Fall 12-18-2013

The Intersection of Working Memory and Emotion Recognition in Autism Spectrum Disorders

Sharlet Anderson

THE INTERSECTION OF WORKING MEMORY AND EMOTION RECOGNITION IN AUTISM SPECTRUM DISORDERS

by

SHARLET A. ANDERSON

Under the Direction of Diana L. Robins, Ph.D.

ABSTRACT

The present study investigates the intersection of working memory and emotion recognition in young adults with autism spectrum disorders (ASD) and neurotypical controls. The executive functioning theory of autism grounds key impairments within the cognitive realm, whereas social-cognitive theories view social functioning impairments as primary. Executive functioning theory of ASD has been criticized because executive functioning is too broad and is composed of separable, component skills. In the current study, the focus is narrowed to one of those components, working memory. It has been suggested that executive functioning may play a role in effective social interactions. Emotion recognition is an important aspect of social reciprocity, which is impaired in ASD. The current study investigates this hypothesis by combining working memory and emotion recognition into a single task, the *n*-back, as a model of social interaction and comparing performance between adults with ASD and controls. A validated set of facial expression stimuli (NimStim) was modified to remove all extraneous detail, and type of emotion was tightly controlled across 1-, 2-, and 3-back conditions. Results include significantly lower accuracy in each of the working memory load conditions in the ASD group compared to the control group, as well as in a baseline, maintenance memory task. The control group's reaction time increased as working memory load increased, whereas the ASD group's reaction time did not significantly vary by *n*-back level. The pattern of results suggests that the limit for *n*-back with emotional expressions is 2-back, due to near chance level performance in both groups for 3-back, as well as definitive problems in short term memory for facial expressions of emotion in high-functioning individuals with ASD, in contrast to previous findings of near perfect short memory for facial expressions in controls.

INDEX WORDS: Autism, Emotion recognition, Working memory, Faces

THE INTERSECTION OF WORKING MEMORY AND EMOTION RECOGNITION IN AUTISM SPECTRUM DISORDERS

by

SHARLET ANDERSON

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

in the College of Arts and Sciences

Georgia State University

2013

THE INTERSECTION OF WORKING MEMORY AND EMOTION RECOGNITION IN AUTISM SPECTRUM DISORDERS

by

SHARLET ANDERSON

Committee Chair: Diana Robins

Committee: Tricia King

Erin Tone

David Washburn

Electronic Version Approved:

Office of Graduate Studies

College of Arts and Sciences

Georgia State University

December 2013

DEDICATION

This work is dedicated to my loving parents, David and Sin Cha Kelly. For their endless support and love, I thank them. I was able to make the journey because they believed in me every step of the way. This work is also dedicated to individuals and loved ones who are affected by autism spectrum disorders, who view the world through unique lenses. I hope that this work will help others see from your perspective.

ACKNOWLEDGEMENTS

I’d like to thank all of the members of the Developmental Neuropsychology Lab at Georgia State University, especially Diana Robins, Kayla Sargent, Meena Khowaja, Natasha Ludwig, Bianca Brooks, Karis Cassagrande, and Mirjana Ivanisevic. This work would not have been possible without you. Also, to others outside of the lab including Dr. Leslie Jackson, Dr. Josie Serrata, Alvina Rosales, and my beloved Charlie Post, thank you from the bottom of my heart for cheering me on.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

As fundamentally social beings, humans are immersed in environments built upon interactional structures (families, communities, cultures, institutions, and societies) from which the most basic aspects of behavior are learned. As children develop, social cognition, or the ability to “perceive, categorize, remember, analyze, reason with, and behave toward other conspecifics” (Pelphrey & Carter, 2008, p.283) becomes increasingly important for successful social interaction. Individuals with autism spectrum disorders (ASD) have clinically significant dysfunction in reciprocal social interaction, which involves social cognition, coupled with deficits in communication and atypical repetitive/restricted interests. These social interaction deficits, often conceptualized as the hallmark of ASD, include impaired awareness and decoding of others’ emotional and interpersonal cues (Constantino et al., 2003), such as facial expressions of emotion. Such deficits, in turn, impact social adjustment in day-to-day functioning (Garcia-Villamisar, Rojahn, Zaja, & Jodra, 2010).

