COGNITIVE PROCESSES CONTRIBUTING TO VISUAL WORKING MEMORY PERFORMANCE IN INDIVIDUALS WITH AUTISM SPECTRUM DISORDER

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KIMBERLY BODNER

Dr. Shawn Christ, Dissertation Supervisor

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

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presented by Kimberly Bodner,

a candidate for the degree of doctor of philosophy,

and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Shawn Christ

Professor Stephen Kanne

Professor Nelson Cowan

Professor John Kerns

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ABSTRACT

Previous investigations of working memory performance in individuals with Autism Spectrum Disorder (ASD) have yielded mixed findings (e.g., Kenworthy, Yerys, Anthony, & Wallace, 2008; Geurts, de Vris, & van den Bergh, 2014). Research examining visual and spatial working memory abilities in older adolescents and adults with ASD specifically is limited. The current study assessed the contribution of working memory capacity, attention, and visual filtering abilities to visual working memory performance in adolescents and adults with and without ASD. Furthermore, the current study examined task performance related to real world report of working memory and attention abilities. Results revealed comparable estimates of visual working memory capacity overall between groups. However, visual working memory performance for individuals with ASD appeared to be more impacted by increases in attention and visual filtering demands. Individuals with ASD allocated their attention differently than non-ASD individuals, and spent less time looking at relevant information. The ASD group had more difficulty filtering distracting information in more challenging conditions. Difficulties on the task did not significantly relate to reported real world working memory or attention abilities. Findings suggest that visual working memory performance is similar between individuals with and without ASD when cognitive demands are low, but individuals with ASD are detrimentally effected when the cognitive load increases (increased attention and visual filtering demands), consistent with previous literature (Kenworthy et al., 2008). Given the complexity of our environments and need to filter visually distracting information, these findings may shed light on ASD-related difficulties in day-to-day functioning and provide a focus for intervention.

Cognitive Processes Contributing to Visual Working Memory Performance in Individuals with Autism Spectrum Disorder

Chapter 1: Autism Spectrum Disorder & Executive Function

Autism spectrum disorder (ASD) is characterized by abnormalities in social communication and repetitive and stereotyped behaviors that are apparent early in development (American Psychiatric Association, 2013). Currently, the estimated prevalence rate for a diagnosis of ASD is 1 in 68 children (Centers for Disease Control, 2014), but could be as high as 1 in 45 given a recent parent survey by the National Center for Health Statistics (Blumberg et al., 2013). ASD-specific deficits include difficulties with language (e.g., delayed development, echolalia, and/or stereotyped speech), initiating and maintaining conversations, processing and expressing facial expressions and emotions, displaying appropriate social behavior, and initiating and maintaining friendships. Individuals with ASD may also have atypically intense interests and/or display repetitive behaviors, as well as hyper- or hypo-sensitivities to sensory stimuli. These symptoms may manifest in a multitude of combinations, severities (mild to severe), and in conjunction with comorbid diagnoses, such as depression, anxiety, attention-deficit/hyperactivity disorder (ADHD) among others. The precise etiology of ASD remains unknown; however, it is postulated that a combination of genetic, developmental, and environmental factors may contribute to the presence of the disorder (Muhle, Trentacoste, & Rapin, 2004; Rapin & Katzman, 1998). The personal and familial cost of ASD is innumerable. The fiscal impact of ASD on society is staggering, with an estimated annual cost of $35-90 billion dollars (Ganz, 2007), and recently estimated at approximately $11.5 billion per year for children 3 to 17 years old alone

(Lavelle et al., 2014). Given the tremendous personal and financial impact of ASD, investigations of the contributing factors to cognitive functioning difficulties are of the utmost importance because they may inform treatment efforts and/or identification of biomedical markers.

Executive Function

Whereas the diagnostic criteria for ASD focuses on impairments related to social communication and repetitive behaviors, ASD is also associated with impairments in cognitive functioning processes such as aspects of executive function (EF; for reviews, see Geurts, de Vris, & van den Bergh, 2014; Hill, 2004; Kenworthy et al., 2008). EF refers to a set of cognitive processes that direct, maintain, and modify thoughts and behaviors to reach desired goals (Stuss & Benson, 1986). Miyake et al. (2000) suggested that there are at least three core components that contribute to EF: updating, inhibition, and shifting (more specifically described as “monitoring and updating of working memory, inhibition of prepotent responses, and shifting of mental sets”). For the purpose of the present study, the broad terms of working memory, inhibitory control, and cognitive flexibility will be used, especially in relation to the most recent reviews of EF and ASD (for reviews, see Geurts, de Vris, et al., 2014; Hill, 2004; Kenworthy et al., 2008). These core components are supported by multiple sub-components and/or contributing cognitive processes, such as the ability to plan actions, ignore distracting information, and focus and shift attention among others (Miyake et al., 2000). To the extent that such sub-components provide a foundation for core EF functions, disruption in any sub-component could potentially contribute to the attenuation and/or failure of the aspect of EF under examination (Cowan et al., 2005; Miyake et al., 2000; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Monsell, 2003).

From a neurologic standpoint, EF relies primarily, though not solely, on the prefrontal cortex (PFC; Miller & Cohen, 2001; Stuss & Benson, 1986). The development of EF parallels the developmental timeline of the PFC, with improvements in EF abilities over the course of typical development (De Luca et al., 2003; Levin et al., 1991). For example, older children are able to keep a larger amount of information “online” or in working memory compared with younger children (Cowan et al., 2005). Researchers also generally find a positive correlation between activation of the PFC and age in children during visuo-spatial working memory tasks (Klingberg, Forssberg, & Westerberg, 2002; Kwon, Reiss, Menon, 2002). This increased PFC activation with age is also seen in other elements of EF, such as inhibition (for reviews see Luna & Sweeney, 2004; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). Additional evidence of EF as a function of the PFC comes from studies of patients with structural damage or lesions to PFC and/or neurophysiological disruption of PFC. Patients with damage to the PFC show deficits in common executive processes such as working memory and cognitive flexibility (Milner, 1963; Owen, Downes, Sahakian, Polkey & Robbins, 1990; Shallice, 1982, 1988).

During performance of EF tasks, the PFC does not act in isolation but acts with a network of supporting brain regions (Alvarez & Emory, 2006; Cummings, 1993), such as a feedforward system with the thalamus, basal ganglia, interparietal sulcus, and other task-dependent associated brain regions. There may be impairment in EF due to the structural or functional abnormality of other areas of the brain, which are further explored in the context of ASD.

Executive Function and Autism Spectrum Disorder

Although there is a general consensus among researchers and clinicians that EF is detrimentally affected in ASD (for reviews, see Hill, 2004; Kenworthy et al., 2008), findings are inconsistent as to what specific aspects of EF (e.g., working memory vs. inhibition vs. cognitive flexibility) are impacted and to what degree. Variability in demographic and diagnostic characteristics of the sampled populations and in methodology across studies have likely contributed to the inconsistencies observed in the existing literature. Other researchers (e.g., Kenworthy et al., 2008) have suggested that ASD-related impairments in EF performance are more apparent when demands are placed simultaneously on multiple components of EF.

One brain region that has been hypothesized to be affected in ASD is the PFC, a region of the brain known to play a primary role in EF as previously discussed. Recently, a small study investigating the histopathological abnormalities of the prefrontal and temporal cortices of children and adolescents with ASD suggests that these abnormalities may occur during prenatal development (Stoner et al., 2014).

Minicolumn abnormalities of the frontal lobe have also been shown to be present in ASD (Buxhoeveden et al., 2007; Casanova, Buxhoeveden, Switala, & Roy, 2002; Kemper & Bauman, 1998). Minicolumns represent clusters or ropes of neurons (approximately 80-100 neurons) that create the local networks and contribute to the global networks of neuronal information processing (Mountcastle, 1997). These structures are plastic, in that they are densely packed in childhood and become less dense with age (Buxhoeveden & Casanova, 2002). Minicolumns are more densely packed in the frontal lobe of children and adults with ASD in comparison to non-ASD individuals, due to “narrow minicolumns and surrounding spaces” (Buxhoeveden et al., 2007; Casanova, et al., 2002; Kemper & Bauman, 1998), which may impact optimal functioning of these neurons and contribute to the known EF dysfunction found in ASD.

In addition to histopathologic evidence of PFC abnormalities in individuals with ASD, gross anatomical abnormalities in the PFC and ASD have also been reported. Structural MRI studies investigating brain volumes in individuals with and without ASD report an increase in frontal lobe volume in children with ASD (Carper, Moses, Tigue, & Courchesne, 2002; Herbert et al., 2004). Taken together with the aforementioned histopathologic studies, these findings suggest an early disruption of micro and macroscopic PFC brain development that persists into adulthood. Furthermore, reviews of structural and functional MRI studies in ASD implicate abnormalities in secondary brain regions associated with PFC functioning, such as the corpus callosum, basal ganglia, and cerebellum among others (Brambilla et al., 2003; Stanfield, et al., 2008; Verhoeven, de Cock, Lagae, & Sunaert, 2010). Given the primary role that the PFC plays in EF, disruption of this region and associated regions in individuals with ASD lays the foundation for behavioral or functional differences in this population.

ASD and EF can be more fully understood by exploring the behavioral and neurological findings of three core EFs: inhibitory control, cognitive flexibility, and working memory. These topics are discussed in the paragraphs below.

Inhibitory control. Inhibitory control (also referred to simply as inhibition) can be defined as the ability to ignore, or suppress, thoughts or behaviors that are irrelevant, or inappropriate, and would likely interfere with goal-directed behaviors (Christ, Kester, Bodner, & Miles, 2007; Geurts, van den Bergh, & Ruzzano, 2014). For example, one may suppress the urge to shout out an answer or interrupt others during conversations. Inhibitory control is thought to consist of at least three sub-components: withholding prepotent responses (e.g. Go/No-Go tasks), resisting distracting information (e.g. Flanker tasks), and overcoming proactive interference (e.g. Cued recall tasks) (Friedman & Miyake, 2004). Christ, Holt, White, & Green (2007) assessed the three main sub-components of executive inhibitory control within a single ASD sample using a prepotent response inhibition task, a flanker visual filtering task, and a proactive interference memory task. Results indicated that individuals with ASD appear to have difficulty ignoring distracting visual information in comparison to typically developing individuals, but no significant differences were found between groups on measures of prepotent response inhibition and resistance to proactive interference. A subsequent study by Christ et al. (2011) found similar results in a study of prepotent response inhibition using a Counting Interference task and visual filtering using a Flanker task. A recent meta-analysis of 41 studies by Geurts, van den Bergh, et al. (2014) suggests that, overall, individuals with ASD display impaired performance on tasks examining resistance to distracting information (similar to Christ et al., 2011) and prepotent response inhibition. However, age and IQ were moderators of these effects and large variations in these areas were noted between studies that likely account for differences between the Christ and Geurts findings. Furthermore, the Christ studies were among the few studies that used the same sample to investigate multiple aspects of inhibitory control, thereby mitigating the possibility that differences in sample characteristics may have contributed to performance.

In addition to significant differences in behaviorally assessed aspects of inhibitory control, researchers utilizing inhibitory control tasks report atypical brain function in individuals with ASD in comparison to individuals without ASD. Individuals with ASD, compared with individuals without ASD, appear to display less activation in the PFC, and also decreased connectivity between the PFC and brain regions that influence the PFC (such as the anterior cingulate cortex; ACC), particularly during inhibitory control tasks (Agam, Joseph, Barton, & Manoach, 2010; Kana, Keller, Minshew, & Just, 2007). Kana et al. (2007) found that individuals with ASD displayed a decrease in ACC activation in comparison to individuals without ASD during a simple inhibitory control task (e.g. go/no-go task). During an anti-saccade task (i.e., a test of the ability to inhibit a prepotent eye movement), individuals with ASD displayed less activation in the frontal eye fields and dorsal ACC, as well as reduced connectivity between these regions in comparison to typically developing individuals without ASD (Agam, et al., 2010). Overall, individuals with ASD appear to have a decrease in brain activation in regions of the PFC and reduced connectivity within the PFC networks in comparison to individuals without ASD. Results appear to support theories of ASD-related differences in brain function during the tasks and/or group differences in performing inhibitory control tasks.

Cognitive flexibility. Cognitive flexibility (also referred to as shifting or task switching) can be defined as the ability to change thoughts and behaviors in response to changing environmental cues and challenges (for reviews, see Monsell, 2003; Miyake et al., 2000). For example, an individual may need to complete multiple tasks over a period of time (e.g., writing a report, responding to emails, and answering the phone), with each task comprised of multiple behaviors to accomplish the goal. There are associated costs to switching from one task to the next, such as increasing the amount of associated interference, memory load, and attention demands. These factors lead to slower response times and poorer efficiency when completing tasks, especially during unexpected changes in environmental demands (Monsell, 2003).

Researchers have postulated that cognitive flexibility is closely related to and integrated with the other EF processes including inhibition and working memory (Miyake et al., 2000). The Wisconsin Card Sorting Task (WCST) is a task that is traditionally associated with assessment of cognitive flexibility (Miyake et al., 2000). During the WCST, stimulus cards are presented, each of which is matched to one of four target cards. The correct ‘rule’ for matching the cards is unspoken, and the participant must deduce the rule based solely on feedback (correct vs. incorrect) from the examiner. Also, unbeknownst to the participant, the correct rule regularly changes, thus requiring the participant to detect the rule change and to modify their behavior accordingly. Consistent with the presence of impairments in cognitive flexibility, a number of studies have reported impaired WCST performance in individuals with ASD compared with typically developing individuals (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Griebling et al., 2010; Lopez, Lincoln, Ozonoff, & Lai, 2005; Tsuchiya, Oki, Yahara, & Fujieda, 2005; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2005; Voelbel, Bates, Buckman, Pandina, & Hendren, 2006; Winsler, Abar, Feder, Schunn, & Rubio, 2007). Studies utilizing other measures of cognitive flexibility (e.g., Trail Making Test/Advanced Trail Making Test, Intradimensional/Extradimensional Shift test – CANTAB, Modified Wisconsin Card Sorting Test), however, have yielded more mixed results (e.g., Edgin & Pennington, 2005; Goldberg et al., 2005; Happé, Booth, Charlton, & Hughes, 2006; Hill

& Bird, 2006; Landa & Goldberg, 2005; Nakahachi et al., 2006; Schmitz et al., 2006; Shafritz, Dichter, Baranek, & Belger, 2008; Sinzig, Morsch, Bruning, Schmidt, & Lehmkuhl, 2008). The lack of consist findings in studies of cognitive flexibility and ASD suggest task differences and/or sample heterogeneity influences, among other explanations. For example, the traditional WCST task is not a pure measure of cognitive flexibility, but includes additional working memory and social challenges. A systematic review or meta-analysis of the cognitive flexibility literature would provide insight into these discrepancies.

Studies utilizing fMRI have also reported atypical brain function in individuals with ASD in comparison to typically developing individuals during cognitive flexibility tasks (Schmitz et al., 2006; Shafritz et al., 2008). Schmitz et al. (2006) reported increased brain activation in right and left parietal regions in adults with ASD in comparison to adults without ASD on a cognitive flexibility task. However, in this study, no significant differences in cognitive flexibility performance were reported between groups. In contrast, a study of adolescents and adults with and without ASD reported a decrease in activation in frontal, parietal, and striatal regions in individuals with ASD during a cognitive flexibility task (Shafritz et al., 2008). Reasons for these activation differences may include atypical brain function and/or differences in performing the tasks between groups.

Working memory. Working memory (or updating) is the third core component of EF and the focus of the current study. Cowan (2008) defined working memory as a “multi-component system that holds and manipulates information in short term memory.” The application of working memory is a daily occurrence. For example, working memory is critical to remembering a name while maintaining a conversational topic, navigating a new city, or searching for objects. Working memory ability is positively correlated with other cognitive abilities, with individuals with higher intellectual functioning typically displaying higher working memory capacity and abilities (see Cowan, 2008 for review). Working memory abilities also improve with age (Gathercole, Pickering, Ambridge, & Wearing, 2004; Cowan et al., 2005) and begin to plateau and decline in the second decade of life (Park et al., 2002). With regards to individuals with ASD, previous studies report mixed findings on working memory performance in individuals with ASD in comparison to typically developing individuals across a range of tasks (see Geurts, de Vris, et al., 2014). A more thorough review of these studies is included in the next section, with studies organized based on distinction of whether the to-be-remember stimuli were primarily verbal or spatial in nature (thus primarily taxing verbal or spatial working memory, respectively).

Consistent with the previously described findings from neuroimaging studies of inhibitory control and cognitive flexibility in individuals with and without ASD, atypical brain activation has been reported in individuals with ASD during tasks of working memory (Luna et al., 2002; Koshino et al., 2005). For example, Luna et al. (2002) reported that individuals with ASD showed decreased activation in the dorsolateral prefrontal cortex (DLPFC) in comparison to a non-ASD comparison group during performance of an oculomotor test of spatial working memory. Koshino et al. (2005) found atypical ASD-related patterns of PFC activation during working memory performance, despite comparable behavioral performance between groups. Individuals with ASD showed greater activation of right prefrontal and parietal regions than individuals without ASD. One reason for these atypical activation patterns during EF tasks in individuals with ASD may be due to neural dysfunction, as described by theories implicating over- and/or under-connectivity of local and distal brain regions in individuals with ASD (Courchesne & Pierce, 2005; Just, Cherkassky, Keller, and Minshew, 2004; Just, Cherkassky, Keller, Kana, & Minshew, 2007). Differences in activation patterns may be due to differences in task performance between groups, such as (intentionally or unintentionally) completing tasks in a less optimal manner.

Visual and spatial working memory & ASD. Whereas some studies have found ASD-related impairments in visual and spatial working memory performance (Barnard, Muldoon, Hasan, O'Brien, & Stewart, 2008; Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Goldberg, et al., 2005; Gomarus, Wijers, Minderaa, & Althaus, 2009; Geurts et al., 2004; Happé et al., 2006; Joseph, McGrath, Tager-Flusberg, 2005; Koczat, Rogers, Pennington, & Ross, 2002; Landa & Goldberg, 2005; Luna et al., 2002; Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; McGonigle-Chalmers, Bodner, Fox-Pitt, & Nicholson, 2008; Minshew, Luna, & Sweeney, 1999; Morris et al., 1999; Sinzig et al., 2008; Steele, Minshew, Luna, & Sweeney, 2007; Verté et al. 2005; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006; Williams, Goldstein, Carpenter, & Minshew, 2005; Williams, Goldstein, & Minshew, 2006), other studies have reported comparable visual and spatial working memory performance in ASD and non-ASD individuals (Edgin & Pennington, 2005; Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & Strayer, 2001; Russell, 1997; Silk et al., 2006; Yerys, Hepburn, Pennington, & Rogers, 2007). The vast majority of previous studies on working memory in ASD have relied on standardized tests of spatial working memory performance, which range from simple (span tasks) to more complex (e.g., CANTAB Spatial Working Memory). Working memory capacity is generally assessed on more simple spatial working memory tasks such as span tasks that ask the individual to recall a sequence of items (e.g. letters, numbers, and locations). On a spatial memory-span task, Ozonoff and Strayer (2001) reported no significant differences in performance in children and adults with and without ASD. In contrast, adolescents, adults, and elderly individuals with ASD displayed significantly poorer performance in comparison to typically developing individuals on a similar span task, the spatial span subtest from the Wechsler Memory Scale (Geurts & Vissers, 2012; Joseph et al., 2005; Williams et al., 2005), see Figure 1.

More complex tasks of spatial working memory generally require updating and/or manipulation of information to be held in working memory. For example, the CANTAB Spatial Working Memory task (CANTAB SWM) is widely used to assess the ability to both retain and manipulate information in spatial working memory. CANTAB SWM is a computer-based, self-ordered task in which participants are presented with a number of colored boxes. Participants are instructed to find a set number of tokens under the boxes by using the process of elimination. The most efficient strategy is to remember and to avoid boxes that have already been noted to have tokens. The number of boxes increases as the task progresses, which challenges working memory demands. Edgin and Pennington (2005) reported no significant difference between children with and without ASD on CANTAB SWM performance. Ozonoff and Strayer (2001) found comparable results on a similar task, Box Search, in children and adults with and without ASD. On another complex task of visuospatial working memory, a Mental Rotation task, participants are presented with a three-dimensional target shape and four test shapes and asked to select the test shape (rotated between 45-180 degrees) that matches the target shape. Adolescents with and without ASD were also found to have similar performance on the Mental Rotation task (Silk et al., 2006). Geurts et al. (2004) reported no significant difference in performance between children with and without ASD on a Self-Ordered Pointing (SOP) task. The SOP task presents children with a number of different designs on a set of cards. The designs remain the same on subsequent cards in the set but the locations of the designs change. Children are asked to point to a different design on each card, which require them to remember designs they pointed to on previous cards.

