and impulsivity.

The expected correlation between inattention, and not hyperactivity/ impulsivity, and the components of working memory were not found to be significant. However, relative symptoms of inattention, hyperactivity, and impulsivity did predict poor performance on the trials that taxed both the maintenance and updating of working memory. Likewise, the ADHD index as measured by two different rating scales had strong negative correlations with the trials requiring both maintenance and updating. It should be noted that, contrary to our predictions, correlations between these trials and hyperactivity/impulsivity appeared to be stronger than correlations between these trials and inattention. These results seem to suggest that in normally functioning college students, relative symptoms of ADHD lead to poor performance in the most cognitively demanding of working memory tasks, namely when increasing amounts of relevant information (as distinguished from irrelevant information) have to be actively maintained during a delay. A previous study that has reported a unique association between visuospatial working memory deficits and inattention (but not hyperactivity/impulsivity) (Martinussen et al., 2006) did not include trials that taxed both updating AND maintenance like the current study did. Unlike the current study, in which the most demanding trials had distractors as well as a delay preceding the participants' responses, the most demanding trials in the Martinussen et al. study were trials in

which a visuospatial sequence had to be generated by the participants in the reverse order (requiring updating), but there was no delay between the stimulus and the subjects' responses. Therefore, it is arguable whether those trials actually required maintenance (rather than only storage). Our study suggests that it is possible that poor performance on visuospatial working memory tasks that require both updating and maintenance is associated with not only symptoms of inattention, but also symptoms of hyperactivity/impulsivity. This needs to be further investigated in samples with clinically diagnosed participants with ADHD.

Being a preliminary pilot study of the task and its association with the separate symptom domains of ADHD, there were several factors that may explain our results. The majority of participants were normally functioning college students, as reported on the demographic form and illustrated in Figure 1 of the CAARS ADHD index t-scores (all participants except two where within the normal range). This led to decreased variability for scores on both the CAARS subscales and WURS subscale, indicating that most participants reported low levels of inattention and hyperactivity/impulsivity. To overcome this weakness, this study will be repeated with a clinical population of adolescents (who will definitely produce a larger range of symptoms of inattention and hyperactivity/impulsivity) to further investigate the difference between the maintenance and updating of working memory and their respective correlations with symptom domains of ADHD.

Implications

Although this study did not produce the expected results, continued research is important to verify the relationship of interest. By determining that individuals with ADHD have deficits in working memory capacity, which has been shown to be specifically related to symptoms of inattention, researchers can design more efficient treatment plans. Klingberg et al. (2002) found

that a combination of medication and cognitive training for working memory in ADHD individuals can drastically improve their academic and social functioning.

Likewise, the specific relationship between inattention and working memory deficits is important in research regarding the neural circuitry of ADHD. Luca et al. (2007) found an association between the dopamine (DA) receptor D1 gene (DRD1) and ADHD, and specifically with symptoms of inattention. Also, D1 receptors have been found as important in attentional processes and working memory function. Thus this study showed that, DA, which is known to be important in ADHD, is correlated with symptoms of inattention. Yet, Luca also found a correlation between DA deficiency and working memory function. This likely signifies a relationship between working memory and inattention (possibly via DA). With studies such as these in mind, drug researchers can perfect ADHD medications for children with the Primarily Inattentive subtype by focusing on the neurotransmitter DA to improve inattention, and in turn working memory.

Furthermore, Frank et al. (2007) investigated his proposed computational models of the involvement of dopamine and norepinephrine (NE) in the deficits of ADHD. They hypothesized that specifically, DA is involved in working memory. Their results indicate not only that the two subtypes of ADHD have separate underlying cognitive pathways, but also that DA is, in fact, associated with performance on working memory tasks. These two studies indicate that DA is involved in both inattention and working memory, and further contribute to the hypothesis that deficits in working memory are primarily associated with inattention.

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