Several theories have been proposed, each of which attempt to provide a comprehensive, cohesive account that spans all three domains of deficit in ASD. Different theoretical models of ASD emphasize different constituent skills as key. One major theory, the executive function theory of ASD (Bennetto, Pennington, & Rogers, 1996; Hughes & Russell, 1993; Ozonoff, Pennington, & Rogers, 1991) grounds key impairments within a set of higher-order cognitive skills mediated by the prefrontal cortex. Deficits in these skills are thought to underlie the problems individuals with ASD experience in everyday contexts, including difficulties in adaptive (Gilotty, Kenworthy, Sirian, Black, & Wagner, 2002) and academic functioning (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009). Criticisms of the executive functioning theory of ASD point out that executive functions (as they are currently defined and investigated) represent a complex set of cognitive functions that are separable and that many tests designed to assess executive functioning tap several of these separate functions (Ozonoff, South, & Provencal, 2005), making it difficult to determine which of the component processes are disrupted and which are intact. Therefore, it may be useful to employ a focused approach to investigating cognitive deficits in the ASD population by targeting component processes, such as working memory, in isolation.

Social-cognitive theories place primacy of ASD-related dysfunction in the social domain and focus on impairments in the capacity to represent and reason about the thoughts, beliefs, and feelings of others, often referred to as Theory of Mind (Baron-Cohen, 1991; Frith, Morton, & Leslie, 1991). Behavioral studies in support of this theory include investigation of joint attention, imitation, and pretend play in early development and, for older individuals with ASD, inferring mental and emotional states using various social cues. It has been proposed that impairments in social perception and behavior in ASD are due to disruptions in brain systems implicated in social functioning, which include such structures as the amygdala, orbitofrontal cortex, superior and middle temporal gyri, and fusiform gyrus (Baron-Cohen et al., 1999; Critchley et al., 2000).

Real-life social interactions likely draw heavily on both executive functioning and social perception skills. Social interaction involves keeping track of a constantly changing stream of perceived details, all the while keeping in mind socio-cultural norms as well as one’s own goals for the interaction. The act of maintaining, updating, or manipulating information is conceptualized as working memory, one of the component processes of executive functioning. Working memory in ASD has been thoroughly investigated, and findings generally indicate impairment in comparison to control populations (Minshew & Goldstein, 2001; Ozonoff & Strayer, 2001; J. Russell, Jarrold, & Henry, 1996; Steele, Minshew, Luna, & Sweeney, 2007; Williams, Goldstein, Carpenter, & Minshew, 2005), though findings vary considerably depending on several factors such as the complexity of the task and the type of stimuli employed (Steele et al., 2007). Working memory tasks that incorporate social or emotional stimuli, which have been employed in studies of typically developing individuals (Braver et al., 2001; Druzgal & D'Esposito, 2001; Owen, McMillan, Laird, & Bullmore, 2005), provide one approach to examining how executive functioning and social/emotional processing deficits may independently or interactively contribute to impaired complex social functioning in day to day life for individuals with ASD.

The extant literatures regarding either working memory or emotion recognition in individuals with ASD are vast. However, there is a paucity of information available describing how these two processes operate when they intersect in the ASD population. The emerging area of research focusing on emotion-cognition integration in typically developing individuals provides an intriguing impetus for investigation within the ASD population. One study to date has partially extended this line of inquiry to the ASD population (Koshino et al., 2008), though the focus was on facial identity recognition, not emotion recognition.

1.1 Purpose of the Study

The primary aim for the current study is to investigate working memory for emotionally expressive faces in a sample of young adults with high functioning autism and typically developing controls. A criticism of the executive functioning theory of ASD is addressed in the current study. This criticism posits that executive functioning as a whole is composed of separable component processes, any one of which may or may not be disrupted in autism. Thus, in the current study the focus is narrowed within the domain of executive functioning to one of its component skills, working memory. It can be argued that social reciprocity, impairments in which are considered to be the hallmark of ASD, is also composed of separable, component processes, one of which is recognition of emotions in facial expressions. Therefore, the focus within the domain of social reciprocity is narrowed to recognition of facial expressions of emotion.