In contrast, other studies utilizing the same measures (e.g., the CANTAB SWM task, SOP task) have found that children and adults with ASD perform more poorly in comparison to individuals without ASD (Corbett et al., 2009; Goldberg et al., 2005; Happé et al., 2006; Landa & Goldberg, 2005; Sinzig et al., 2008; Steele et al., 2007, Verté et al., 2005, 2006). The cause of these equivocal findings is unclear, as the aforementioned studies do not differ noticeably in methods or aspects of participant sample demographics (e.g. sample size, age, FSIQ). For example, studies utilizing CANTAB SWM typically tested individuals with and without ASD between the ages of 6-29 years with FSIQs above 70. Future research, including a systematic review and/or meta-analysis, will be employed to explore the contribution of task elements and complexity and sample heterogeneity to spatial working memory performance.

Effect sizes in visual and spatial working memory studies. The studies previously discussed employ Null Hypothesis Significance Testing (NHST) and rely on p-values to indicate significant or non-significant differences between groups. More information regarding the performance outcomes between groups can be derived from effect sizes, or the magnitude of the difference between groups. There may be an effect that did not reach significance in studies that previously reported similar performance between individuals with and without ASD. In investigating effect sizes, strengths and/or weaknesses in previously reported non-significant studies may be revealed. Not all studies reported the information needed to calculate effect sizes (e.g., mean, standard deviation), therefore only studies that reported the necessary information are discussed.

Indeed, a number of studies that reported comparable performance between individuals with and without ASD on tasks of spatial working memory showed an effect, though at times small. For example, despite not reaching statistical significance, Edgin & Pennington (2005) reported that individuals with ASD had a lower CANTAB SWM strategy score (or better strategy) than typically developing individuals, which was calculated to have a small effect (unbiased Cohen's $d = 0.23$). A small effect was also noted (unbiased Cohen's $d = 0.12$) in a study by Silk et al. (2006), with individuals with ASD performing with less accuracy on a task of Mental Rotation in comparison to non-ASD individuals (49% vs 51%). A study by Geurts et al. (2004) revealed a medium effect (unbiased Cohen's $d = 0.57$) on the SOP task, with individuals with ASD making more errors than non-ASD individuals on the task. These three studies indicate that an effect is present (small to medium) in both directions of performance (better or worse performance) for individuals with ASD in comparison to individuals without ASD in studies that previously reported non-significant findings. See Figure 1 for representation of spatial working memory studies including effect sizes and 95% confidence intervals (studies 1 through 7 are spatial span tasks, studies 8 through 23 are more complex spatial working memory tasks). Observations of Figure 1 suggest that, although not uniform, there appears to be overall differences in spatial working memory performance across simple and complex tasks between individuals with and without ASD, with individuals with ASD performing more poorly than individuals without ASD.

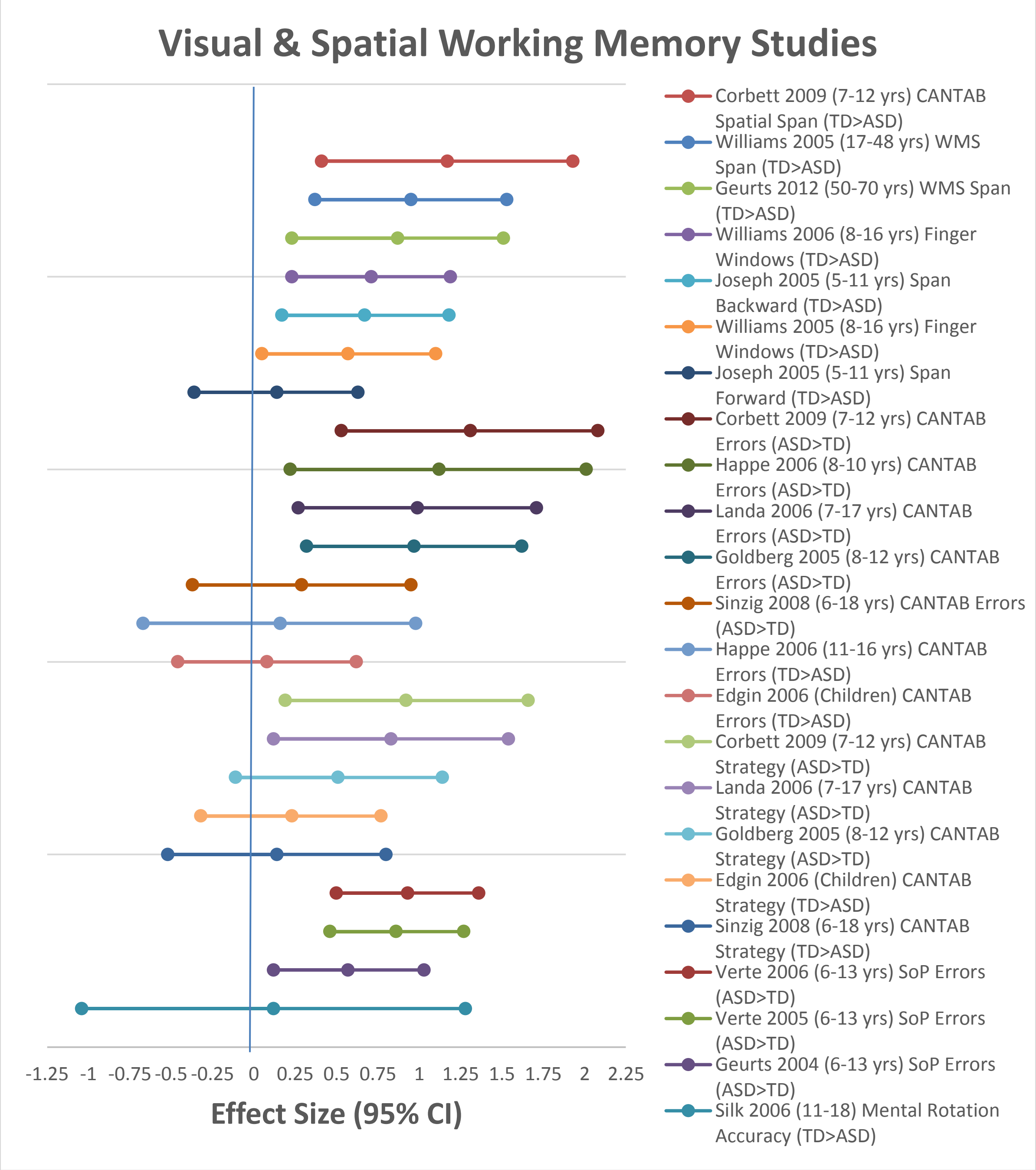

Figure 1: Visual & Spatial Working Memory and ASD Studies (effect sizes and 95% Confidence Intervals)

Verbal working memory & ASD. A number of studies of verbal working memory performance in individuals with and without ASD have reported comparable performance between groups (Koshino et al., 2008; Lopez et al., 2005; Nakahachi et al., 2006; Russell, 1997; Williams et al., 2005, 2006), whereas studies have also reported significantly poorer performance in individuals with ASD in comparison to non-ASD individuals (Bennetto, Pennington, & Rogers, 1996; Bodner, Beversdorf, Saklayen, & Christ, 2012). Studies of relatively simple verbal working memory tasks (e.g., digit, letter, number, and word span recall) generally find similar performance in individuals with ASD in comparison to individuals without ASD (Joseph et al., 2005; Nakahachi et al., 2006; Williams et al., 2005, 2006). Letter and Number sequencing tasks require the participant to remember a series of letters and numbers presented in random order. The participant is then asked to recall the numbers in order, and then recall the letters in order, to challenge retention and manipulation of incoming verbal information. Furthermore, individuals with and without ASD appear to display similar performance on more complex verbal working memory tasks such as N-back working memory tasks (Williams et al., 2005). However, in contrast, studies reported impaired performance for individuals with ASD in comparison to non-ASD individuals on Counting and Sentence Span (Bennetto et al., 1996), Digit Symbol (Nakahachi et al., 2006), Sentence and Story Recall (Williams et al., 2006), and Continuous Performance tasks (Bodner et al., 2012). The mixed findings in this domain mirror findings in previous spatial working memory literature, and may be the result of methodological challenges and/or sample differences.

Effect sizes in verbal working memory studies. Investigation of effect sizes in spatial working memory studies and ASD was helpful, and was also examined in studies of verbal working memory and ASD. On simple tasks, Nakahachi et al. (2006) reported better performance on Digit Span in individuals with ASD (19 vs 18 raw score) in comparison to individuals without ASD, resulting in a small effect (unbiased Cohen's *d* = 0.26). Joseph et al. (2005) also reported better performance on Word Span Forward subtest in individuals with ASD compared with individuals without ASD (mean words remembered: 4.8 vs 4.6) resulting in a small effect (unbiased Cohen's *d* = 0.10). However, in the same study, individuals with ASD displayed poorer performance on a more complex version of the task Word Span Backward (2.4 vs 3.0), resulting in a small effect (unbiased Cohen's *d* = 0.34). Studies using the WMS Letter/Number Sequence subtest (Williams et al., 2005, 2006) appear to result in lower standard scores for individuals with ASD in comparison to non-ASD individuals (2005: 12.14 vs 12.54; 2006: 8.61 vs 9.26), resulting in small effect sizes (unbiased Cohen's *d* = 0.15 and 0.22). Figure 2 displays effect sizes and 95% confidence intervals for studies of verbal working memory performance and ASD (ordered by effect size). Studies that reported the necessary summary statistics to calculate effect sizes were included in Figure 2.

Overall, in light of calculated effect sizes, there appears to be less consistency in findings in studies verbal working memory performance and ASD. Five of the seventeen effect sizes reported medium to large effects, and all five relate to more complex verbal working memory tasks (e.g., story recall, digit symbol). However, eight other effect sizes from complex studies (e.g., letter number sequencing, 2-back task) of verbal working memory were indicative of little to no effect. There appears to be ASD-related difficulties on more complex tasks of verbal working memory. A future line of research will include a systematic review and subsequent meta-analysis of verbal working memory studies and ASD.

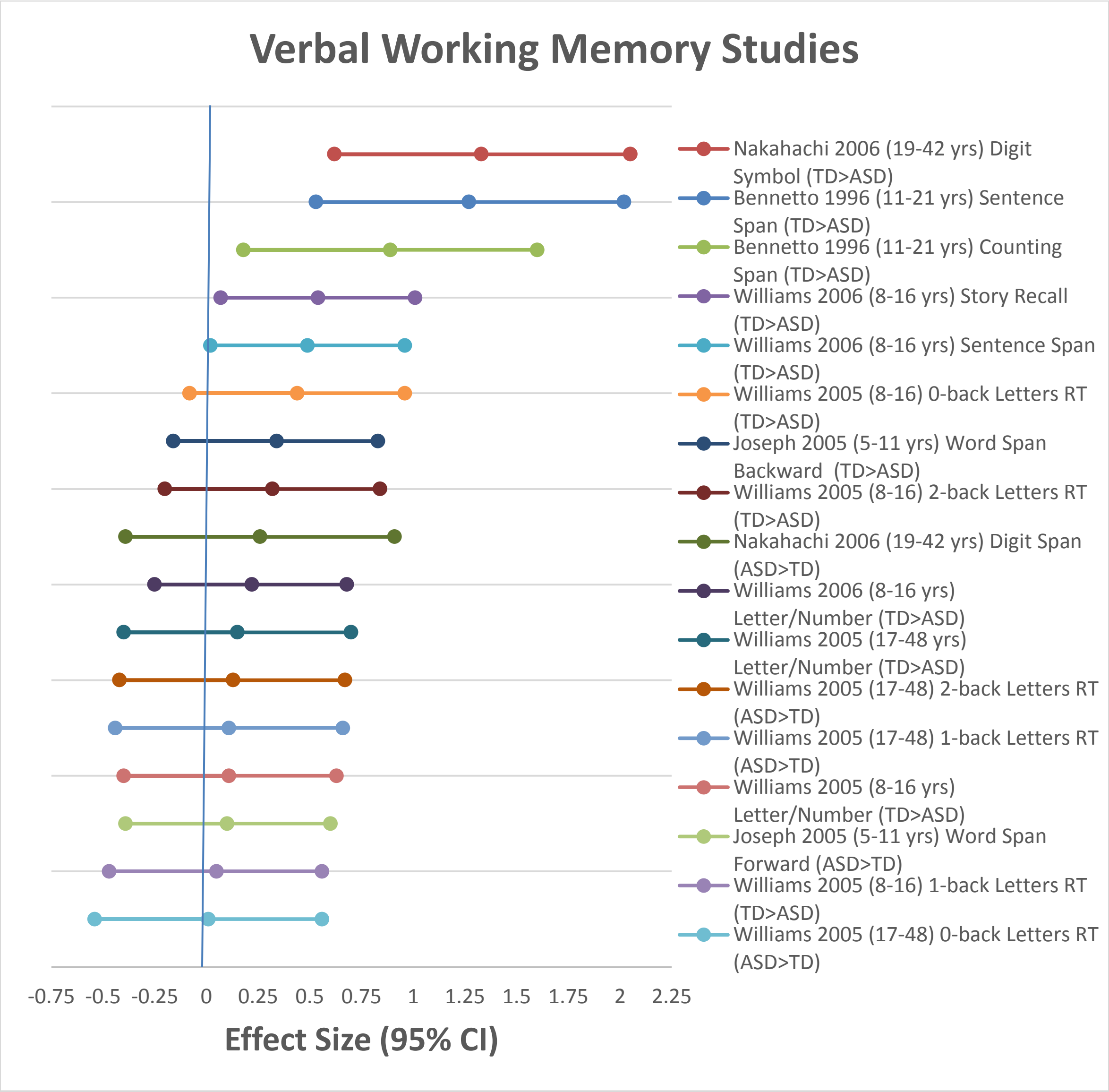

Figure 2: Verbal Working Memory and ASD Studies (effect sizes and 95% Confidence Intervals)

Contributions to equivocal working memory findings in ASD. As described in detail above, past findings on the integrity of working memory performance in individuals with ASD are quite mixed. A review of studies indicates that whereas interstudy differences in participant characteristics/demographics (e.g., age, symptom severity, overall level of functioning) may contribute to the discrepant findings, they cannot fully explain them. For example, studies of working memory performance using the same task have reported both similar and poorer performance in samples of both children and adults with ASD in comparison to age-matched typically developing individuals without ASD. Two studies using the CANTAB SWM task on similarly aged children and adolescents have reported both intact (Edgin & Pennington, 2005) and also impaired (Goldberg et al., 2005) performance in children with ASD. Fewer studies have investigated spatial working memory performance in adults with ASD and most of them have used and found impairments in WMS Spatial Span subtest performance (Barnard et al., 2008; Geurts et al., 2012; Williams et al., 2005). However, adults with and without ASD performed similarly on a more complex spatial working memory task that included a social component (e.g., n-back task using face stimuli) (Koshino et al., 2005).

Functioning level or cognitive abilities could also potentially impact the results of such studies, with an individual's overall level of functioning possibly moderating performance on working memory tasks. One might hypothesize that higher functioning individuals with intact cognitive abilities (FSIQ $\geq$ 80) may be more likely to have similar working memory performance, similar to typically developing individuals (see Cowan, 2008 for review). Conversely, one might postulate that lower functioning individuals may have better performance on working memory tasks due to enhanced or intact spatial functioning, as evidenced by faster performance on an embedded figure task (Jolliffe & Baron-Cohen, 1997). Similar spatial working memory performance was found between individuals with and without ASD with cognitive abilities in the average (Geurts et al.,

2004) and high average range (Silk et al., 2006). In contrast, differences in spatial working memory performance were found between groups with both average (Goldberg et al., 2005) and high average cognitive functioning (Sinzig et al., 2008). As mentioned earlier, nearly all studies recruit and test individuals with FSIQs >70, which makes an evaluation of much lower functioning individuals with ASD difficult.

Another potential factor for mixed findings could be due to the diversity of tasks used to assess working memory and the degree to which they place demands on different components of working memory. For example, studies of typically developing individuals have previously shown that working memory performance improves as individuals remember relevant information and ignore irrelevant information (Cowan, Morey, AuBuchon, Zwilling, & Gilchrist, 2010; Cowan, AuBuchon, Gilchrist, Ricker, & Saults, 2011). By identifying components that are most likely candidates for disruption (given past ASD research), and then systematically assessing the contribution of these specific components to working memory performance in ASD, we may provide valuable insight into the nature of working memory performance in individuals with ASD. In the next chapter, I review a leading theory of working memory and explore how disruptions in particular core components of working memory might affect task performance.

Chapter 2: A Model of Working Memory Development and Disruption

As our understanding of working memory has evolved, multiple definitions and models of working memory have been postulated. Our understanding of working memory is constantly evolving in light of new research and with the advancement of technology. One of the earliest and influential models of working memory was proposed by Baddeley and Hitch (1974). Baddeley's model of working memory highlights a complex system of specialized components (Baddeley & Hitch, 1974; Baddeley, 1992). Baddeley suggested that working memory is maintained by a central executive that manipulates two subsystems, verbal and spatial, consisting of a phonological loop and visual spatial sketchpad. Baddeley later updated his model to include an episodic buffer (or a shared space for the two subsystems) in order to more fully capture and explain working memory processes (Baddeley, 2000).

Subsequent models of working memory challenge the presence of specialized neural systems for auditory and visual spatial information, as other memory modalities (e.g., tactile) are excluded (e.g., Cowan, 1988; Postle, 2006). Cowan's model proposes that working memory consists of (1) activating elements of long term memory and (2) holding activated information in the focus of attention (Cowan, 1988; 1995; 2005). His model generally downplays the notion of specialty systems devoted to specific modalities (e.g., auditory and visual spatial only). Growing evidence from neuroimaging studies support this conceptualization of working memory (see review Bledowski, Kaiser, & Rahm, 2010). Therefore, the current study and future body of research lends itself to Cowan's model of working memory, as it accounts for a common method of functioning regardless of modality. This model represents the core components of working memory that can be evaluated such as working memory capacity and attention.

Working Memory Components

Working memory performance is dependent on a number of cognitive functions, such as capacity (amount of information stored), attention (focus on relevant information), filtering (ignoring irrelevant information), manipulation (updating information), encoding and maintaining (storing information), and rehearsal (techniques to maintain information). These cognitive functions and processes have their own unique contribution to working memory performance, yet these processes are dependent on each other. For example, poor working memory capacity may be the result of low capacity and/or attention or filtering impairments. Individuals with high working memory capacity may have such strength due to exceptional rehearsal and encoding abilities or perhaps due to effective filtering of distracting information. As such, interruptions or impairments in one or more of these cognitive functions can significantly disrupt working memory performance. Strengths in one or more of these areas may indeed compensate for other underperforming processes. However, identifying specific intact and/or impaired cognitive functions that contribute to working memory performance in an individual is quite difficult. For the purpose of the current study, three distinct but interdependent components of working memory performance were examined (capacity, attention, and filtering), with the contribution of other working memory processes to be evaluated by future research.

Working memory capacity. Capacity refers to the maximum amount of information an individual can hold in working memory at one time (Cowan, 2005). Individuals may vary in their capacity; however, in the general population, the typical amount of information that can be kept in working memory is typically 3-4 items (Cowan, 2001). This number may increase or decrease depending on the relatedness of the items to be remembered and their propensity to be “chunked” or grouped together.