By taking this approach, the manner in which working memory and emotion recognition come together, or intersect, is investigated by examining the pattern of performance on an emotion recognition task that increases parametrically in working memory load (see Figure

2.2.3.2, p 35.). Use of such a task, commonly labeled an “*n*-back” paradigm, necessarily imposes tight experimental control which could be viewed as reducing the ecological validity of the findings. Though reducing the complex domains of executive functioning and social reciprocity to working memory and emotion recognition is several steps removed from an in vivo social interaction, the particular design of the task serves as a model of real-life social interaction. It does so by requiring moment-to-moment updating of a constantly changing stream of socially relevant information, as opposed to other experiments that employ more simple tasks of facial expression matching or recall/recognition of facial identity.

The *n*-back task is a widely used working memory paradigm (Owen et al., 2005) that entails varying levels of working memory load, and has been shown to activate prefrontal cortex areas (Cohen et al., 1997). It involves viewing stimuli presented at a fixed rate, one after another on a computer screen. The participant must indicate which stimulus is the same as the one “*n*” positions ago. For example, the 1-back involves pressing a button when the stimulus that is currently up on the screen is the same as the one immediately preceding, or one position “back.” The 2-back involves pressing a button when the current stimulus is the same as the one *before* the immediately preceding stimulus, or two positions “back.” The 3-back follows this same rule. The emotion recognition aspect of the model resides in the type of stimuli employed within the *n*-back task. The stimuli consist of a validated set of photographs of emotionally expressive faces called the NimStim Face Stimulus Set (Tottenham et al., 2009).

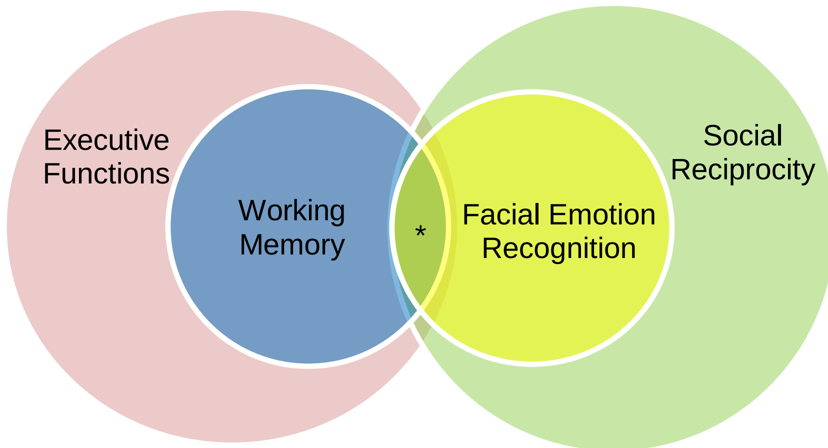

Figure 1.1. Visual representation of the domains of interest in the current study.

In order to lay a solid foundation for the current study, the following sections draw on a number of distinct areas in the literature. First, literature on working memory in ASD will be reviewed. Second, findings regarding facial emotion recognition in ASD will be reviewed. Third, how the two domains intersect will be discussed in reviewing the emotion-cognition integration literature.

1.1.1 Working memory in ASD

Executive functioning is defined as a set of capacities that underlie an individual's ability to engage in goal-directed, independent, self-serving behavior (Lezak, Howieson, Loring, Hannay, & Fischer, 2004). These capacities generally include attentional shifting (mental flexibility), inhibition, working memory, planning, and fluency (Engle, Kane, Tuholski, Miyake, & Shah, 1999). Deficits have been demonstrated in individuals with ASD in the areas of set-shifting (Liss et al., 2001; Ozonoff & Jensen, 1999; Szatmari, Tuff, Finlayson, & Bartolucci, 1990), inhibition (Hill & Bird, 2006; Hughes & Russell, 1993; Ozonoff, Strayer, McMahon, & Filloux, 1994), and working memory (Dawson, Meltzoff, Osterling, & Rinaldi, 1998; Joseph, McGrath, & Tager-Flusberg, 2005; Russo et al., 2007), as well as higher-order processes such as planning, fluency, and cognitive control. However, the literature regarding executive functioning abilities in ASD is not unequivocal. A substantial minority of studies demonstrate intact abilities such as spatial working memory (Barnard, Muldoon, Hasan, O'Brien, & Stewart, 2008) and inhibition (Ozonoff, 1997; Ozonoff & Jensen, 1999; Ozonoff & Strayer, 1997; James Russell, Jarrold, & Hood, 1999). The current study focuses on working memory.