Working memory capacity is often the primary outcome variable measured during working memory performance tasks. For example, a higher score on the WMS spatial span subtest is generated from a higher number of objects kept in working memory at one time. Furthermore, poor working memory capacity would ultimately impair more complex working memory performance abilities (e.g. manipulation of objects in working memory). For example, individuals with known impairments in working memory capacity (e.g. only able to hold 1 piece of information in working memory) would presumably perform less well on 2-back working memory tasks. Such difficulties would be attributed to working memory capacity rather than a deficit in manipulation or attention abilities. Conversely, working memory capacity is also susceptible to the performance of other cognitive abilities, such as attention and filtering. For example, an individual with difficulties with attention and filtering may not be selective in the "type" of information retained and may retain more irrelevant information in storage, resulting in a lower working memory capacity. Working memory capacity is one of the variables of interest for the current study.

Relevant to the current proposal, the literature (when effect sizes are calculated) appears to support working memory capacity impairment in individuals with ASD in comparison to individuals without ASD (Corbett et al., 2007; Geurts et al., 2012; Williams et al., 2005, 2006). Individuals with ASD may have less working memory capacity and keep less information in working memory at one time than typically developing individuals. Alternatively, individuals with ASD may have impairments in the associated cognitive processes that support capacity, such as impairments in attention and/or visual filtering, meaning they may keep the same amount of information in working memory but fill capacity slots with irrelevant or less important information.

Attention. The next two cognitive processes discussed, attention and visual filtering, are quite closely related and dependent on each other. Initially, Broadbent

(1958) defined attention as selectively attending to stimuli while simultaneously ignoring other stimuli. Later discussions of attention and selective attention indicate that individuals orient to novel stimuli and habituate to monotonous stimuli over time, which can be an active or passive process (Cowan, 1988, 1995). For example, more effort is used to focus attention on visual input over simultaneously presented auditory input.

Similar to capacity, the cognitive process of attention is an integral component to working memory performance. Previous research has reported that attention contributes to working memory capacity and performance. For example, individuals with low working memory capacity performed more slowly (poorer control of attention) on an anti-saccade task than individuals with high working memory capacity (Engle, 2002). Difficulty with social aspects of attention can be an early sign of the presence of a diagnosis of ASD. For example, parents often report that their child with ASD does not attend to them when they call their name (socially orienting) and/or respond to parents' efforts to direct their child's attention (joint attention, Dawson et al., 2004). Poor social response (e.g., attention to name call, eye contact) is assessed as part of the diagnostic process for ASD, as evidenced by use of standardized measures to assess the presence or classification of ASD, such as the Autism Diagnostic Interview (Rutter, Le Couteur, & Lord, 2003) and Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore, & Risi, 2003). In situations without a social component (using visual orienting tasks similar to Posner, 1978), individuals with ASD also display difficulties orienting attention in comparison to individuals without ASD (Townsend, Courchesne, & Egaas, 1996; Townsend, Harris, & Courchesne, 1996; Wainwright-Sharp & Bryson, 1993). Attention is another primary outcome variable of interest for the current study due to its direct relationship to working memory performance and known deficits in individuals with ASD.

Visual filtering. Visual filtering is distinct, yet related to, the cognitive process of attention. Attention orients one's focus on target objects, whereas the cognitive process of visual filtering attenuates the signal from irrelevant or distracting information (Luck & Hillyard, 1994). In doing so, more relevant information may be passed into working memory because irrelevant information does not occupy valuable capacity space. For example, McNab & Klingberg (2007) found that individuals with high working memory capacity may be more efficient at filtering out irrelevant information than individuals with lower working memory capacity, thereby improving working memory performance. Important to the current study, attention and visual filtering work in tandem during visual working memory tasks for optimal functioning in a visually complex environment (Cowan & Morey, 2006; Vogel, Woodman, & Luck, 2006).

Previous research has highlighted that individuals with ASD have difficulty filtering out distracting visual information (Christ et al., 2007, 2011; Dichter & Belger, 2007; Geurts, Luman, & van Meel, 2008). In turn, these visual filtering impairments may contribute to some of the atypical working memory performance previously discussed. As such, the inability to filter visually distracting information may make it more difficult to focus on and remember visually important information. Given the countless types of incoming visual information we must process in order to function effectively in daily life (e.g. lights, people), the ability to filter out irrelevant visual information and focus on the important information is essential for optimal functioning. However, to date, the contribution of visual filtering abilities to working memory performance in individuals with ASD remains unclear.

Additional working memory components. Capacity, attention, and visual filtering are just a few of the contributing processes to working memory. They are also the primary variables of interest for the current study and serve as starting points for a future body of research. However, these three variables do not fully encompass all aspects of working memory abilities and performance. Remaining cognitive processes, such as encoding, maintenance, and manipulation, are also integral to working memory performance. The process of encoding is defined as the consolidation or transferring a “perceptual representation” of information into working memory (Vogel et al., 2006). Afterward, these representations are intentionally maintained or kept in an active state (Cohen, et al., 1997). Woodman & Vogel (2005) suggest that these two processes, encoding and maintenance of information, are distinct from each other. Manipulating and/or updating information in working memory is an active and more complex process that requires individuals to monitor incoming information as it relates to existing information in working memory, as evidenced in n-back working memory tasks (Owen, McMillan, Laird, & Bullmore, 2005). These cognitive processes are important to working memory performance, but they are secondary to capacity, attention, and filtering abilities. The three variables of interest for the current study consist of the most critical core components of working memory performance and are potentially impaired in individuals with ASD.

Chapter 3: The Current Study

The current study is designed to clarify conflicting literature on working memory performance in individuals with and without ASD. In doing so, the current study assesses visual working memory performance as a starting point for a body of research, not just by examining one outcome variable, but by evaluating the contribution of multiple cognitive processes. This method of evaluating working memory has not been utilized by any previous study and fills a gap in the literature. Furthermore, findings from the current study will lay groundwork for understanding working memory performance in other modalities in individuals with ASD such as spatial and verbal working memory.

The domain of visual working memory was chosen for this initial research for multiple reasons. First, visual and spatial working memory is integral to participation in daily life. We use this cognitive process to navigate the environment and maintain directions to reach locations, search for and find objects, and perform academic tasks (e.g., arithmetic, geometry, science, arts). Second, investigating visual working memory in individuals with and without ASD removes the “social” challenges that may be present in verbal working memory performance. Given that a diagnosis of ASD is characterized by social and communication impairments, the addition of language or socialization challenges makes assessing verbal working memory more complex. Cowan’s model of working memory suggests that working memory processes are not modality specific (e.g., Cowan, 1988); therefore findings in visual working memory performance may be applied to spatial and verbal working memory performance. Further understanding is needed about the underlying processes that contribute to visual working memory impairments in individuals with ASD.

The current study examined (a) capacity, attention, and/or visual filtering abilities in relation to visual working memory performance in individuals with ASD in comparison to individuals without ASD and (b) the relationship between visual working memory performance and reports of EF abilities in daily life in individuals with ASD.

Rational for Participant and Task Selection

Given the rapid development of brain structure and function in children and adolescents, as a starting point the current study focuses on older adolescents and adults with and without ASD. Furthermore, previous studies typically investigate visual and spatial working memory performance in children or combine both children and adults with ASD, leaving a gap in knowledge in this later stage of development.

Working memory performance and intelligence are highly related (Conway, Kane, & Engle, 2003). In testing a higher functioning sample of individuals with ASD (average or above verbal and cognitive abilities), individuals more fully understand task instructions and are more likely to be compliant with task procedures. Individuals with ASD that had comorbid diagnoses with known impairments in attention were included in the study, as having a both a diagnosis of ASD and ADHD are extremely common (>30% Leitner, 2014). Although a diagnosis or symptoms of ADHD would likely cause deficits in working memory performance, the current study utilizes multiple measures to assess and investigate the influence of attention (e.g., behavioral, eye tracking, and questionnaires).

Previous research investigating spatial working memory performance utilized diverse methodology to investigate this construct in individuals with ASD; therefore, methodological differences may contribute to, though do not fully explain, underlying group differences. For example, spatial span tasks assess simple working memory capacity, and CANTAB SWM assesses attention, updating, and capacity processes supporting working memory performance. However, using two different types of tasks to investigate spatial working memory introduces confounds. The current study employed one task that is manipulated to tease apart simple and complex working memory processes, such as capacity, attention and visual filtering.

Hypotheses & Predictions

The current study investigates how capacity, attention, and visual filtering abilities contribute to visual working memory performance in individuals with ASD and the extent to which such performance differs in comparison to individuals without ASD. Furthermore, for individuals with ASD, the current study elucidates how visual working memory performance may relate to real world executive function abilities such as reported working memory abilities. The current study addresses the following hypotheses:

Hypothesis #1: Individuals with ASD have lower working memory capacity than healthy individuals without ASD. In general, studies investigating visual or spatial working memory capacity across a range of ages in individuals with ASD have reported impaired performance in comparison to individuals without ASD (Geurts et al., 2012; Joseph et al., 2005; Williams et al., 2005). One study has investigated purely adult performance on a spatial span working memory task in individuals with and without ASD and reported impaired performance in individuals with ASD (Williams et al., 2005). The current study hypothesizes that adults with ASD will display lower visual working memory capacity overall on the Attention and Visual Filtering Working Memory Task **(**AVF-WM; for description of task, attention conditions, and outcome variables see Methods section) in comparison to individuals without ASD.

This hypothesis would be supported by behavioral data showing that individuals with ASD have significantly lower estimated capacity k scores than non-ASD participants on the AVF-WM task overall. The best measures of working memory capacity will be observed during the *1-shape* condition of the AVF-WM task, as there are no task distractors present to interfere with performance by further challenging attention and visual filtering abilities. In the *1-shape* condition, I predict that individuals with ASD will display larger differences in more challenging conditions, such as conditions with more items in the tested shape (e.g., 4 and 6 objects). I further predict that I will observe a basal effect (or no differences between groups) during the *1-shape* condition with less objects in the tested shape (e.g., 2 and 3 objects). In contrast, should this hypothesis be incorrect, I predict that there will be no significant group differences in the *1-shape* condition despite the number of objects in the tested shape. Results would then imply there are no working memory capacity differences on this task between individuals with and without ASD. These results could occur because the task was not challenging enough or older individuals with ASD may compensate for potential early differences in capacity with age by performing the task in a different manner. Investigation of eye gaze between groups in this condition would inform the latter.

Hypothesis #2: Individuals with ASD are less effective than healthy individuals without ASD at preferentially allocating attention, especially to targets, during performance of a visual working memory task with a higher number of objects in the tested shape. The diagnostic criteria for ASD is inclusive of difficulties with attention as evidenced by poor social response or orienting, poor joint attention, and lack of or inconsistent eye contact among others (Dawson et al., 2004; Rutter et al., 2003; Lord et al., 2003). Behavioral studies employing eye tracking capabilities have also reported poorer selective attention in individuals with ASD in comparison to participants without ASD (Minshew et al., 1999). Furthermore, comorbid diagnoses of ADHD and ASD are quite common (Leitner, 2014), potentially suggesting an overlap in symptomatology and neural commonalities related to difficulties with attention. I hypothesize that individuals with ASD will display impaired selective attention in comparison to non-ASD participants. The first hypothesis, lower working memory capacity in the ASD group in comparison to non-ASD participants, may be due to underlying difficulties with attention. Importantly, the present task does not measure "pure" attention or visual filtering independently, but I acknowledge that the roles of these two functions are intertwined during the AVF-WM. For example, in the *1-shape* condition, participants must ignore incoming visual information unrelated to the task (e.g., computer equipment, peripheral motion from the examiner). As such, attention conditions are examined with the understanding that concurrent visual filtering processes are at work to various degrees (and especially as distractors and the number of objects in the tested shape increases) during performance on the AVF-WM task.

The current study utilizes both behavioral and eye tracking outcomes to investigate this hypothesis. Overall, I hypothesize that both groups will be impacted by attentional demands, thus resulting in lower working memory capacity estimates as attention demands increase (or attention is divided). Similar to my hypothesis regarding working memory capacity, I predict that I will observe no differences in performance between groups within the lowest number of objects in the tested shape (e.g., 2 objects) across attention conditions (*1-shape, DP-100, High Frequency,* and *Low Frequency*). However, I predict that as the number of objects in the tested shape increases (e.g., 3 and 4 objects), individuals with ASD will be more impacted (or have lower capacity estimates) by an increase in attention demands (*DP-100, High Frequency,* and *Low Frequency*) than non-ASD participants.

Alternatively, analyses may reveal no significant differences between groups when examining estimates of capacity across the number of objects in the tested shape and attention condition. Independently, these results would suggest comparable selective attention between groups. However, previous studies have shown differences in brain activation patterns during tasks despite equivalent behavioral performance among ASD and non-ASD groups (Griebling et al., 2010; Koshino et al., 2005; Schmitz et al., 2006). These findings suggest that individuals with ASD may perform EF tasks in a different manner (possibly in a less optimal manner) than non-ASD participants, but not so much so that impacts performance outcomes. Therefore, the current study utilizes eye tracking capabilities to assess attention in both groups. Mall, Morey, Wolff, & Lehnert (2014) highlighted that “fixations meaningfully affect behavioral performance,” in that the more time spent looking at (or fixating on) a target the more likely one is to remember it.

Therefore, further support for ASD-related impairments in attention may be observed in eye tracking data. I predict that, across conditions and the number of objects in the tested shape, individuals with ASD will spend significantly less time than non-ASD participants looking at target stimuli during the object array presentation. In a sense, individuals with ASD will not utilize the “best strategy” for remembering probed stimuli (e.g., to look at the target stimuli). However, should results reveal no significant differences between groups on this outcome variable (e.g., groups spend equal time looking at target stimuli), such a result may suggest difficulties with other cognitive processes (e.g., visual filtering, encoding, and rehearsal among others).

If no significant differences between groups are found on behavioral or eye tracking outcome variables, these results would suggest that groups did not differ on attention overall or that the task did not accurately measure this variable of interest. However, given the known impairments in attention in ASD, such as outcome seems unlikely. Self- and parent-report questionnaires of attention and hyperactivity were administered for each participant. Analyses of questionnaire data provides more information about how attention relates to task performance.

Hypothesis #3: Individuals with ASD have more difficulty filtering out irrelevant (distracting) incoming information during a visual working memory task in comparison to healthy individuals without ASD. The literature on attention and visual filtering in individuals with ASD is more conclusive. Individuals with ASD display more impairments in visual filtering in comparison to non-ASD individuals (Christ et al., 2007, 2011; Geurts et al., 2008). However, impairments are generally evident in children and adolescents with ASD (e.g., under 16 years of age) rather than adult participants. Therefore, I hypothesize there will be no differences between groups in visual filtering scores in the smallest number of objects in the tested shape (2 objects) in the *High/Low Frequency* condition. As task complexity increases (3 and 4 objects in the tested shape the *High/Low Frequency* condition), I hypothesize that the current study will display lower visual filtering scores (or poor visual filtering abilities) in individuals with ASD in comparison to non-ASD participants. Furthermore, results would suggest that individuals with ASD may take up working memory “slots” with more distracting or unimportant information, resulting in lower working memory capacity for target information overall. These findings lend support to the theory that EF impairments in ASD become more pronounced as cognitive demands increase (Kenworthy et al., 2008).

As previously discussed, the present study may not detect differences between groups in visual filtering abilities. Independently, these results would suggest comparable visual filtering abilities between groups. Analyses of eye tracking data during object array, specifically the proportion of time spent looking at distractors, will be informative. I predict that differences will be observed in eye tracking data between groups. Specifically, I expect to find that individuals with ASD will spend significantly more time than non-ASD participants looking at distractors during the object array presentation. These findings will become most evident during more challenging conditions (3 and 4 objects in the tested shape in the *DP-100* and *High/Low Frequency* conditions). These results would suggest that individuals with ASD spend more time looking at “less optimal” information, which is a less efficient strategy for performing the task.

Hypothesis #4: Performance on the AVF-WM task will relate to real world performance of EF in daily life. EF abilities are hypothesized to consist of multiple subcomponents or interconnected cognitive processes that support goal direct behaviors, and deficits in one area may lead to deficits in adjoining areas (Cowan et al., 2005; Miyake et al., 2000; Miyake et al., 2001; Monsell, 2003). Although the AVF-WM task evaluates visual working memory performance specifically, the task also investigates the cognitive processes needed to support working memory (e.g. attention, visual filtering, planning, and initiation among others). These supporting processes are essential to real world functioning.

The current study hypothesizes that performance on the AVF-WM will relate to reported EF abilities in daily life. I expect the data to show that performance on the AVF-WM will be correlated with BRIEF questionnaire data, which assesses EF within the context of an individual's day-to-day environment overall and working memory abilities. Results will show that poorer performance on aspects of the AVF-WM task will relate to reported EF and attention symptoms. However, should no relationship be found between the AVF-WM and BRIEF (especially working memory abilities), one may assume that the reported aspects of reported EF and attention abilities may be too broad overall and not specific to those utilized during the AVF-WM task. For example, reported working memory abilities may be assessing multiple modalities (e.g., verbal, visual, tactile) with potential social constraints that are not assessed during the AVF-WM.

Methods

Participants

Participants with and without ASD were recruited for the current study. Participants with ASD were recruited using a pre-existing database of previously diagnosed individuals with ASD from the Thompson Center for Autism and Developmental Disorders. All participants with ASD had been diagnosed with ASD by qualified clinical or medical personnel based on diagnostic interviews, caregiver questionnaires, and observation focused on DSM-IV criteria (American Psychiatric Association, 2000). The diagnosis of ASD was further confirmed using the Autism Diagnostic Observation Schedule (ADOS-G, Lord et al., 2003 or ADOS-2, Lord et al., 2012) and/or the Autism Diagnostic Interview-Revised (ADI-R, Lord, Rutter, & Le Couteur, 1994). Descriptions of the ADOS and ADI-R can be found below. Individuals with severe cognitive impairment, learning disorders, or major medical disorders unrelated to autism were excluded. Typically developing participants were recruited from Columbia, Missouri. Participants in this group were excluded from the study if they reported having a diagnosis or reported taking medication for a neurodevelopmental, psychopathological, and/or neurodegenerative disorder. Estimated Full Scale IQ (FSIQ) for all participants was at or above the average range ($\geq$ 80).

All participants were screened for color blindness and for medications related to treating attention and anxiety/depression difficulties, such as stimulants (e.g. Adderall, Ritalin), non-stimulants (e.g. Strattera, Intuniv), antidepressants (e.g. Wellbutrin), and anti-hypertensive medications (e.g. Clonidine, Tenex, propranolol). Participants with ASD taking attention-related medications or medications known to affect working memory performance (Vyvanse or propranolol) were included in the study if they were able to safely refrain (as per their treating physicians) from taking the relevant medication for 24 hours prior to testing. Participants with ASD who could not refrain from taking these medications were excluded.

Over three months, 178 individuals and families were either contacted by our lab (between one to three inquiry phone calls or emails per family to inform them of our study) or contacted our lab themselves to inquire about participation in the current study (approximately 55% with ASD), of which 94 individuals were screened for eligibility. Sixty individuals (31 individuals with ASD and 29 individuals without ASD) were found to eligible for the study and all attempts were made to schedule their participation. Nine individuals (5 with ASD and 4 without ASD) were eligible but declined to participate. A total of 51 participants (26 with ASD and 25 without ASD) were tested for this study.

Three participants were excluded after participation (2 participants with ASD and 1 participant without ASD) due to excessive sleepiness, poor effort (e.g., subject informed examiner he did not try his best at end of study), or computer malfunction. Thus, data from 48 participants (24 with ASD; 24 without ASD) between the ages of 16 and 24 years of age were analyzed for this study.

The ASD and non-ASD groups did not statistically differ in age, level of intellectual ability (FSIQ, VIQ, and PIQ) as estimated using the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II, Wechsler, 2011), or parent education level, $ts(46) < 1.69$, $ps > 0.09$, Cohen's $ds < 0.49$. However, compared with individuals without ASD, individuals with ASD had both lower education and lower parent total income, $ts(46) > 2.47$, $ps < 0.02$, Cohen's $ds > 0.73$ (see Table 1, sample characteristics).