Various models of working memory have been presented, including a widely accepted conceptualization consisting of a central executive component that coordinates two subsystems (phonological loop and visuospatial sketchpad) that temporarily store information for immediate problem-solving, early in the stream from perception to encoding in long-term memory (Baddeley, 2003). The working memory literature in the ASD population is equivocal regarding whether or not there truly are deficits in this population, though differences in methodology and participant characteristics make direct comparisons across studies difficult. Studies vary in terms of the domain tapped (verbal vs. nonverbal), sample characteristics, as well as in experimental task.

Several kinds of tasks designed to target nonverbal working memory have been used in behavioral studies in the ASD population. For example, Morris et al. (Morris et al., 1999) employed an Executive Golf Task, which is a computer-administered spatial working memory task that requires participants to identify targets successively further from the start point, without selecting the same target twice within a trial. They found that adults with ASD performed more poorly and exhibited more perseverative errors than the age-matched control group. Various spatial span tasks including the Wechsler Memory Scale, 3rd Edition (WMS-III; Wechsler, D. 1997B) Spatial Span subtest, the Finger Windows subtest of the Wide Range Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990), the Corsi-Block-Tapping task (Corsi, 1972), the Spatial Working Memory subtest of the Cambridge Automated Neuropsychological Test and Battery (CANTAB ©; Cambridge Cognition Cognition, 1996), and other block span tasks have been used to demonstrate deficits in spatial working memory in adults and children with ASD (Goldberg et al., 2005; Happe, Booth, Charlton, & Hughes, 2006; Joseph et al., 2005;

Landa & Goldberg, 2005; Williams, Goldstein, & Minshew, 2005; Zinke et al., 2010). Other types of tasks that have revealed deficits in individuals with ASD in non-verbal working memory include the NEPSY Knock Tap subtest (Korkman, Kirk & Kemp, 1998), visual perspective taking, and various others that involve having to recall a series of visual displays in sequence (Joseph et al., 2005; Reed, 2002; J. Russell et al., 1996).

However, some types of working memory tasks such as CANTAB © Stockings of Cambridge subtest, block span forward, NEPSY-II Tower subtest, and box search (Happe et al., 2006; Joseph et al., 2005; Ozonoff & Strayer, 2001) have failed to elicit evidence of deficits in ASD. Finally, the very same tasks that revealed group differences in some studies (e.g., block span and variant visual pattern—remembering the sequence of a series of spatial displays) failed to do so in other studies (Cui, Gao, Chen, Zou, & Wang, 2010). Differences in group characteristics and other aspects of methodology makes comparisons across these studies difficult. In general, the literature appears to provide more support for the presence of deficits in nonverbal working memory in ASD than it does for the absence of deficits in this domain.

However, an important exception to this conclusion is that deficits have not been revealed in ASD with one of the classic tests of working memory, the *n*-back. The *n*-back task involves viewing or hearing a steady stream of stimuli, presented one after another, and the participant must indicate when the current stimulus is the same as the one '*n*' (e.g., 1, 2, or 3) trials ago. Several studies have employed versions of the *n*-back task that incorporate varied stimulus classes (spatial, digits, faces) in samples of individuals with ASD and control groups and have failed to demonstrate group differences in terms of accuracy (Cui et al., 2010; Koshino et al., 2008; Ozonoff & Strayer, 2001). Cui et al. (2010) found differences in reaction time, whereas Koshino et al. (2008) did not. This exception has also been shown in more verbally based *n*-back tasks (see below).