Table 1

Sample Characteristics

	ASD **(n = 24)**		**Non-ASD** **(n = 24)**		
Variable	*M*(*SD*)	*Range*	*M*(*SD*)	*Range*	*ps*
Age (years)	19.61(2.18)	16.1-24.2	20.31(2.15)	16.3-23.7	0.272
Verbal IQ[a]	106.33(9.06)	75-126	104.75(8.24)	86-124	0.530
Perform. IQ[a]	115.75(13.22)	94-148	109.75(11.14)	89-138	0.096
FSIQ[a]	112.17(9.40)	83-130	108.13(8.31)	89-127	0.122
Ed Level	11.92(1.17)	9-15	13.00(1.71)	10-16	0.014
Parent Ed Level	15.97(1.87)	13-19.5	15.81(1.64)	13-19	0.761
Parent Income[b]	$100,477 ($58,459)	$25-50,000	$147,250 ($68,846)	$70-400,000	0.017

[a]Based on the WASI-2 (Wechsler, 2011); [b]Two participants with ASD could not estimate parent income

Procedure

Autistic symptomatology. In order for participants with ASD to be eligible for the current study, they had to meet cutoffs on at least one of two gold standard tools for assessing the presence of ASD: the Autism Diagnostic Interview – Revised and/or the Autism Diagnostic Observation Schedule. These measures are used to inform clinical judgment and a diagnosis of ASD. Given the known heterogeneity of symptom presentations in the population of individuals with ASD, classification of ASD on the ADI-R and/or ADOS ensures that clinical symptoms reached a common threshold of severity to warrant diagnoses. Current ASD symptomatology was measured with a self- or parent-report version of the Social Responsiveness Scale, Second Edition (SRS-2 - Adult Self Report & School-Aged).

Autism Diagnostic Interview-Revised (Rutter et al., 2003). The ADI-R is an investigator-based structured interview that is administered to the participant's principal caregiver with the purpose of obtaining detailed descriptions of current behavior and early development necessary to document symptoms consistent with ASD, especially within the context of early development. The interview focuses on those features concerned with developmental delays and deviance in reciprocal social interactions, language, communication and play, and on restricted, repetitive and stereotyped behaviors and interests. The information provided by the informant is scored using a structured scoring system, and then DSM-IV or ICD-10 algorithm is applied that relates the item scores to the diagnostic criteria. The ADI-R results in cutoff scores in three domains (Social Interaction, Communication, and Restricted and Repetitive Behaviors). A classification of ASD is indicated when all three cutoffs are met and are consistent with informed clinical diagnostic impressions.

Autism Diagnostic Observation Schedule – Generic (Lord et al., 2003) or Autism Diagnostic Observation Schedule – 2 (Lord et al., 2012). The Autism Diagnostic Observation Schedule (ADOS-G or 2) is a direct assessment instrument administered to evaluate the presence of observable behaviors associated with ASD. The ADOS is a semi-structured assessment in which the child or adult is presented with a number of situations, tasks, and presses. The evaluator is provided the opportunity to observe behaviors across four domains: communication, qualitative impairments in reciprocal social interaction, imagination/creativity, and stereotyped behaviors and restricted interests. Observed behaviors are coded using a structured system. The items are scored using an algorithm that links items to DSM-IV or ICD-10 criteria for ASD. The ADOS-G total scores from the social and communication domains are used to classify individuals as meeting criteria for a classification of Autistic Disorder or Autism

Spectrum Disorder. The ADOS-2 total scores include scores from the social affect domain (sum of communication and reciprocal social interaction) and restricted and repetitive behavior domains to classify individuals as meeting criteria for ASD.

Of the 24 participants with ASD included in analyses, 6 were only administered and met clinical cutoffs on a version of the ADOS, 4 were only administered and met cutoffs on the ADI-R, and 14 were administered and met cutoffs on both a version of the ADOS and ADI-R.

Social Responsiveness Scale, Second Edition - Adult Self Report & School-Aged (SRS-2, Constantino & Gruber, 2012). Adult participants completed the Social Responsiveness Scale, Second Edition – Adult Self Report, a 65-item self-report rating scale to measure the severity of autism spectrum symptoms in natural social settings. Areas assessed are Social Awareness, Social Cognition, Social Communication, Social Motivation, and Restrictive and Repetitive Behaviors. Raw scores for each domain and total scores are converted to T scores based on normative data. Higher T-scores indicates more severe ASD symptomatology. T-scores are categorized as follows: 59 and below are considered within normal limits, 60-65 are in the mild range, 66-75 in the moderate range, and 76+ are in the severe range. T-scores indicate the presence or absence of clinically significant impairments in ASD-related areas. A SRS-2 Total Score is computed based on the combination of all five domains previously described. DSM-5 compatible T-scores are provided for the domains of Social Communication Impairment and Restricted and Repetitive Behaviors.

The parents/guardians of adolescent participants were given the Social Responsiveness Scale, Second Edition, School-Aged form to complete (Constantino &

Gruber, 2012). The 65 parent-reported items on the SRS-2 School-Aged are nearly identical to the SRS-2 Adult Self Report Form, with the exception that the School-Aged form is worded in third person (e.g., "Is able to communicate his or her feelings to others" versus "I am able to communicate my feelings to others"). Items on the SRS-2 School-Aged form are tallied in a similar manner as the SRS-2 Adult Self-Report form to calculate the domain and total scores.

As expected, for adult participants, independent t-tests revealed significant differences between groups on all domains of the SRS-2 Self Report form, *ts*(35) > 2.95, *ps* < 0.03, Cohen's *ds* > 0.96, with the ASD group displaying higher T-scores compared with the non-ASD group (see Table 2). Similar to adult participants, independent t-tests among the adolescent participants revealed significant differences between groups on all domains of the SRS-2 Parent Form, *ts*(9) > 2.73, *ps* < 0.02, Cohen's *ds* > 1.72, with the ASD group displaying higher T-scores in comparison to the non-ASD group. These differences are depicted in Table 3. Results reveal the current presence of significant ASD symptoms in the ASD group as a whole, and the relative lack of ASD symptoms in the non-ASD group as a whole.

Table 2

SRS-2 Scores for Adult participants by Group

	ASD (n=18)		**Non-ASD (n=19)**		
	Mean (SD)	*Range*	*Mean (SD)*	*Range*	*Cohen's d*
Social Awareness T*	60.6 (10.7)	47-83	48.2 (5.5)	41-58	1.45
Social Cognition T*	57.4 (9.6)	41-76	49.0 (7.4)	41-72	0.98
Communication T*	59.6 (10.8)	38-80	47.8 (5.8)	40-59	1.36
Social Motivation*	64.4 (9.4)	44-84	51.3 (6.9)	39-64	1.58
RRB*	63.8 (11.7)	42-92	52.9 (6.6)	40-68	1.14
SRS Total T*	62.1 (10.0)	40-81	49.6 (5.5)	40-64	1.54

**ps* < .03

Table 3

SRS-2 Scores for Adolescent Participants by Group

	ASD **(n=6)**		**Non-ASD** **(n=5)**		
	Mean (SD)	*Range*	*Mean (SD)*	*Range*	*Cohen's d*
Social Awareness T*	60.5 (13.2)	45-82	43.6 (3.7)	38-48	1.74
Social Cognition T*	58.6 (5.2)	50-66	41.4 (2.4)	39-44	4.24
Communication T*	62.5 (11.7)	51-84	40.2 (1.9)	38-43	2.66
Social Motivation*	64.1 (12.2)	46-81	44.4 (5.5)	40-54	2.08
RRB*	67.5 (12.5)	48-80	42.6 (1.6)	41-45	2.79
SRS Total T*	64.3 (10.9)	49-82	41.2 (.83)	40-42	2.98

*$ps < .02$

Executive function and attention in the context of everyday life. The current study investigated the relationships between the lab-based measure of EF (aspects of AVF-WM task) and variables from the self- or parent-report measures of EF abilities and attention. These measures are described in the paragraphs that follow.

Behavior Rating Inventory of Executive Functioning – Adult Version (BRIEF-A; Roth, Isquith, & Gioia, 2005) and Parent Form (Gioia, Isquith, Guy, & Kenworthy, 2000). Adult participants were administered the Behavior Rating Inventory of Executive Functioning – Adult Version (BRIEF-A). The BRIEF-A is a standardized self-report questionnaire designed to assess EF within the context of an individual's day-to-day environment. It consists of 75 items assessing behavioral manifestations of executive problems in daily life. Items comprise nine non-overlapping clinical scales reflecting different aspects of EF including inhibitory control, self-monitoring ability, planning and organizational skill, emotional control, and working memory. In addition, two broader indices (Behavioral Regulation Index, BRI and Metacognition Index, MI) as well as an overall index reflecting overall executive ability (Global Executive Composite, GEC) are computed. The Inhibit, Shift, Emotional Control, and Self-Monitor clinical scales contribute to the BRI score and the Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials clinical scales contribute to the MI score. The BRI and MI are then used to compute the GEC. Raw scores on the BRIEF-A are further converted to age- and gender-normed T scores (M = 50; SD = 10) based on normative data collected from over 1000 individuals of varying socioeconomic, geographical, and cultural backgrounds.

The parents of adolescent participants were administered the Behavior Rating Inventory of Executive Functioning - Parent Form (Gioia et al., 2000). Although similar to the BRIEF-A, the BRIEF-P consists of 86 parent reported items assessing an adolescent's behavioral manifestations of executive problems in his daily life. Similar to the BRIEF-A, the BRIEF-P provides eight clinical scales (all reported above except Self-Monitoring), BRI, MI, and GEC.

Conners' Adult ADHD Rating Scales – Self Report, Long Version (CAARS-S:L) (Conners, Erhardt, & Sparrow, 1999). Adult participants were administered the Conners' Adult ADHD Rating Scales – Self Report, Long Version (CAARS-S:L), a 66 item self-report measure of ADHD symptoms and severity. For the purpose of the study, the three DSM-IV ADHD subscales were calculated and used in subsequent analyses: Inattentive Symptoms, Hyperactive-Impulsive Symptoms, and Total ADHD Symptoms.

Conners 3– Parent (Conners, 2008). Parents of adolescent participants completed the Conners 3 – Parent Form, which consists of 108 parent reported items assessing the presence of ADHD symptoms and symptoms of comorbid disorders based on DSM-5 criteria. For the purpose of the current study, raw scores were converted to

ADHD Predominantly Inattentive Presentation t-score, ADHD Predominantly Hyperactive-Impulsive Presentation t-score, and an ADHD Index Probability score.

Attention and Visual Filtering Working Memory Task (AVF-WM). The task procedures were similar to what had been described previously (Cowan et al., 2010; 2011; Mall et al., 2014). Participants were seated in front of a computer monitor in a well-lit, sound-attenuated room. The sequence of trial events is shown in Figure 3. Each trial began with a fixation point (represented by a small shape) presented in the center of the display for 1000 milliseconds (ms). The shape reminded participants as to what shape stimulus (circle or square) that they should attend to during the experimental session. The target shape designation remained constant throughout the experiment and was counterbalanced across individuals.

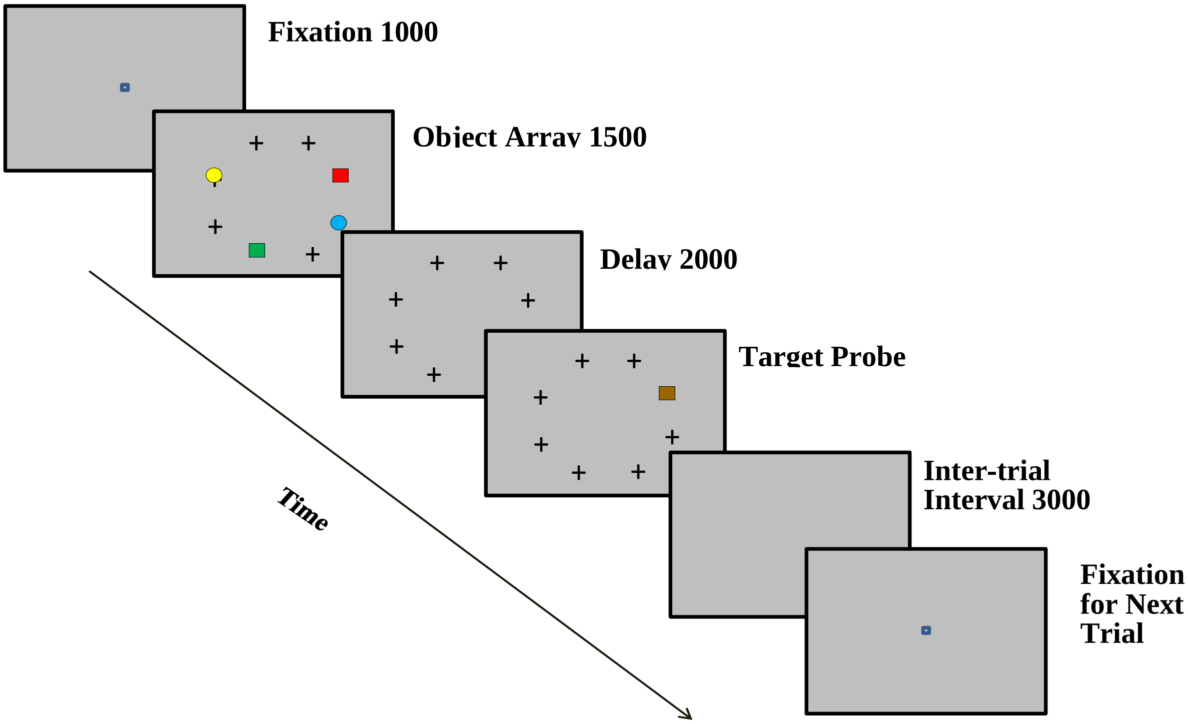

Figure 3: Attention and Visual Filtering Working Memory Task (AVF-WM)

After removal of the initial fixation shape, a sample array of colored objects was presented. Each object consisted of a small circle or square that subtended approximately 0.5º vertically and 0.5º horizontally. Each object appeared at one of eight possible locations arranged equidistant (first location = 22.5º from vertical) around an imaginary circle 2.7º in radius and centered on the middle of the display. Each object's specific location was determined randomly, and all empty locations were marked with a small placeholder ("+").

After 1500 ms, all objects were removed and replaced with placeholders. Following a 2000 ms delay, a single probe object was presented. The probe object was identical to one of the sample array objects (i.e., same shape and location) with the exception that the color may be the same or different than the initially presented shape in the same location. Participants were instructed to respond as quickly as possible by pressing a button with their right or left index finger (via pressing the "/"or "z" keys, respectively) if the probe shape was the same or different color than the previous shape in the same place. The response probe was presented until the participant made a response. The next trial was presented after an inter-trial interval of 3000 ms.

The response button mapping (e.g., left = same, right = different) was counterbalanced across participants. The shape associated with high frequency targets was counterbalanced across participants. The color of the shapes was drawn from a set of 10 possibilities without replacement (black, white, red, blue, yellow, green, orange, purple, brown, and pink). Response probe color that was "different" was sampled from colors not previously displayed during object array. Response time and accuracy were recorded.

Four types of conditions (differing in attention demands) were presented over seven blocks, and consisted of 48 trials per block. One condition consistent of a sample array of target shapes (*1-shape* condition). Three conditions consisted of a sample array of target shapes and an equal number of "distractor" objects appearing in the contrasting shape (*DP-100%, High Frequency* and *Low Frequency* conditions). For example, if the target shapes were circles, then the distractor objects were squares. See Figures 4-6 for representation of each condition. Of note, *High Frequency* and *Low Frequency* condition trials were presented within the same block.

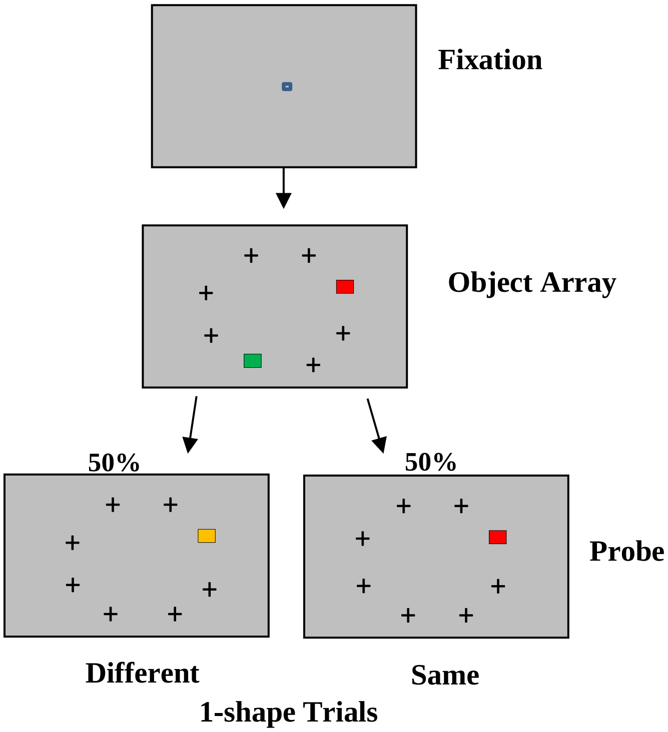

Figure 4: 1-shape Condition Trials and Probes for Two Objects of Tested Shape

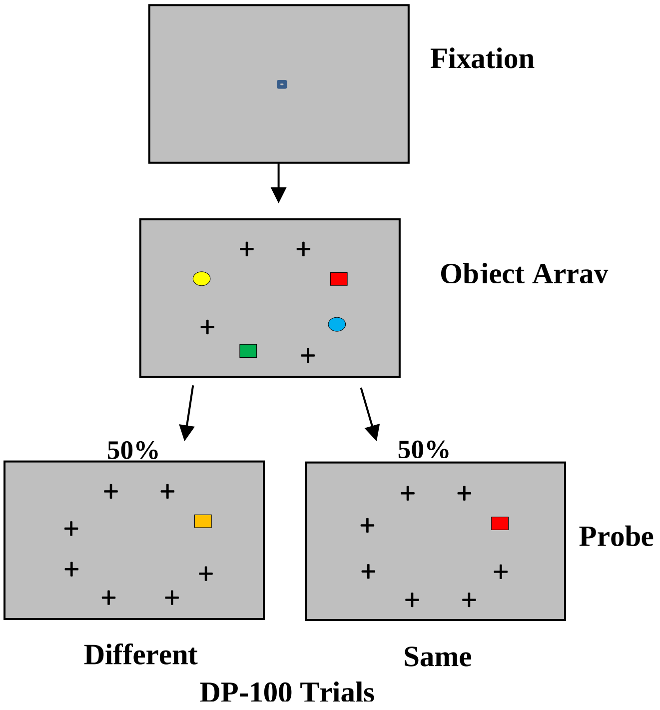

Figure 5: DP-100 Condition Trials and Probes for Two Objects of Tested Shape

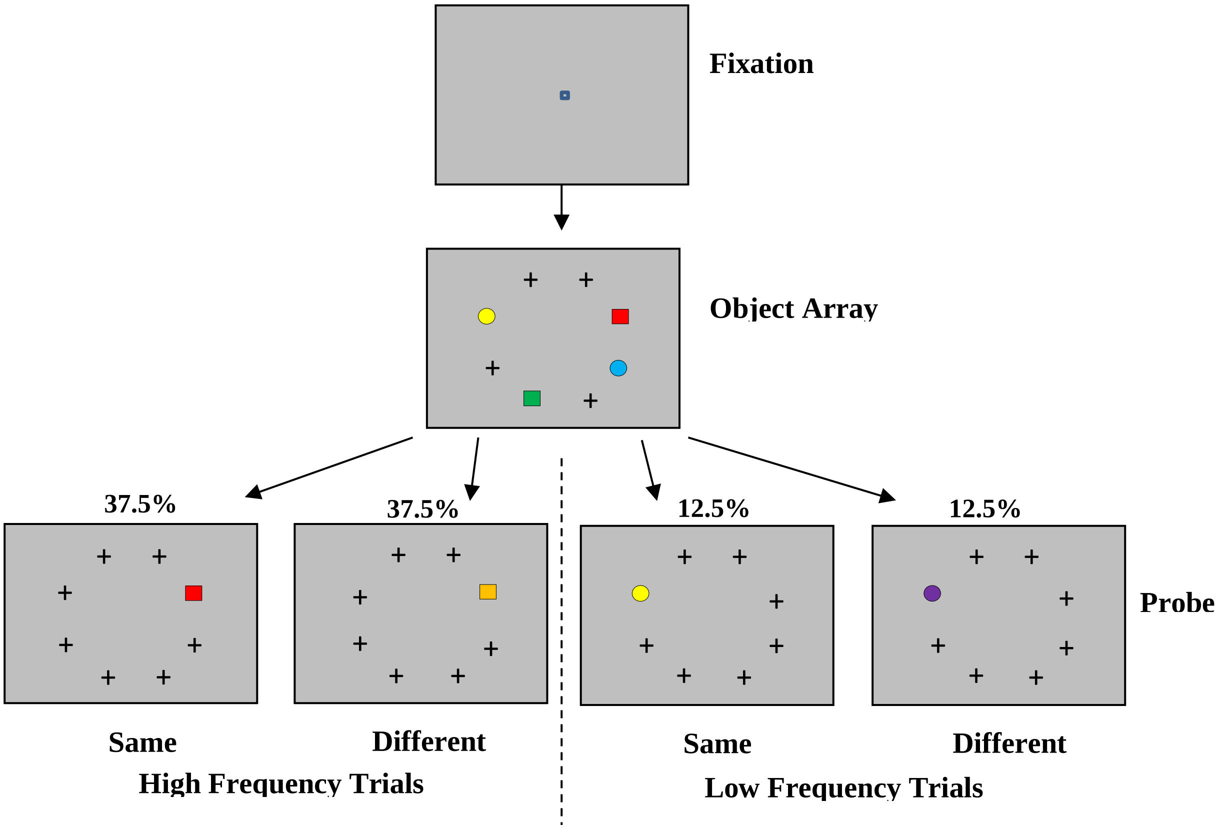

Figure 6: High Frequency and Low Frequency Condition Trials and Probes for Two Objects of Tested Shape

(1) In the *1-shape* condition, trials consisted of sample arrays of target shapes only. The sample array consisted of 2, 3, 4, or 6 target shapes. Prior to the start of a *1-shape* condition, participants were instructed to respond with a button press if the probe shape was the same or different color than the previous shape in the same place. Half of the time, in random order, the probe shape changed color from the shape in the original location. Two blocks consisting of the *1-shape* condition was presented during the task for a total of 96 trials total (24 trials for each number of objects in the tested shape).

(2) In the *DP-100%* condition, trials consisted of a sample array of targets and equal number of distractors (with 2, 3, or 4 targets). In *DP-100%* blocks, participants were instructed that they would only be probed for target shapes, and to respond with a button press if the target shape was the same or different color than the previous shape in the same place. Half of the time, in random order, the probed target shape changed color from the shape in the original location. 96 *DP-100%* target trials were completed over two blocks (32 trials per number of objects in the tested shape).

(3) Three additional blocks simultaneously consisted of trials that probed for high frequency targets 75% of the time (*High Frequency* condition) and trials that probed for low frequency targets 25% of the time (*Low Frequency* condition). During *High/Low Frequency* condition blocks, participants were instructed that *most* of the time they would be probed for target shapes. Half of the time, in random order, the probed target or distractor shape changed color from the shape in the original location. A total of 108 *High Frequency* trials (36 trials

per number of objects in the tested shape) and 36 *Low Frequency* target trials (12 trials per number of objects in the tested shape) were completed over three blocks.

Consistent with previous research (Mall et al., 2014), participants were given a series of practice trials and feedback was provided as needed to ensure the participant understood the task. One practice block consisting of the *DP-100%* target condition was presented (24 practice trials) prior to the experimental trials to ensure that participants understood the task. Participants then completed seven experimental blocks containing 48 experimental trials each block. The order of the blocks was counterbalanced. Participants were given the opportunity to take breaks at any time, but encouraged to take breaks (if any) between trial blocks.

Eye tracking. Eye tracking data was collected from participants while they completed the AVF-WM task. Data was collected in a similar manner as described in Mall et al. (2014) and in the same testing environment and equipment as described in Zamzow et al. (2014). Participants were seated in front of a computer in a dimly lit room. A chin rest and forehead bar ensured minimal head movements during the task. Participants were instructed to only move their eyes when viewing and responding to the behavioral task. Eye movements were recorded using an Eye-Trac R6 remote eye movement monitor with video head tracking (Applied Sciences Laboratories, Bedford, MA, USA). Before starting the experiment, a participant's eye position was calibrated on nine fixation points (points of intersection on an equally spaced 3 x 3 grid). Eye position was computed using a piecewise linear interpolation of the calibration points. Instructions for the task were presented on the screen. Prior to beginning each trial of the experimental task, the participant's eye position was sampled and central fixation was confirmed. If a participant's eye position fell outside of 2° of the central fixation point, the examiner was prompted to recalibrate the participant.

Eye positioning data was collected at a rate of 60 Hz. Fixations were defined as periods of time exceeding 50 ms in which the participant foveated on a given area of the display. For analysis purposes, we examined fixation data for the period of time associated with encoding (i.e., presentation of the to-be-remembered sample array; 1500 ms). Future studies will investigate the period of time associated with the delay between the sample array and probe (2000 ms) and recall (i.e., presentation of the memory probe; until response).

For each of the aforementioned epochs, fixation time was further categorized based on the location of fovea: time spent fixating target objects vs. distractor objects vs. placeholders. [A fixation was associated with a given stimulus if it occurred within 1.75° of the object's location.] In accordance with previous studies (Kliemann et al., 2010; Zamzow et al., 2014), data was excluded from analyses when the participants looked away from the computer screen and during shorter fixations (accounting for blinking, head motion, poor calibration, and quick saccades).

Results

Estimates of working memory capacity were estimated using Cowan's k (see Cowan 2001; Cowan et al., 2005, 2010, 2011). Cowan et al. (2005) defined it as, $k = A(hits - false\ alarms)$, where *hits* is defined as the "proportion of new probes correctly judged to be new" ($hits = k/A+(1-k/A)g$). *False alarms* is identified as the "proportion of old probes incorrectly judged to be new" ($false\ alarms = (1-k/A)g$). The formula also accounts for guessing *[g]* or the "probability of guessing 'new' when object is not in working memory" and number of objects in the tested shape *[A]* (the number of target objects that match the probe). Furthermore, Cowan et al. (2005) reported that estimates of k for targets (k_t) and distractors (k_d) can be used to estimate the "proportion of remembered items coming from the set to be attended" or visual filtering abilities ($k_t /(k_t + k_d)$. The variable k was utilized as a primary dependent variable in the current study because it can be used to provide a detailed account of capacity, attention, and filtering. Estimates of k were calculated for all combinations of conditions (*1-shape, DP-100, High Frequency,* and *Low Frequency*) and number of objects in the tested shape (2, 3, 4, and 6, as appropriate), and can be seen in Appendix A. Visual filtering scores for each number of objects in the tested shape (proportion of working memory capacity devoted to targets as opposed to distractors in the *High/Low Frequency* condition) were calculated. Response time (RT) data was obtained in milliseconds (see Appendix B). Of note, analyses of RT did not reveal a main effect of group or interactions including group; therefore RT analyses are not reported in text.

Additional variables of attention and visual filtering were calculated from eye tracking information, specifically the proportion of time fixating targets (e.g. more time fixating to targets is taken as a measure of attention allocation) and proportion of time fixating distractors (e.g. less time fixated may reflect more efficient filtering).

Working Memory Capacity

Hypothesis #1: Individuals with ASD have lower working memory capacity than healthy individuals without ASD. To test this hypothesis, I examined potential group differences in estimated working memory capacity *[k]* as a function of the number of objects in the tested shape in the *1-shape* condition. Estimated working memory capacity scores were analyzed using a repeated measures analyses of variance (ANOVA) with the number of objects in the tested shape (2, 3, 4, and 6) serving as the within subjects factor and group (ASD and non-ASD) serving as the between subjects factor. As can be seen in Figure 7, there was a main effect of the number of objects in the tested shape, $F(1,46) = 81.04$, $p < 0.001$, $\eta_P^2 = 0.64$, indicating that estimates of working memory capacity increased as the number of objects in the tested shape increased. The main effect for group, $F(1,46) < 1$, $p = 0.44$, $\eta_P^2 = 0.01$, and the number of objects in the tested shape x group interaction, $F(1,46) < 1$, $p = 0.85$, $\eta_P^2 = 0.006$, were not significant. My hypothesis was partially supported as I did not expect significant differences in performance between groups when there were 2 and 3 objects in the tested shape. My hypothesis that ASD participants would have lower performance in comparison to non-ASD participants when there were 4 and 6 objects in the tested shape was not supported.

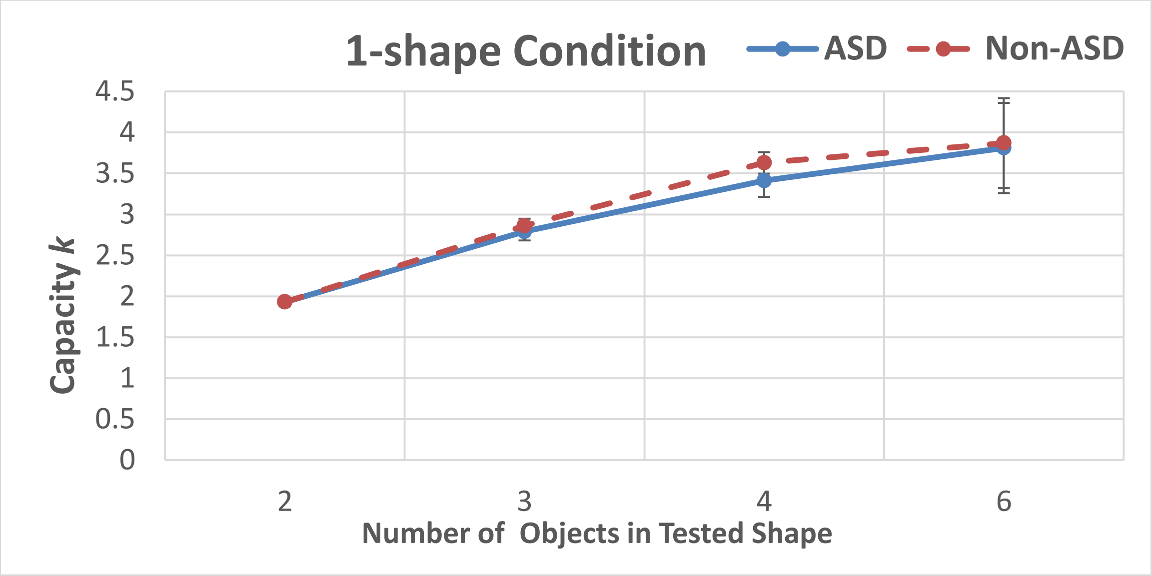

Figure 7: Estimates of Working Memory Capacity across # of Objects in the Tested Shape by Group in the 1-shape Condition (95% Confidence Intervals)

Attention

Hypothesis #2: Individuals with ASD are less effective than healthy individuals without ASD at preferentially allocating attention, especially to targets, during performance of a visual working memory task during a higher number of objects in the tested shape. To test this hypothesis, I examined estimates of working memory capacity *[k]* across attention conditions and the number of objects in the tested shape. Data were analyzed using a using a repeated measures analyses of variance (ANOVA) with attention condition (*1-shape, DP-100, High Frequency,* and *Low Frequency*) and the number of objects in the tested shape (2, 3, and 4) serving as within subjects factors and group (ASD and non-ASD) serving as a between subjects factor.

Results revealed a significant main effect of objects in the tested shape and a main effect of attention condition, $Fs(1,46) > 142.32$, $ps < 0.001$, $\eta_P^2 > 0.75$, but no main effect of group, $F(1,46) = 1.64$, $p = 0.20$, $\eta_P^2 = 0.03$. A significant two way interaction was found for attention condition x objects in the tested shape, $F(1,46) = 31.74$, $p < 0.001$, $\eta_P^2 = 0.40$. No other two way interactions were significant (attention condition x group or objects in the tested shape x group), $Fs(1,46) < 1$, $ps > 0.47$, $\eta_P^2 < 0.016$.

Most important to my hypothesis, results revealed a significant three way interaction (group x objects in the tested shape x attention condition), $F(1,46) = 3.34$, $p = 0.003$, $\eta_P^2 = 0.06$. In order to further investigate the nature of this interaction, post-hoc ANOVAS were conducted separately for each number of objects in the tested shape (2, 3, and 4) with attention condition serving as a within subjects factor and group serving as a between subjects factor.

2 Objects in the Tested Shape. For both groups, capacity estimates decreased as attention demands increased, $F(1,46) = 37.99$, $p < 0.001$, $\eta_P^2 = 0.45$. Moreover, as can be seen in Figure 8, individuals with ASD had lower capacity estimates across attention conditions as compared with individuals without ASD, $F(1,46) = 6.24$, $p = 0.01$, $\eta_P^2 = 0.12$. No significant interaction of attention condition x group was found, $F(1,46) = 1.95$, $p = 0.12$, $\eta_P^2 = 0.04$.

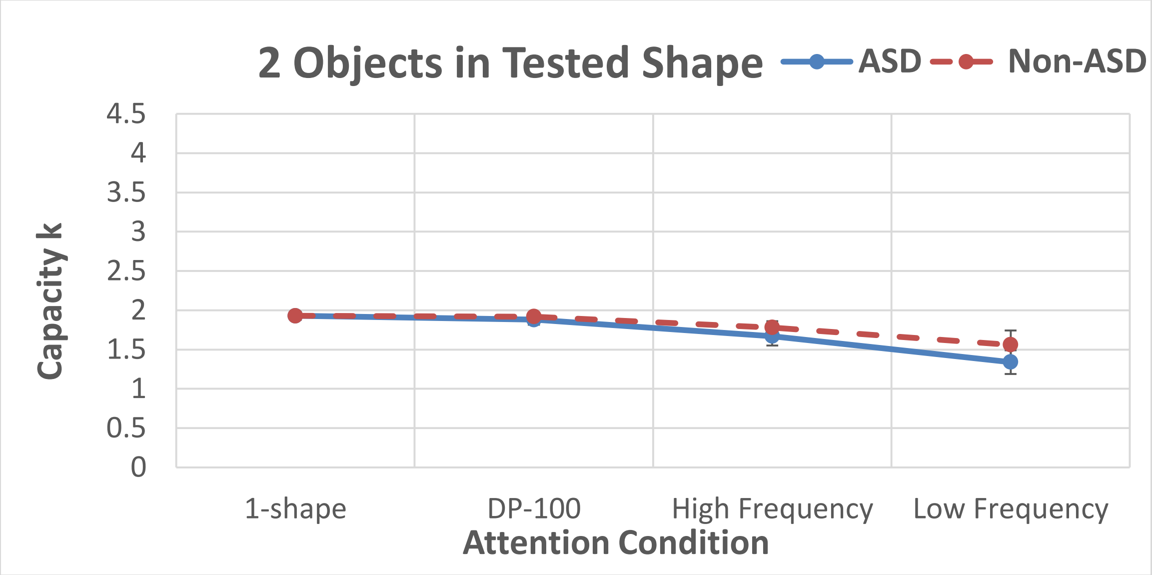

Figure 8: 2 Objects in the Tested Shape – Working Memory Capacity Estimates across Attention Conditions by Group (95% Confidence Intervals)

3 Objects in the Tested Shape. A main effect of attention condition was found when three objects were presented in the tested shape, $F(1,46) = 74.72$, $p < 0.001$, $\eta_P^2 = 0.61$. In general, capacity decreased for both groups as attention demands increased. As can be seen in Figure 9, no significant main effect of group or interaction of attention condition x group were evident, $Fs(1,46) < 2.67$, $ps > 0.10$, $\eta_P^2 < 0.05$.

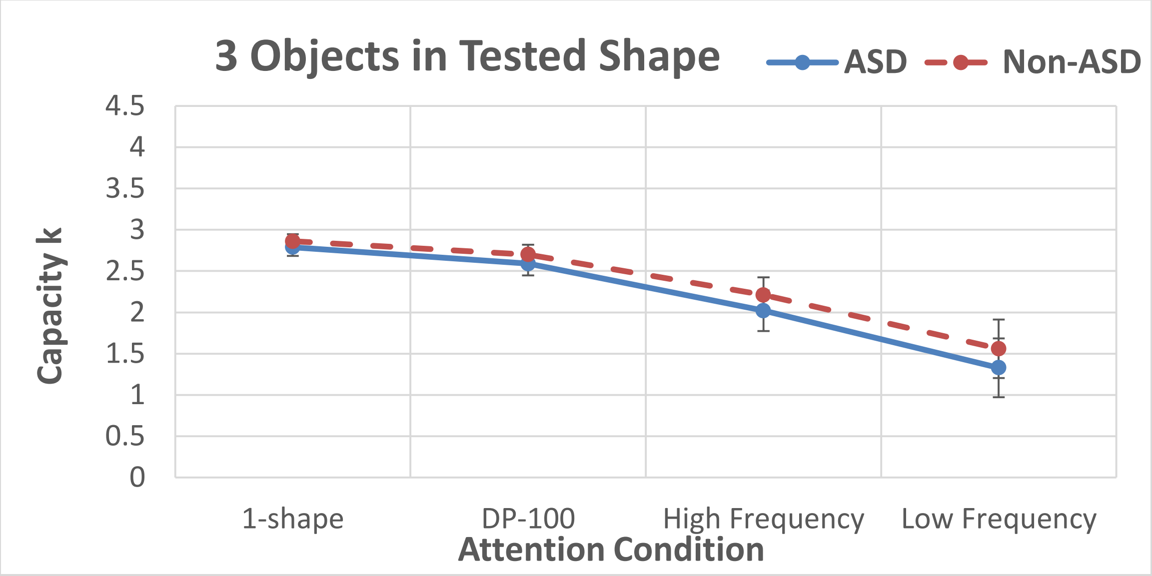

Figure 9: 3 Objects in the Tested Shape – Working Memory Capacity Estimates across Attention Conditions by Group (95% Confidence Intervals)

4 Objects in the Tested Shape. Similar to what was observed for 2 and 3 objects in the tested shape, there was a main effect of attention condition, with capacity decreasing with increased attentional demands, $F(1,46) = 88.54$, $p < 0.001$, $\eta_P^2 = 0.65$. The main effect of group was not significant, $F(1,46) < 1$, $p = 0.78$, $\eta_P^2 = 0.002$. The interaction between attention condition x group, however, was significant, $F(1,46) = 3.03$, $p = 0.03$, $\eta_P^2 = 0.06$. As can be seen in Figure 10, the interaction appears driven by the fact that capacity estimates were slightly higher for the non-ASD group compared with the ASD group for all conditions except the *Low Frequency* condition (ASD group had higher capacity estimates).

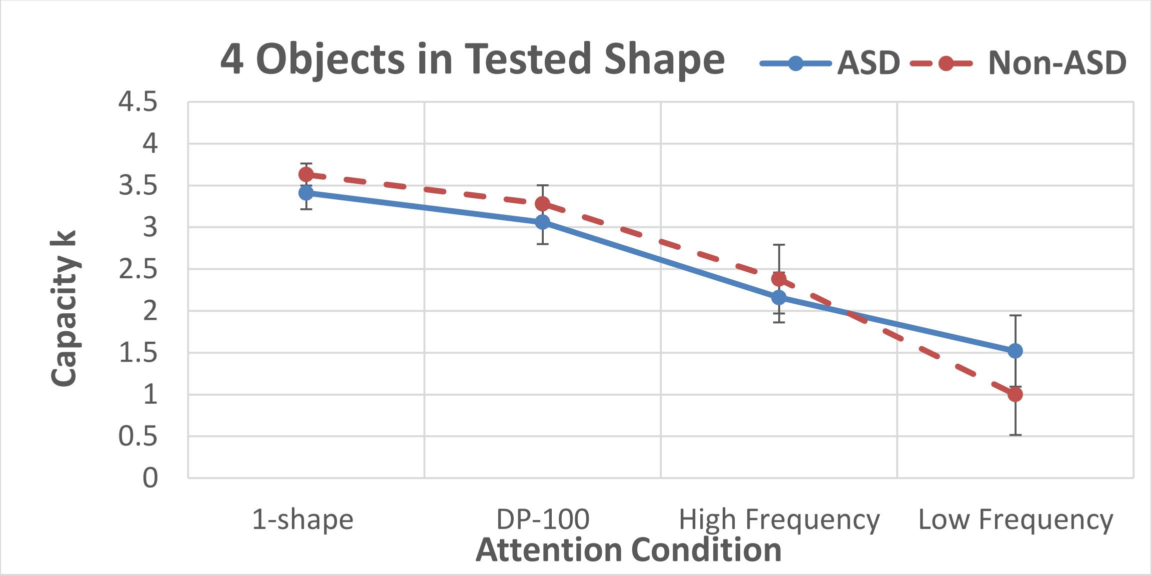

Figure 10: 4 Objects in the Tested Shape – Working Memory Capacity Estimates across Attention Conditions by Group (95% Confidence Intervals)

Low Frequency Condition across Number of Objects in the Tested Shape. As reflected in the previously described analyses and illustrated in Figures 8-10, the observed group differences and interactions appear to be driven primarily by differences in the *Low Frequency* condition specifically, especially as the number of objects in the tested shape increases. In order to explore this possibility further, estimates of capacity for the *Low Frequency* condition were analyzed using a mixed-model repeated measures ANOVA with the number of objects in the tested shape serving as a within subjects factor and group serving as a between subjects factor.