Methods to assess verbal working memory in ASD vary as well. Some studies, such as those employing sentence span tasks (Bennetto et al., 1996; J. Russell et al., 1996), non-word repetition, and sentence imitation (Gabig, 2008) demonstrated poorer performance in ASD than controls. In contrast, group differences were not revealed in studies that used other tasks including WMS-III and WAIS-III Letter Number Sequencing subtests (Lopez, Lincoln, Ozonoff, & Lai, 2005; Williams, Goldstein, Carpenter, et al., 2005), WRAML Number/Letter Memory (Williams et al., 2005), and digit recall backward (Lopez et al., 2005; Cui et al., 2010). Yet other studies have produced conflicting results for the same task (digit recall forward), including poorer performance by the ASD group (Gabig et al., 2008), superior performance by the ASD group (Cui et al., 2010), and comparable performance between ASD and control groups (Lopez et al., 2005). In general, the literature appears to lend more support for a lack of deficit in verbal working memory, despite the methodological inconsistencies across studies, which are also seen in nonverbal working memory studies.

Similar to findings regarding the *n*-back with nonverbal stimuli, comparable performance (in terms of accuracy) in ASD and control groups has been demonstrated using the classic *n*-back task that employs letters as stimuli (Kana, Keller, Minshew, & Just, 2007; H. Koshino et al., 2005; Williams, Goldstein, Carpenter, et al., 2005) . In fact, Williams et al. (2005) found that error rates in both ASD and control groups were so low that they did not pursue analyses based on accuracy, though the ASD group demonstrated slower reaction times. Additionally, one of those studies also employed digits as stimuli for the *n*-back task, which could be considered a verbally-based task if verbally mediated strategies are used; this study also failed to reveal group differences (Cui et al., 2010).

Few studies have investigated neural correlates of working memory performance in ASD using neuroimaging techniques, and even fewer have employed the *n*-back task to assess the effect of increasing working memory load or have investigated working memory for social/emotional information in ASD and control groups. Luna et al. (2002), employed an oculomotor delayed response task with eye tracking and fMRI procedures and found that not only did the ASD group demonstrate poorer performance at the behavioral level, which the authors attributed to decreased activity in dorsolateral prefrontal cortex and in posterior cingulate cortex in comparison to healthy controls. Kana et al. (2007) investigated simple response inhibition, as well as a 1-back inhibition (pressing a button for all stimuli except for one that is the same as the one presented 1 trial ago) with letters, which failed to elicit behavioral group differences in accuracy or reaction time, but which yielded increased activation in bilateral premotor areas for both tasks, as well as less synchrony between anterior cingulate inhibition network and parietal regions during the 1-back task in the ASD group compared to controls.

Koshino and colleagues conducted a series of fMRI studies in ASD and control groups, one with the *n*-back task using letters as stimuli (2005) and the other using faces (2008) where the task response was based on facial identity. In both studies, behavioral group differences in terms of accuracy or reaction time were not apparent. With the letter *n*-back, the ASD group demonstrated not only less activation than controls in some left frontal and parietal areas (dorsolateral prefrontal cortex, inferior frontal gyrus, posterior precentral sulcus, inferior parietal lobe) but also more activation than controls in some right frontal and parietal areas (inferior frontal gyrus and inferior parietal lobe). Furthermore, functional connectivity analysis showed that the ASD group's left and right frontal regions were synchronized with right parietal areas, whereas the control group's left and right frontal regions were synchronized with left parietal areas. The authors interpreted this pattern of results as evidence for controls using a verbally mediated strategy and ASD participants using a more visually mediated strategy to perform the task. Lastly, the ASD group appeared to have a smaller working memory network, which only included eight ROIs, whereas the control group showed 11.

In Koshino and colleagues' 2008 study of *n*-back with face stimuli, the ASD group demonstrated comparable performance at the behavioral level again, but less activation in left inferior prefrontal and right posterior temporal areas, which are associated with working memory and theory of mind, respectively, as well as activations in slightly different areas of the fusiform area in comparison to controls. Again, they found smaller activated networks, but in the 2008 study they also found less synchrony indicating underconnectivity in fusiform-frontal networks. In sum, several intriguing findings have been published about working memory neural network differences in ASD vs. controls, but interpretation in the absence of corresponding behavioral differences is difficult.