No main effect of number of objects in the tested shape or main effect of diagnosis were found, $Fs(1,46) < 1.02$, $ps > 0.36$, $\eta_P^2 < 0.02$. Results revealed a significant interaction of objects in the tested shape x group, $F(1,46) = 4.05$, $p = 0.02$, $\eta_P^2 = 0.08$. Observation of Figure 11 appeared to implicate group differences in performance between 3 and 4 objects. In order to investigate this observation further, a difference score was calculated between estimates of capacity at 4 and 3 objects for each group (ASD group mean difference score = 0.194 and non-ASD group mean difference score = -0.562). Mean difference scores were found to be significantly different between groups, $t(46) = 2.12$, $p = 0.03$, Cohen's $d = 0.64$. The non-ASD group appears to have lower estimates of capacity between 3 and 4 objects in the tested shape, and the ASD group appears to increase estimates of capacity slightly between 3 and 4 objects.

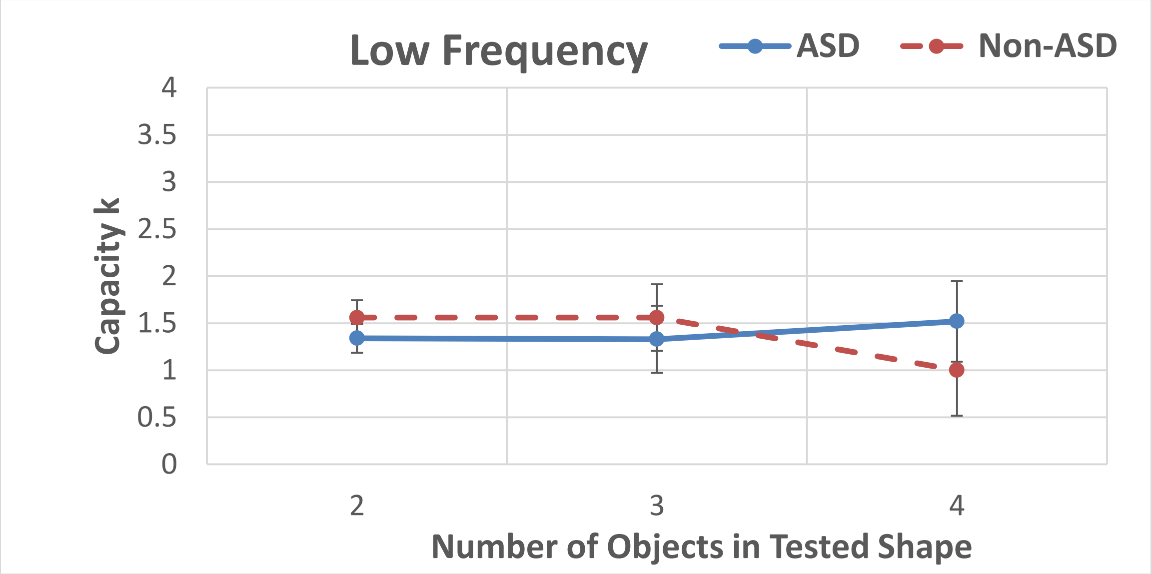

Figure 11: Low Frequency Condition - Capacity across # Objects in the Tested Shape by Group (95% Confidence Intervals)

Ocular fixation of target stimuli. The proportion of time spent looking at targets during object array was analyzed using a mixed-model repeated measures analyses of variance (ANOVA) with attention condition (*1-shape, DP-100, High/Low Frequency*) and the number of objects in the tested shape (2, 3, 4) serving as a within subjects factors, and group (ASD and non-ASD) serving as a between subjects factor. Of note, *High Frequency* and *Low Frequency* conditions were combined as the high frequency shape remained consistent across conditions. More importantly, at the time of eye movement, the participant did not know whether the target would be a high or low frequency target. Results revealed a significant main effect of attention condition, $F(1,46) = 118.16$, $p < 0.001$, $\eta_P^2 = 0.72$. There was a trend for a main effect of group, $F(1,46) = 3.07$, $p = 0.08$, $\eta_P^2 = 0.06$, and a trend for an interaction of attention condition x group, $F(1,46) = 2.73$, $p = 0.07$, $\eta_P^2 = 0.05$, but these effects did not reach significance. No main effect of objects in the tested shape was found, $F(1,46) = 1.24$, $p = 0.29$.

Furthermore results indicated significant interaction of number of objects in the tested shape x group, $F(1,46) = 7.21$, $p = 0.001$, $\eta_P^2 = 0.13$. In order to further investigate the nature of these interactions, post-hoc ANOVAs were conducted separately for each number of objects in the tested shape (2, 3, and 4) with attention condition serving as a within subjects factor and group serving as a between subjects factor.

2 Objects in the Tested Shape. For both groups, proportion of time spent on targets decreased as attention demands increased, $F(1,46) = 111.09$, $p < 0.001$, $\eta_P^2 = 0.70$, as can be seen in Figure 12. No significant difference between groups was observed, $F(1,46) = 1.07$, $p = 0.30$, $\eta_P^2 = 0.02$. Although not significant, there was a trend for a significant attention condition x group interaction, $F(1,46) = 2.50$, $p = 0.08$, $\eta_P^2 = 0.05$.

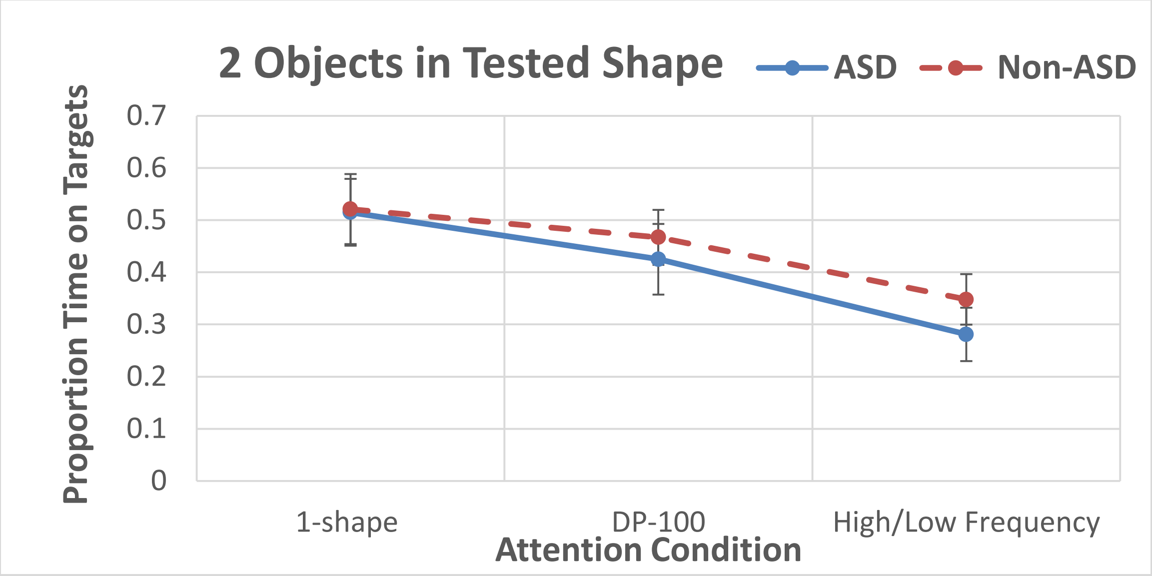

Figure 12: 2 Objects in the Tested Shape – Proportion of Time Looking at Target Stimuli across Attention Conditions by Group (95% Confidence Intervals)

3 Objects in the Tested Shape. A main effect of attention condition was observed, $F(1,46) = 91.39$, $p < 0.001$, $\eta_P^2 = 0.66$. There was a trend for a main effect of group, with individuals with ASD spending less time looking at targets than individuals without ASD, $F(1,46) = 3.80$, $p = 0.05$, $\eta_P^2 = 0.07$, as can be seen in Figure 13. No significant interaction of attention condition x group was reported, $F(1,46) = 0.95$, $p = 0.39$, $\eta_P^2 = 0.02$.

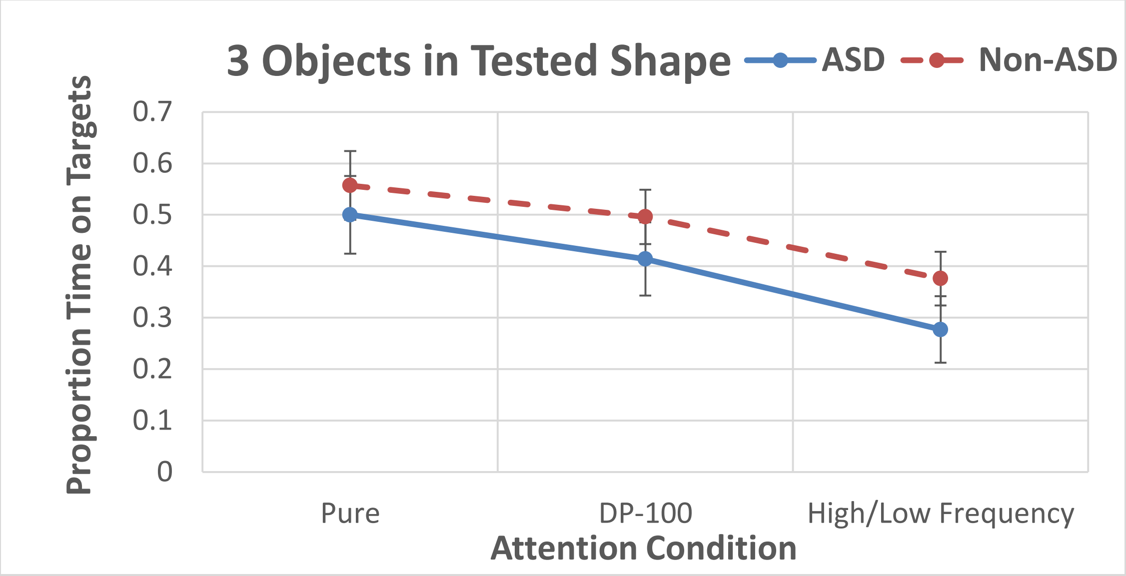

Figure 13: 3 Objects in the Tested Shape – Proportion of Time Looking at Target Stimuli across Attention Conditions by Group (95% Confidence Intervals)

4 Objects in the Tested Shape. Similar to what was observed for 2 and 3 objects in the tested shape, there was a main effect of attention condition, $F(1,46) = 90.60$, $p < 0.001$, $\eta_P^2 = 0.66$. A main effect of group was significant, $F(1,46) = 4.45$, $p = 0.04$, $\eta_P^2 = 0.08$, with the ASD group spending a smaller proportion of time looking at targets than the non-ASD group. A significant attention condition x group was reported, $F(1,46) = 4.11$, $p = 0.01$, $\eta_P^2 = 0.08$. As can be seen in Figure 14, the interaction appears to be driven by larger differences between groups in the most demanding attention condition (*High/Low Frequency*).

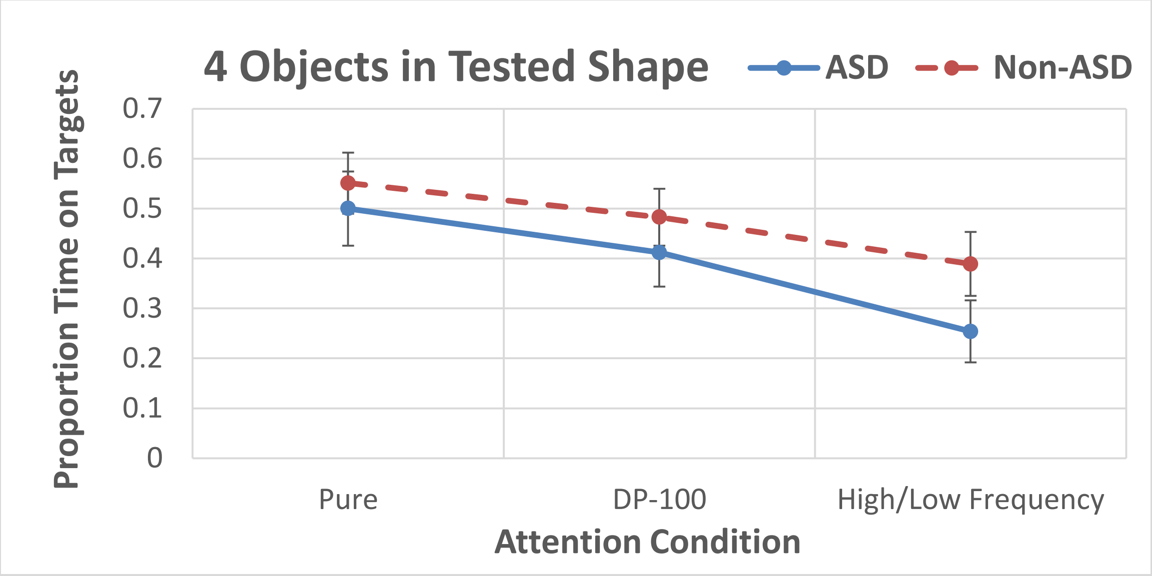

Figure 14: 4 Objects in the Tested Shape – Proportion of Time Looking at Target Stimuli across Attention Conditions by Group (95% Confidence Intervals)

Visual Filtering

Hypothesis #3: Individuals with ASD have more difficulty filtering out irrelevant (distracting) incoming information during a visual working memory task in comparison to healthy individuals without ASD. To test this hypothesis, I examined participants' ability to ignore or filter distracting information as opposed to focusing attention (as in analyses for hypothesis #2). Analyses included visual filtering scores (calculated from the *High/Low Frequency* condition) as well as eye gaze (proportion of time looking at distractors). Visual filtering score data were analyzed using a repeated measure ANOVA with the number of objects in the tested shape (2, 3, and 4) serving as a within subjects factor and group (ASD and non-ASD) serving as a between subjects factor. A main effect of objects in the tested shape was present, $F(1,46) = 7.90$, $p = 0.001$, $\eta_P^2 = 0.14$, with an increase in visual filtering score as the number of objects in the tested shape increased. No main effect of group was observed, *F*(1,46) = 1.12, *p* = 0.29, η_P^2 = 0.02.

An interaction of objects in the tested shape x group was also significant *F*(1,46) = 4.16, *p* = 0.01, η_P^2 = 0.08. Visual filtering scores at each number of objects in the tested shape for both groups can been seen in Figure 15. Similar to previous analysis, observations of performance suggests that visual filtering scores for each group appear to diverge between 3 and 4 objects in the tested shape. In order to investigate this potential effect, a visual filtering difference score was calculated between visual filtering scores at 4 and 3 objects in the tested shape for each group (mean visual filtering difference scores: ASD group = -0.029 and non-ASD = 0.142). There was a significant group difference found between these visual filtering difference scores, *t*(46) = 2.19, *p* = 0.03, Cohen's *d* = 0.63. The non-ASD group appears to have an increase in visual filtering scores between 3 and 4 objects in the tested shape, and the ASD group appears to have a slight decrease in visual filtering scores between 3 and 4 objects.

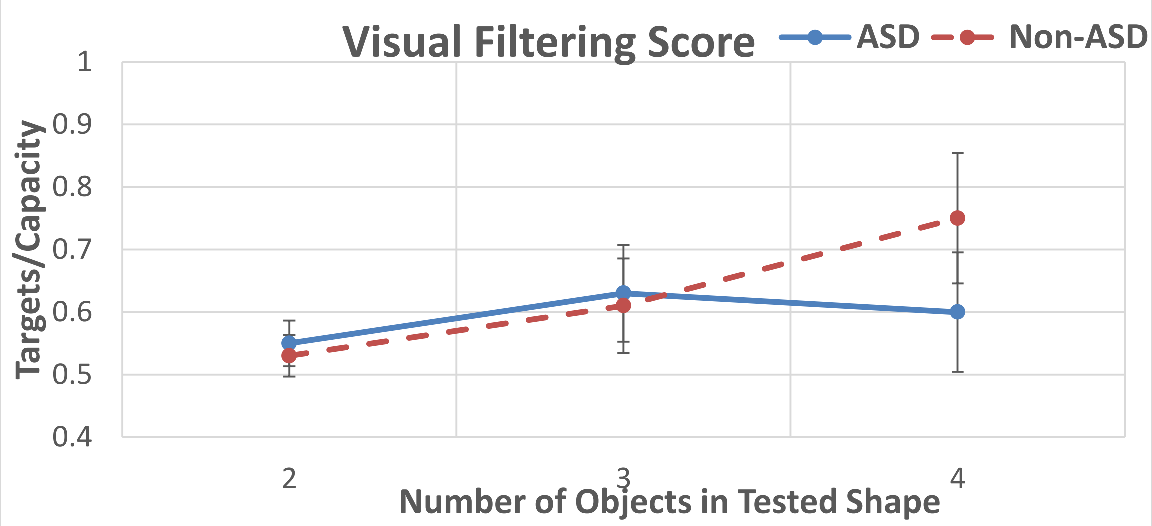

Figure 15: Visual Filtering Scores across Number of Objects in the Tested Shape by Group (95% Confidence Intervals)

Ocular fixation of distractor stimuli. Analyses of the proportion of time spent looking at distractors during object array utilized a mixed-model repeated measures analyses of variance (ANOVA) with attention condition (*DP-100* and *High/Low Frequency*) and the number of objects in the tested shape (2, 3, 4) serving as a within subjects factor, and group (ASD and non-ASD) serving as a between subjects factor.

Results revealed main effects of the number of objects in the tested shape and also attention condition, as well as a significant interaction of objects in the tested shape x attention condition, $Fs(1,46) > 11.78$, $ps < 0.001$, $\eta_P^2 > .20$. In general, participants appear to spend less time looking at distractor stimuli as the number of objects in the tested shape increases. As expected, participants spent a smaller proportion of time looking at distractors in the *DP-100* condition (consistent with task instructions that only targets are probed) than in the *High/Low* condition. A significant two way interaction of the number of objects in the tested shape x group was revealed, $F(1,46) = 3.51$, $p = 0.03$, $\eta_P^2 = 0.07$. No main effect of diagnosis or three way interaction including diagnosis were significant, $Fs(1,46) < 1$, $ps > 0.67$, $\eta_P^2 < 0.02$. Representation of these results can be found in Figures 16 and 17.