It has been suggested that failure to reveal deficits at the behavioral level in some studies may be an artifact of a facilitative effect of computer administered tasks, as opposed to tasks administered by a person, given the significant social interaction difficulties in ASD (Nakahachi et al., 2006; Ozonoff & Strayer, 2001). The implication here is that the act of administering a task in person is a social interaction of its own accord, and that this may interfere with task performance. However, this speculative hypothesis does not explain all of the equivocal findings regarding executive functioning in ASD, given that performance on several computer administered visuo-spatial working memory tasks such as the *n*-back (colored shapes), spatial span (colored shapes at varying distances from a target), and box search task did not reveal significant differences across groups, but did reveal the expected main effect of working memory load in each of the groups. Furthermore, another study using tasks administered by a person (letter number sequencing in Williams et al., 2005) did not reveal deficits. Other explanations for conflicting results, as mentioned above, include differences in group characteristics across studies such as age (children vs. adults) or IQ, or within group heterogeneity in the ASD group such as varying degrees of severity of social and/or communication impairments.

In general, the literature suggests that deficits in working memory become apparent when the level of task complexity is sufficient (Steele et al., 2007). It can be argued that the *n*-back task with simple stimuli such as letters, digits, or geometric shapes are not complex enough to reveal group differences. One way to increase complexity of the task would be to employ a socially-salient stimulus, such as an emotionally expressive face. This approach is undertaken in the current study.

1.1.2 Face processing and emotion perception

Deficits in face processing in general and emotion recognition in particular are well documented in the ASD literature. Many researchers attribute the difficulty individuals with ASD demonstrate in emotion perception, or in facial processing in general, to differences between individuals with ASD and controls in the style of cognitive processing employed during perception of complex visual stimuli (Frith 1989). In the typically developing population, perception of faces and other complex stimuli is an automatic process achieved by global or holistic processing (Behrmann et al., 2006; Dawson, Webb, & McPartland, 2005; De Sonneville et al., 2002; Gauthier, Curran, Curby, & Collins, 2003; Lahaie et al., 2006). In contrast, individuals with ASD may employ a more piecemeal approach to processing complex information, in accordance with the “weak central coherence” theory (Frith, 1989).

According to this theory, those with ASD demonstrate a deficit in global, holistic processing of complex information, including human faces, that is characterized by a bias toward feature-level visual analysis and a piecemeal approach. The weak central coherence theory has been used to explain peculiarities in face processing in the ASD population despite accurate facial identity task performance (Deruelle, Rondan, Gepner, & Tardif, 2004). For example, the ASD group achieved facial identity task performance comparable to that of verbal and mental age-matched controls when viewing faces presented in high spatial frequency (local, featural-level processing), whereas only the control group was able to identify faces presented in low spatial frequency properties (global, configural-level processing).

Though earlier studies couched the weak central coherence account within a deficit model (impaired global processing), later investigations reconceptualized this phenomenon in ASD as a local processing bias or a preferred cognitive style, with evidence of the ability to integrate information into a gestalt, global whole when specifically cued to do so (Happe et al., 2006). For example, performance by individuals with ASD on tasks that require disembedding a target featural detail from a gestalt whole has been found to be superior to that of a typically developing control group (Jolliffe & Baron-Cohen, 1997). This notion of a preferred style can be extended to emotionally salient stimuli. For example, Celani and colleagues (1999) reported that children with ASD initially and spontaneously sorted pictures of faces according to non-emotional aspects, whereas the TD group initially sorted according to facial expression. However, when the participants with ASD were specifically instructed to sort according to emotion, the children did so at a comparable level to the TD group (Celani, Battacchi, & Arcidiacono, 1999).