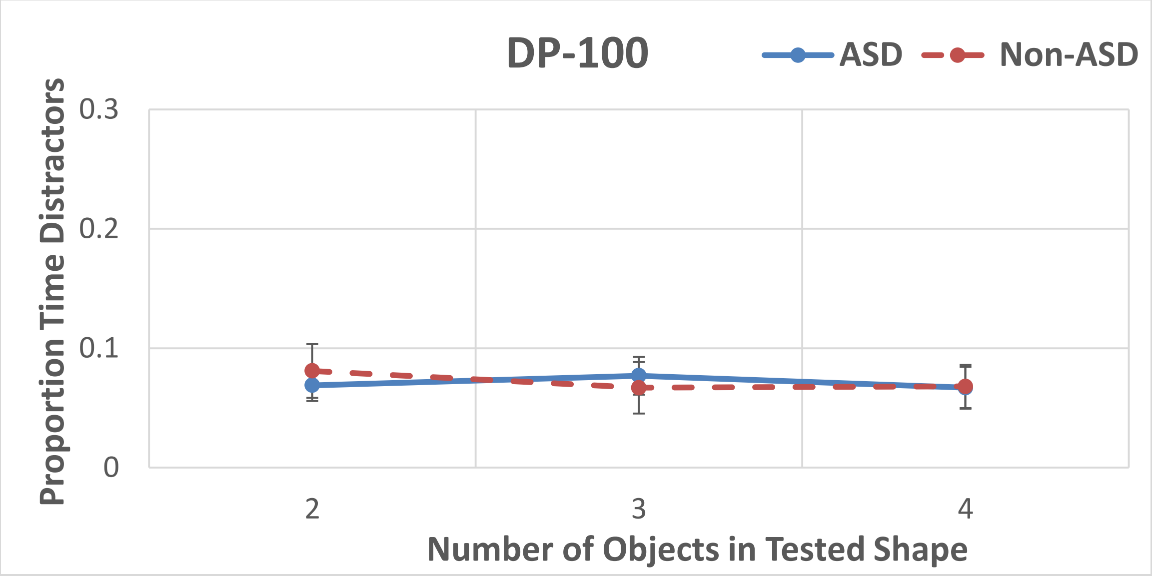

Figure 16: DP-100 Condition – Proportion of Time Looking at Distractor Stimuli across Number of Objects in Tested Shape by Group (95% Confidence Intervals)

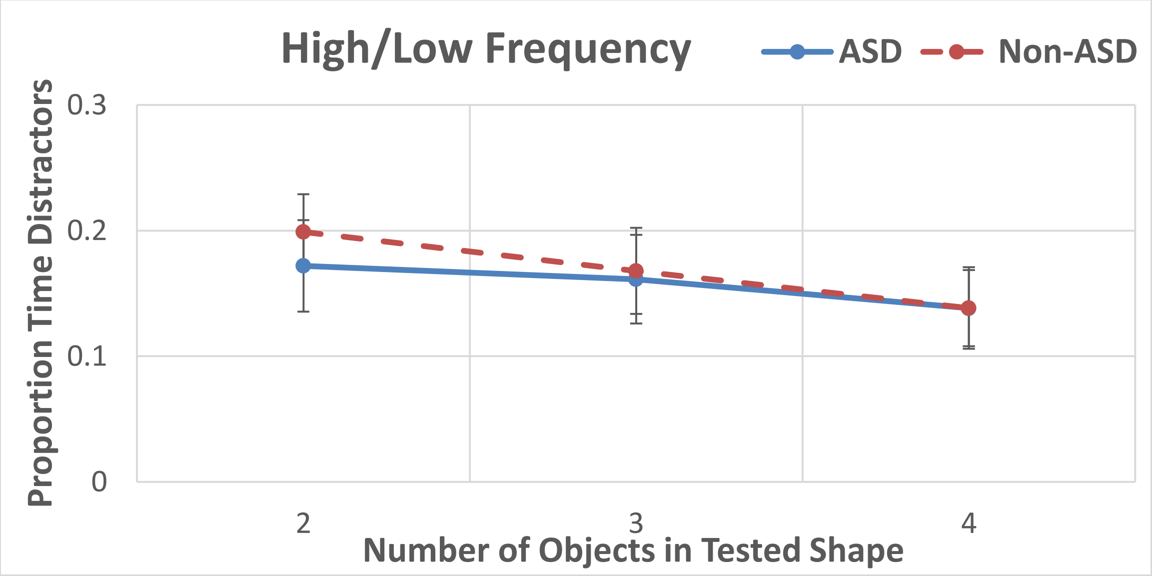

Figure 17: High/Low Condition – Proportion of Time Looking at Distractor Stimuli across Number of Objects in Tested Shape by Group (95% Confidence Intervals)

Real World Executive Functioning Abilities

Hypothesis #4: Performance on the AVF-WM task will relate to reported real world performance of EF in daily life. I investigated the relationship between reported real world EF ability and attention (assessed by questionnaires) and aspects of performance on the task. Previous analyses revealed significant attention and visual filtering differences between groups. A significant group x attention condition interaction for estimates of capacity for 4 objects in the tested shape (noted in *High Frequency* and *Low Frequency* conditions), as well as a significant group x objects in the tested shape interaction was noted for visual filtering scores. These two findings represent the most apparent differences in task performance between groups. A difference score was calculated for 4 objects in the tested shape between estimated capacity in the *High Frequency* and *Low Frequency* conditions. A second difference score was calculated between visual filtering scores in 4 and 3 objects in the tested shape. Difference scores were correlated with reported EF (overall and working memory) and attention symptoms.

As a first step, group differences were examined for reported EF abilities using the BRIEF questionnaire data and reported attention difficulties using the CAARS (adults) and Conners (adolescent) questionnaire data. Due to the similarities between adult and adolescent BRIEF measures, outcome variables were combined and used in subsequent analyses. Independent t-tests of BRIEF scores revealed significant differences between groups on the General Executive Composite (GEC) overall, $t(46) = 3.70$, $p = 0.001$, with the ASD group reporting more difficulties with EF in comparison to the non-ASD group. Of particular importance, analyses revealed significant differences between groups in the domain of working memory, $t(46) = 4.65$, $p < 0.001$, as the ASD group reported more difficulties with working memory functioning in comparison to the non-ASD group. The ASD group also reported significantly higher t-scores than the non-

ASD group in other EF domains, such as shifting, self-monitoring, initiation, planning/organizing, and monitoring, $ts(46) > 2.35$, $ps < 0.05$, see Table 4.

Table 4

BRIEF Scores by Group

	ASD (n=24)		**Non-ASD (n=24)**		
	Mean (SD)	*Range*	*Mean (SD)*	*Range*	*Cohen's d*
General Exec. Comp.*	58.9 (8.5)	36-74	50.4 (7.2)	35-65	1.07
Behav Reg Index*	54.7 (8.0)	35-70	48.2 (7.4)	36-60	0.84
Inhibit	54.9 (8.1)	36-67	52.2 (10.3)	36-74	0.29
Shift*	62.3 (11.2)	39-83	49.8 (7.9)	39-64	1.28
Emotional Control	48.4 (8.0)	38-65	46.5 (6.3)	38-60	0.26
Self-Monitoring [a]*	55.4 (10.1)	39-77	47.4 (8.0)	39-64	0.87
Metacognition Index*	60.8 (9.6)	39-78	51.7 (7.5)	36-67	1.05
Initiate*	60.7 (9.1)	43-79	52.4 (9.1)	37-69	0.91
Working Memory*	63.0 (10.8)	43-83	50.7 (7.0)	39-66	1.35
Plan/Organize*	60.0 (11.4)	40-81	51.2 (7.7)	38-68	0.90
Org. of Materials	53.9 (8.9)	36-69	50.7 (10.0)	36-72	0.33
Monitor*	60.0 (10.2)	36-77	53.2 (9.9)	36-72	0.67

[a] Self-Monitoring obtained for adult participants only (ASD n = 18, Non-ASD n = 19);* $ps < .05$

Independent t-tests of adult participant self-reported attention difficulties (CAARS) revealed significant differences between groups on the DSM ADHD Total, $t(34) = 4.05$, $p < 0.001$, and specifically in the domain of DSM Inattention, $t(34) = 2.96$, $p < 0.001$. Adults with ASD reported more significant symptoms of ADHD and symptoms of inattention in comparison to the non-ASD group, see Table 5. Independent t-tests of adolescent participants parent reported difficulties with attention (Conners) revealed significant differences between groups overall, $t(9) = 3.10$, $p = 0.01$, and specifically in the domain ADHD Hyperactivity, $t(9) = 2.36$, $p = 0.04$. Adolescents with ASD displayed more significant symptoms of ADHD and symptoms of hyperactivity in comparison to the non-ASD group, see Table 6.

Table 5

CAARS Scores for Adult Participants by Group

	ASD (n=18)		**Non-ASD (n=18[a])**		
	Mean (SD)	*Range*	*Mean (SD)*	*Range*	*Cohen's d*
DSM Inattention*	63.0 (11.3)	39-87	48.7 (9.7)	36-66	1.35
DSM Hyperactive	49.1 (8.5)	35-66	45.9 (10.2)	33-69	0.34
DSM ADHD Total*	58.0 (11.1)	33-83	47.5 (10.0)	31-72	0.99

[a]One non-ASD participant did not complete a CAARS; *$ps < 0.01$

Table 6

Conners Scores for Adolescent Participants by Group

	ASD (n=6)		**Non-ASD (n=5)**		
	Mean (SD)	*Range*	*Mean (SD)*	*Range*	*Cohen's d*
ADHD Inattention	58.1 (9.5)	50-70	48.2 (7.2)	36-55	1.17
ADHD Hyperactive*	62.3 (14.3)	45-81	46.2 (5.3)	42-53	1.49
ADHD Index*	41.3 (21.6)	11-64	11.0 (0.0)	11-11	N/A

*$ps < .05$

Relationship with executive functioning. In order to investigate the relationship between real-world reported difficulties with EF (represented by GEC and working memory scores) and aspects of AVF-WM performance (using the two difference scores described above), Spearman's rho correlations were conducted with both groups combined, and then again for the ASD group separately. No significant correlations between BRIEF variables and AVF-WM difference scores were observed when groups were combined (r_s range = -0.262 and -0.226, $ps > 0.05$). However, there appeared to be a trend toward significant negative correlations between BRIEF variables and visual filtering difference score (GEC: $p = 0.08$ and working memory score: $p = 0.07$), suggesting that larger visual filtering difference scores may relate to less difficulties with EF overall and working memory. Investigation of the ASD group revealed no significant correlations between variables (r_s range = -0.171 and -0.039, *ps*> 0.05). No trends were noted between BRIEF Variables and visual filtering difference score for the ASD group only (GEC: $p = 0.78$ and working memory score: $p = 0.85$).

Relationship with attention. In order to investigate the relationship between self-reported difficulties with attention for adult participants (CAARS ADHD Total, DSM Hyperactivity, and DSM Inattention) and AVF-WM difference scores, Spearman's rho correlations were conducted between these variables for both groups combined, and then the ASD group separately. No significant correlations were observed when groups were combined (r_s range = -0.290 and -0.203, *ps* > 0.13). When correlations were investigated for the ASD group only, no significant correlates were noted (r_s range = -0.313 and 0.041, *ps* > 0.20). Spearman's rho correlations were conducted for all adolescent participants between parent-reported difficulties of attention (Conners ADHD Index, ADHD Hyperactivity, and ADHD Inattention) and AVF-WM difference scores. Similar to the adult sample, no significant correlations were evident in the sample as a whole (r_s range = -0.484 and 0.053, *ps* > 0.13), or for the adolescents with ASD (r_s range = -0.765 and 0.257, *ps* > 0.05). However, a trend toward a significant negative correlation between ADHD Inattentive and visual filtering difference score was observed for the ASD adolescent group ($r_s = -0.765$, $p = 0.07$), suggesting that lower visual filtering difference scores may relate to more symptoms of inattention. Correlations for all participants can be viewed in Table 7 and for ASD participants specifically in Table 8.

Table 7

All Participant Correlations between Reported EF & Attention and Aspects of AVF-WM

	Difference Scores	
	Capacity SS4 (High – Low Freq.)	Visual Filtering Score (SS4 – SS3)
BRIEF[a]		
Global Exec. Comp.	-0.238	-0.252*
Working Memory	-0.226	-0.262*
CAARS[b]		
DSM Inattention	-0.210	-0.203
DSM Hyperactive	-0.276	-0.289
DSM ADHD Total	-0.290	-0.290
Conners[c]		
ADHD Inattention	-0.345	-0.484
ADHD Hyperactive	0.053	0.109
ADHD Index	0.250	-0.135

[a]ASD group n = 24 and non-ASD group n = 24; [b]Adults: ASD group n = 18 and non-ASD group n = 18; [c]Adolescents: ASD group n = 6 and non-ASD group n = 5; **ps* > 0.07

Table 8

ASD Participant Correlations between Reported EF & Attention and Aspects of AVF-WM

	Difference Scores	
	Capacity SS4 (High – Low Freq.)	Visual Filtering Score (SS4 – SS3)
BRIEF[a]		
Global Exec. Comp.	-0.171	-0.058
Working Memory	-0.152	-0.039
CAARS[b]		
DSM Inattention	-0.165	0.041
DSM Hyperactive	-0.313	-0.159
DSM ADHD Total	-0.178	0.005
Conners[c]		
ADHD Inattention	-0.441	-0.765*
ADHD Hyperactive	0.257	0.486
ADHD Index	0.353	-0.177

[a]ASD group n = 24; [b]ASD Adults: n = 18; [c]ASD Adolescents: n = 6; **p* = 0.07

Discussion

Previous investigations of working memory performance in individuals with ASD have yielded mixed findings (e.g., Geurts, de Vris, et al., 2014; Kenworthy et al., 2008). Research examining visual and spatial working memory abilities in older adolescents and adults with ASD specifically is limited. The current study used an experimental computerized paradigm to assess working memory capacity, attention, and visual filtering abilities in relation to visual working memory performance in adolescents and adults with and without ASD. Furthermore, for individuals with ASD, the current study examined how visual working memory performance on the AVF-WM task may relate to reported real world EF (e.g., working memory) and attention abilities.

Working Memory Capacity

The present study investigated potential working memory capacity differences between participants with and without ASD when distracting information was not present during the task (*1-shape* condition). My hypothesis that individuals with ASD would show no differences in estimates of working memory capacity compared with individuals without ASD when there were less objects in the tested shape was supported. As expected, for 2 and 3 objects in the tested shape, no differences in working memory capacity were found between groups (mean estimates of capacity for 2 objects: ASD group = 1.93 and non-ASD group = 1.93; for 3 objects: ASD group = 2.79 and non-ASD group = 2.86).

I also hypothesized that the ASD group would have significantly lower estimates of capacity on with more objects in the tested shape than the non-ASD group. Contrary to expectations, estimates of working memory capacity continued to be comparable between groups as the number of objects in the tested shape increased (mean estimates of capacity for 4 objects: ASD group = 3.41 and non-ASD group = 3.63; for 6 objects: ASD group = 3.81 and non-ASD group = 3.87). This finding appears to challenge previous findings of lower performance in individuals with ASD on other tests of spatial working memory such as the Wechsler Memory Scale spatial span subtest, especially in adults with ASD (Geurts et al., 2012; Williams et al., 2005). Although speculative, presentation differences between the current task and spatial span task may have contributed to these seemingly discrepant findings. In the current task, the full set of to-be-remembered stimuli were presented all at once. In contrast, in the WMS spatial span task, stimuli to be remembered are presented one at a time. The additional challenge of maintaining and updating information over time is likely more cognitively challenging, therefore may have contributed to lower performance in individuals with ASD in comparison to non-ASD individuals on the spatial span task. In order to investigate this hypothesis, the AVF-WM task can be modified to present stimuli to be remembered one at a time rather than all at once, therefore providing more information about the contribution of maintaining and updating information when distractors are not present. Regardless, current findings support comparable visual working memory capacity between individuals with and without ASD for simultaneously presented visual stimuli. Furthermore, the present study contributes to an understudied population of individuals with ASD, specifically the results provide information about working memory capacity in older adolescents and adults with ASD.

Attention

The second goal of the current study was to investigate the role of attention on visual working memory performance in ASD. As previously discussed, the AVF-WM task does not measure attention in a pure form, but attention is measured with interference from distracting information to various degrees. ASD-related difficulties with attention are well established (Dawson et al., 2004; Minshew et al., 1999; Rutter et al., 2003; Lord et al., 2003). Questionnaire measures confirmed difficulties with attention in the ASD sample. Adult participants with ASD reported significantly higher symptoms of inattention and parents of adolescent participants with ASD reported significantly higher symptoms of hyperactivity, with subclinical attention concerns.

As expected, as attention demands increased on the AVF-WM task (or as attention to target stimuli was divided), capacity estimates decreased for both groups in general, regardless of the number of objects in the tested shape. Estimates of capacity were slightly lower for ASD participants compared with non-ASD participants, although not significantly different. However, with 4 objects in the tested shape and between the most challenging attention conditions (*High Frequency* and *Low Frequency*), estimates of capacity for ASD participants were higher than non-ASD participants in the *Low Frequency* condition. Analyses suggest a larger drop in estimates of capacity between *High Frequency* and *Low Frequency* in 4 objects in the tested shape for non-ASD group than observed in the ASD group. These results suggest that when attention is most challenged, individuals with ASD appear to less efficiently allocate attention when distractors are relevant (potentially probed). In a sense, ASD participants may be utilizing a less optimal strategy during the most challenging attention condition of the AVF-WM task.

Analyses of eye fixation during object array presentation provide further support for the notion that individuals with ASD allocate attention differently than non-ASD participants. Individuals with ASD spent less time looking at objects to be remembered than non-ASD participants when attention demands (*High/Low Frequency*) and number of objects in the tested shape (3 and 4) were highest. Interestingly, the ASD group also spent less time looking at target shapes when presented with 6 items in the tested shape during the *1-shape* condition than the non-ASD group (45% of the time looking at targets versus 55% respectively) despite similar estimates of capacity. In the *1-shape* condition, trials with higher numbers of objects in the tested shape appear to contribute to differences in task performance for individuals with ASD, as evidenced by group differences in eye gaze, but does not appear to influence behavioral findings. Eye gaze analyses also revealed that individuals with ASD tended to spend less time looking at targets when the number of objects in the tested shape increased, rather than more time looking at targets (as did the non-ASD group). This pattern of results suggests that individuals with ASD may employ a different approach to the task when attention demands are at their highest. Future research may investigate if individuals with ASD are intentionally focusing on non-target stimuli or if their process is more automatic. Analyses of eye fixation data for the surroundings spaces and central fixation point would be informative. Participants could also complete a post-study questionnaire that asks retrospective questions about task completion for each condition.

Visual Filtering

I hypothesized that our sample of adolescents and adults would display similar visual filtering performance between groups at a smaller number of objects in the tested shape, but that individuals with ASD would have poorer visual filtering performance in comparison to non-ASD individuals at a higher number of objects in the tested shape. My predictions were largely confirmed. Visual filtering difficulties were noted on the most difficult trials (4 objects in the tested shape), with the ASD group displaying a lower visual filtering score (or poorer visual filtering) compared with the non-ASD group when attention was most divided (*High/Low Frequency*). For the non-ASD group, visual filtering scores dramatically increased in the most demanding trials (4 objects in the tested shape). For the ASD group, however, visual filtering scores remained flat regardless of the number of objects in the tested shape increases, which reflected poorer visual filtering abilities as the task became more challenging.

Analyses of eye gaze for distractor stimuli did not appear to reflect significant differences between groups. However, analyses indicated that ASD participants spent less time looking at targets in more challenging conditions and as the number of objects in the tested shape increased than non-ASD participants. These two findings appear to suggest that ASD participants are spending more time looking at non-stimuli. As such, reasons for these findings may be due to differences in eye gaze between groups that were not assessed, implicating differences in strategy or attention/filtering abilities. For example, behavioral observations of ASD participants during the task revealed some qualitative differences, such as participants focusing on the center fixation point during object array. In doing so, ASD participants may be utilizing “peripheral” vision rather than employing direct focus of attention on targets during the task.

Generally speaking, my findings are consistent with previous studies of visual filtering performance that reported impairments in individuals with ASD in comparison to non-ASD individuals (Christ et al., 2007, 2011; Geurts et al., 2008). Previous studies of visual filtering using a flanker task reported similar performance in older adolescents and adults (above the age of sixteen years old). Present findings remain consistent with previous literature, by reporting comparable visual filtering scores between groups in less challenging arrays (or less objects in the tested shape), similar to the task complexity (or lack of complexity) in the flanker task. Most importantly, the AVF-WM task progressively challenges participants with higher arrays and more challenging attention demands until difficulties in older individuals with ASD become evident. The present study is the first of its kind to utilize a uniform and progressive approach to investigate core components of working memory performance in the same sample of individuals with and without ASD. Previous research in visual and spatial working memory and ASD using “simple” (e.g., spatial span) and more “complex” (e.g., n-back) make such comparisons difficult given the diversity of the tasks and differences in samples tested. The current study demonstrates that increasing the attention and visual filtering demands changes how individuals with ASD complete the AVF-WM task. Findings may suggest that older adolescents and adults with ASD become “overloaded” or “overwhelmed” when cognitive demands are too great and may not fully utilize effective filtering strategies, similar to performance of typically developing young children (Cowan et al., 2010).

Report of Real World Working Memory Abilities

Overall, as assessed by self- and parent-report questionnaires, participants with ASD were reported to have more difficulties with real world EF abilities and attention in comparison to non-ASD individuals. I hypothesized that reported EF and attention symptom levels would be related to aspects of AVF-WM performance that appeared to be most impacted in individuals with ASD in comparison to individuals without ASD. However, reported EF abilities (as assessed by the BRIEF Global Executive Composite or working memory) did not appear to be significantly related to the difficulties with attention and filtering on the AVF-WM task (as assess by two difference scores) for the group as a whole or the ASD group individually. However, a trend for a significant relationship between BRIEF variables and visual filtering differences were noted for the group as a whole, suggesting that higher visual filtering difference score related to lower EF impairments overall and lower working memory impairments. Reported symptoms of attention and hyperactivity were also not significantly related to difficulties on the AVF-WM task for the sample as a whole or for individuals with ASD. However, a trend for a significant relationship was observed between symptoms of inattention and visual filtering score differences for adolescents with ASD, suggesting more symptoms of inattention may be related to lower visual filtering differences.

Limitations & Future Directions

The current study extends the literature on the integrity of visual working memory in older adolescents and adults with ASD. However, results of the study should be viewed in light of specific limitations. The present study restricted participant samples to higher functioning individuals with ASD (approximate mean FSIQ = 103 with a range of

FSIQ: 83-130). High functioning individuals were more likely to understand the presented task and be compliant with testing. The heterogeneity of ASD, however, makes it difficult to generalize these findings to individuals with ASD who have impaired cognitive abilities (FSIQ < 80). Our sample also tested older adolescents and adults (between 16 and 24 years of age) in order to contribute to the gap in literature on older individuals with ASD. However, in doing so, questions remain how younger (>16 years old) and older (>25 years old) individuals would perform on the task. The present results appear consistent with previous studies reporting ASD-related visual filtering difficulties in children with ASD in comparison to children without ASD (Christ et al., 2007, 2011). Future research using the AVF-WM task to investigate core components of EF in children and adolescents with and without ASD may inform the progression of these difficulties. Additional research is needed to investigate whether the observed results remain consistent or change across a range of ages and functioning levels.

The current study utilizes multiple methods of investigating the role of attention and visual filtering on visual working memory performance. However, the role of other cognitive processes, such as manipulation, encoding, rehearsal, and retrieval, among others, play a role in visual working memory performance. For example, investigation of eye gaze during the time between object array and probe (delay period) could be insightful. Investigation of the time spent looking at locations of previous targets would inform potential rehearsal strategies used by each group. Furthermore, the current task could be modified to be presented temporally in order to investigate storage and manipulation effects between groups. The extent to which these processes contribute to visual working memory performance in ASD remains unknown. Future research will be developed to investigate these processes.

Results of this study do not answer questions related to specific task strategies (whether intentional or unintentional) used by each group. Behavioral observations during data collection suggest that some individuals with ASD focused on the center fixation point during the object array. Questions remain regarding whether participants actively choose this or any specific strategy to complete the task or naturally settle into an automatic process. Also, results do not indicate if task strategy changes over time. Future studies may survey participants after completion of the task to understand intentionality and strategy changes as the task progresses.

The lack of significant correlations between aspects of the AVF-WM task and reported EF and attention symptoms was surprising. As previously hypothesized, the reported aspects of EF may be too broad, and inclusive of a variety of modalities (e.g., verbal, visual, tactile, etc.) that are not presently assessed. Furthermore, the reported outcomes on the BRIEF questionnaire may contain more socially relevant information, which is not a major component of the current AVF-WM task. A more specific EF questionnaire that highly focuses on the domain of working memory may be more appropriate for future studies (e.g., Working Memory Questionnaire, Vallat-Azouvi, Pradat-Diehl, & Azouvi, 2012). In regards to the lack of relationship between the reported attention symptoms and difficulties with the AVF-WM task, the lack of relationship could be due to a lack of power to detect a relationship. This may especially be the case given the lower sample sizes for report of attention symptoms (CAARS samples: ASD n = 18, non-ASD n = 18; Conners samples: ASD n = 5; non-ASD n = 6).

Future research will obtain a larger sample of individuals with and without ASD for sufficient power to detect the relationship between EF, symptoms of attention, and aspects of working memory performance.

Additional research through the use of neuroimaging techniques may shed light on potential neurophysiological disruptions of the PFC and associated networks that may be implicated in the ASD-related difficulties in visual working memory performance found in this study. Histopathologic, structural, and functional studies have largely implicated differences in the structure and function of the PFC and secondary brain regions in individuals with and without ASD (Brambilla et al., 2003; Carper et al., 2002; Herbert et al., 2004; Kemper & Bauman, 1998; Verhoeven et al., 2010). Individuals with ASD have been reported to have atypical frontal-parietal functional connectivity during working memory processes, with less activation in the DLPFC and lower functional connectivity in the frontal-parietal network (Just, Cherkassky, Keller, Kana, & Minshew, 2007; Luna et al., 2002). However, reasons for these differences are unclear, and may relate to structural or functional brain differences in PFC and associated regions, dysregulation of neurotransmitters (proposed by Bodner et al., 2012), and/or less than optimal task strategies (intentional or unintentional). Additional research through the use of imaging techniques may shed light on potential neurophysiological disruptions of the PFC that may be implicated in the impairments found in this study. Future research will use functional magnetic resonance imaging (fMRI) to investigate brain activity that is associated with filtering out visually distracting information in adolescents and adults with and without ASD. By doing so, researchers can identify potential biomarkers that contribute to these ASD-related impairments and subsequently inform individual treatment efforts.

Whereas imaging research can provide great insight into brain function in ASD, additional behavioral studies will also be vital in better characterizing working memory performance in ASD overall. Cowan and colleagues (1988) proposed a model of working memory that is not modality specific, but rather universal. As a next step, research investigating additional working memory modalities in individuals with and without ASD is warranted, especially in spatial working memory and verbal working memory. The current study could be modified to challenge location (e.g., sampling colors from previously displayed colors in object array) and inform spatial working memory processes. A study of verbal working memory could be systematically modified, similar to the current task, to increase the amount of information to be remembered (capacity) and progressively challenge attention and filtering abilities.

Given the countless types of incoming visual information we must process in order to function effectively in daily life (e.g. lights, movement), one’s the ability to filter out irrelevant visual information and focus on important information is essential for optimal functioning. The process of optimal filtering and focusing appears to naturally develop for typically developing individuals and gradually improves with age. However, results of the current study appear to support ASD-related difficulties in visual filtering and attention that persist into late adolescence and adulthood when cognitive demands are heavily challenged. ASD treatment and therapy efforts, especially in early childhood, that teach optimal strategies may have long-lasting effects. Pharmacological intervention (e.g., propranolol), has also been shown to improve working memory performance in individuals with ASD (Bodner et al., 2012), is another intervention avenue. Future research may utilize randomized controlled trials and/or longitudinal studies to investigate the effectiveness of incorporating these treatments into existing behavioral therapies.

Summary & Conclusions

In summary, the present study revealed comparable estimates of visual working memory capacity overall between groups. However, performance of individuals with ASD appeared to be more impacted by increases in attention and visual filtering demands, especially when attention was most divided. Individuals with ASD allocated their attention differently and spent less time looking at relevant information than non-ASD participants. The ASD group also appeared to have more difficulty filtering distracting information than the non-ASD group. Difficulties on the AVF-WM did not significantly relate to reported real world EF or attention symptoms. Findings suggest overall that individuals with ASD are detrimentally affected when the cognitive load increases, consistent with previous literature (Kenworth et al., 2008). Given the complexity of our environments, these findings shed light on ASD-related difficulties in day-to-day functioning and provide a focus of intervention.

APPENDIX

Appendix A

Table A.1

Average Estimated k (and Standard Deviation) per Condition and Number of Objects in the Tested Shape by Group

	1-shape				DP-100			High Frequency			Low Frequency		
# Objects in Tested Shape	6	4	3	2	4	3	2	4	3	2	4	3	2
ASD	3.81(1.3)	3.41(.46)	2.79(.25)	1.93(.10)	3.06(.62)	2.59(.33)	1.88(.14)	2.16(.70)	2.02(.58)	1.67(.27)	1.59(.97)	1.39(.81)	1.34(.36)
Non-ASD	3.87(1.2)	3.63(.30)	2.86(.20)	1.93(.11)	3.28(.52)	2.70(.28)	1.92(.11)	2.38(.97)	2.21(.50)	1.78(.19)	1.14(1.1)	1.56(.83)	1.56(.43)

Appendix B

Table B.1

Average Response Time in Milliseconds (and Standard Deviation) per Condition and Number of Objects in Tested Shape by Group

	1-shape				DP-100			High Frequency			Low Frequency		
# Objects in Tested Shape	6	4	3	2	4	3	2	4	3	2	4	3	2
ASD	1236(312)	1052(283)	1012(275)	1072(865)	1143(315)	1054(378)	889(186)	1362(406)	1239(346)	1097(284)	1516(514)	1445(655)	1239(387)
Non-ASD	1178(358)	1067(327)	939(293)	918(341)	1009(265)	926(197)	896(251)	1167(332)	1146(304)	1034(320)	1569(626)	1304(333)	1169(423)

Appendix C

Table C.1

Visual Filtering Scores by Group

	ASD		**Non-ASD**	
	Mean (SD)	*Range*	*Mean (SD)*	*Range*
Visual Filtering Score				
2 Objects in Tested Shape	.55 (.08)	.36-.75	.53 (.07)	.46-.75
3 Objects in Tested Shape	.63 (.18)	.37-1.00	.61 (.17)	.31-1.00
4 Objects in Tested Shape	.60 (.22)	.25-1.00	.75 (.24)	.25-1.00

Appendix D

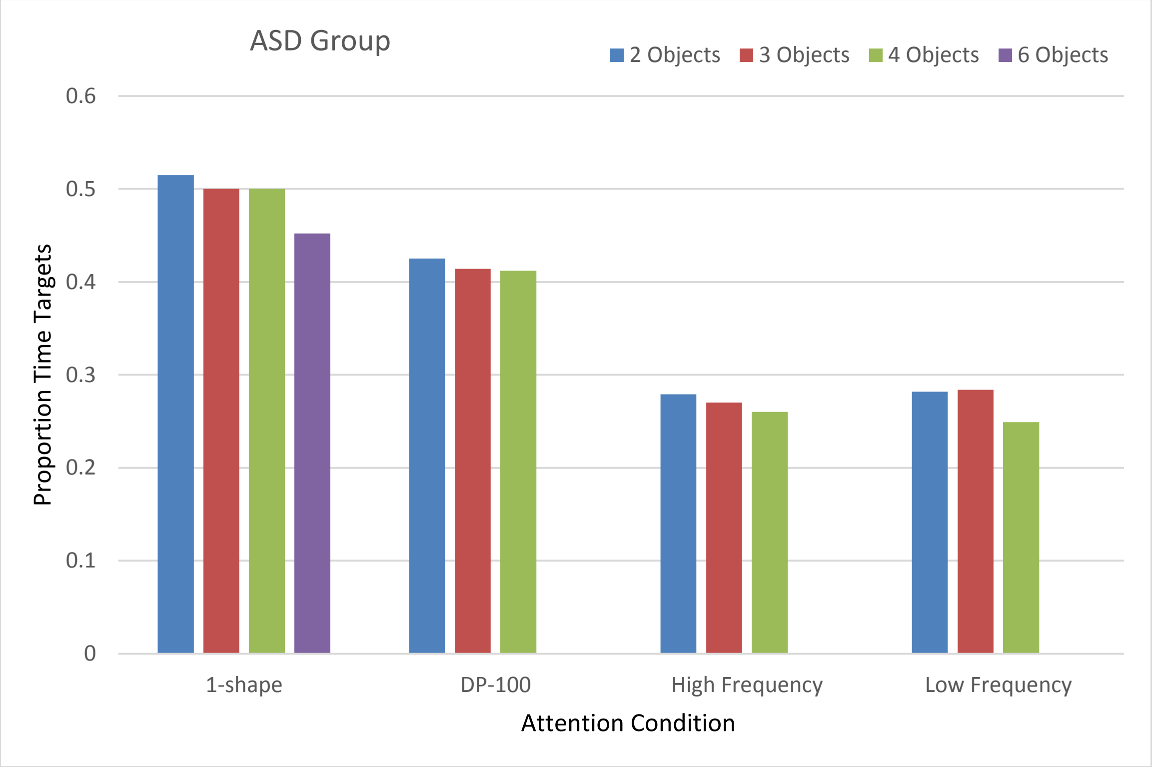

Figure D.1: ASD Group - Proportion of Time Looking at Targets by Condition and Number of Objects in Tested Shape

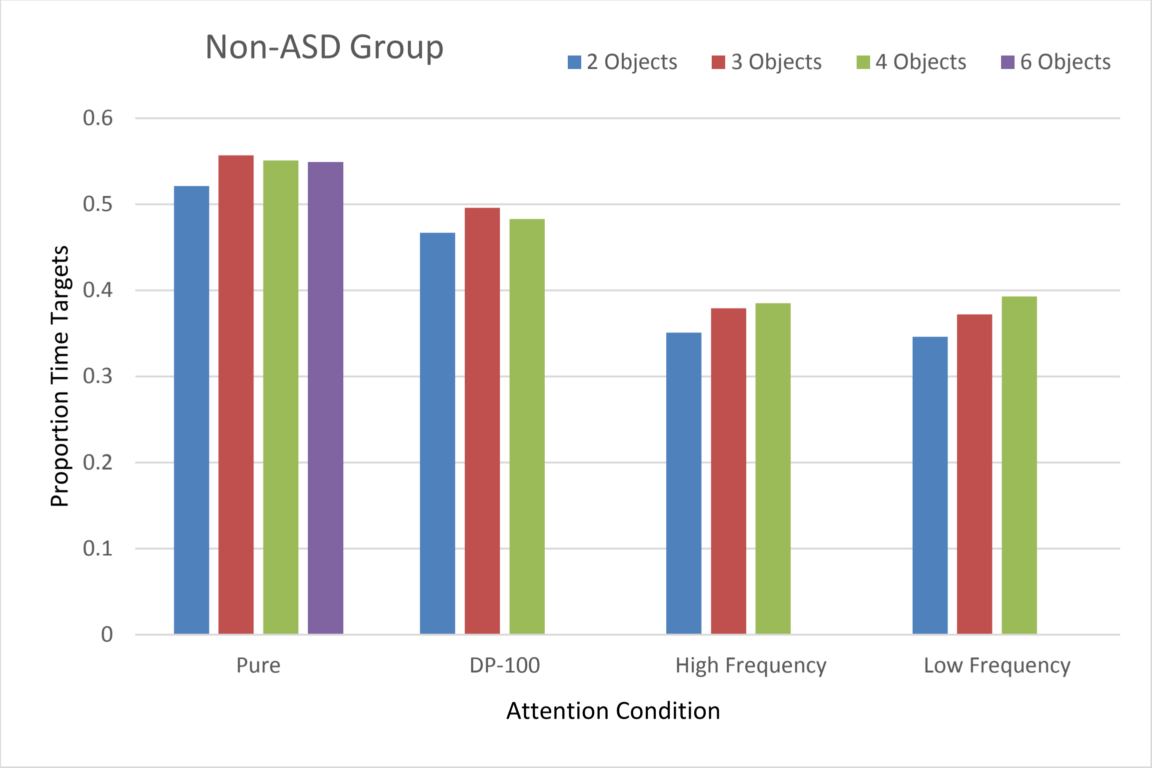

Figure D.2: Non-ASD Group - Proportion of Time Looking at Targets by Condition and Number of Objects in Tested Shape

Appendix E

Table E.1

BRIEF-A Scores for Adult Participants by Group

	ASD (n=18)		**Non-ASD (n=19)**	
	Mean (SD)	*Range*	*Mean (SD)*	*Range*
General Exec. Composite*	58.9 (8.2)	36-70	50.7 (7.7)	35-65
Behavior Regulation Index	53.3 (8.2)	35-70	49.2 (7.8)	36-60
Inhibit	55.5 (8.9)	36-67	54.1 (10.5)	36-74
Shift*	60.2 (11.5)	39-77	50.9 (8.1)	39-64
Emotional Control	46.3 (6.9)	38-65	47.1 (6.9)	38-60
Self-Monitor*	55.4 (10.1)	39-77	47.4 (8.0)	39-64
Metacognition Index*	62.0 (9.0)	39-78	51.7 (7.9)	36-67
Initiate*	61.7 (8.4)	43-79	52.5 (9.4)	37-69
Working Memory*	64.8 (10.8)	43-83	50.7 (7.3)	39-66
Plan/Organize*	61.8 (10.4)	44-81	51.2 (8.5)	38-68
Organization of Materials	53.0 (7.6)	36-67	49.5 (10.29)	36-72
Monitor	60.7 (11.2)	36-77	53.7 (10.7)	36-72

*ps < .05

Table E.2

BRIEF Scores for Adolescent Participants by Group

	ASD (n=6)		**Non-ASD (n=5)**	
	Mean (SD)	*Range*	*Mean (SD)*	*Range*
General Exec. Comp.	58.8 (10.0)	47-74	49.4 (5.5)	41-55
Behavior Regulation Index*	58.8 (6.3)	47-65	44.2 (3.9)	40-50
Inhibit*	53.0 (5.5)	45-60	45.0 (5.1)	42-54
Shift*	68.5 (8.3)	61-83	45.6 (5.8)	40-54
Emotional Control*	54.5 (8.8)	41-65	44.2 (2.7)	41-48
Metacognition Index	57.3 (11.2)	47-75	52.0 (6.2)	42-59
Initiate	57.6 (11.3)	46-79	52.0 (8.8)	39-63
Working Memory	57.5 (9.6)	45-69	50.4 (6.5)	40-56
Plan/Organize	54.5 (13.5)	40-75	51.4 (3.5)	47-56
Org. of Materials	56.5 (12.5)	37-69	55.2 (8.3)	43-63
Monitor	57.8 (6.6)	48-68	51.2 (6.0)	43-57

*ps < .05

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VITA

Kimberly Bodner was born in Cincinnati, Ohio to Robert and Donna Bodner. She has a younger sister, Kelly Bodner. Ms. Bodner is married to Christopher Engelhardt, and they have a son, August Engelhardt.

Ms. Bodner earned a Bachelor of Arts in psychology from Duquesne University in Pittsburgh, Pennsylvania and a Master of Science by Research in psychology under the supervision of Dr. Margaret McGonigle-Chalmers at the University of Edinburgh, Scotland. Ms. Bodner worked at the Autism Center of Excellence, University of Pittsburgh, investigating the biological basis of autism (cognitive, brain, and genetic) under the direction of Dr. Nancy Minshew.

In 2009, she was accepted and offered a fellowship to the clinical psychology doctoral program at University of Missouri, Columbia. She earned a Master of Arts in clinical psychology in 2011. Ms. Bodner's graduate research investigated cognitive and neurocognitive functioning in autism spectrum disorders, and also phenylketonuria. Her clinical work specialized in diagnostic and neuropsychological assessments of children and adolescents with neurodevelopmental disorders. Ms. Bodner completed an APA accredited clinical internship, pediatric psychology and neurodevelopmental track, through the Missouri Health Sciences Consortium (2015-2016 year). She accepted a postdoctoral fellowship with training in pediatric psychology and neuropsychology at the Thompson Center for Autism & Developmental Disorders (August 2016). Her career goals are to provide clinical services to children with neurodevelopmental disorders and also contribute to a body of knowledge to better inform education and treatment efforts for individuals with ASD.