Within the broad area of face processing research, the literature regarding emotion perception and recognition is reviewed. Many researchers have described general, overall deficits in facial emotion perception in the ASD population (Baron-Cohen, Golan, & Ashwin, 2009; Hobson, Ouston, & Lee, 1988; Klin et al., 1999; Philip et al., 2010). Some studies do not reveal groups differences in detecting simple emotions such as *happy* and *angry* faces, but suggest instead that deficits are limited to complex emotional expressions such as *confusion* (Adolphs, Sears, & Piven, 2001; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Bauminger & Kasari, 1999; Golan, Baron-Cohen, & Golan, 2008). Other studies have revealed less specificity and reliability in facial emotion recognition in high-functioning adults with ASD (Kennedy & Adolphs, 2012). Comparable emotion recognition ability between adolescents with ASD and typically developing controls has been demonstrated with exposure times as short as 250ms, but with structured response formats, such as multiple choice (Weng et al., 2011). These findings are in stark contrast to the near perfect short term memory for facial expression of emotion demonstrated in typically developing individuals (Banko, Gal, & Vidnyanszky, 2009).

Of the features in a facial expression that convey emotional content, the eye region is the area that conveys the most emotional information and the area to which typically developing individuals attend, though the mouth region tends to be the area to which individuals with ASD attend (Baron-Cohen et al., 2001). If a piecemeal strategy in facial processing is employed, it is conceivable that with adequate cognitive resources and time for processing, those “pieces” could eventually be integrated into a gestalt whole, leading to accurate, though inefficient, performance on emotion perception tasks. Indeed, researchers have speculated about compensatory strategies that may account for null findings in the facial emotion recognition in ASD literature (Harms, Martin, & Wallace, 2010; Kennedy & Adolphs, 2012). However, a global processing bias would allow for more efficient decoding, freeing up cognitive resources that could be allocated to processing more information while allowing for simultaneous formulation of appropriate responses during social interaction, as is done in the typically developing population.

In the emotion recognition literature, like the working memory literature, factors that may account for conflicting findings have been identified. These include group characteristics (age, level of functioning), stimuli and task demands, and the dependent variable of interest (accuracy vs. reaction time for behavioral studies) (Harms et al., 2010). It has also been suggested that heterogeneity within ASD samples that include participants with very mild social cognition symptoms may highlight the lack of sensitivity in some tests and that increasing the difficulty of the task avoids ceiling effects by precluding the use of compensatory strategies (Harms et al., 2010).

Attempts to probe further into the nature of emotion perception difficulties in ASD have used functional neuroimaging to demonstrate differing patterns of activation at the neural systems level in ASD vs. typical control groups. For example, Weng et al. (Weng et al., 2011) investigated neural activation patterns while participants viewed emotionally expressive and neutral faces. Their results indicated greater activation in participants with ASD than in controls in ventral prefrontal cortex, amygdala, and striatum while viewing expressive vs. neutral faces. After acquisition of fMRI image, participants also completed a multiple choice response format emotion labeling task. Group differences on this task were not revealed in terms of accuracy or reaction time. Koshino and colleagues (2008) also investigated neural activation patterns during an *n*-back task using faces as stimuli, though the task focused on facial identity rather than emotional expression. This study will be discussed in more detail later (section 1.1.3, p. 18). Notably, the stimuli used included both neutral and non-neutral faces, which potentially obscured the results, as literature regarding differing patterns of cortical activation for recognition of facial identity vs. emotion recognition have been reported (D'Argembeau & Van der Linden, 2011; Krebs et al., 2011).

One approach to investigating the effects of increasing the difficulty level of an emotion recognition task would be to embed it within a working memory paradigm with parametric variation in level of difficulty. In other words, employing a task that requires integration of emotion and cognition may increase the sensitivity of a task and thus facilitate demonstrating putative group differences in ASD vs. typically developing controls. Researchers have taken this approach to emotion-cognition integration in the typically developing population (Neta & Whalen 2010) (see below). This is the approach taken in the present study.

1.1.3 Emotion-cognition integration

Historically, cognition and emotion were regarded as separate entities in psychological research. However, modern views generally suggest an interdependent, interconnected system (Pessoa, 2008). Some researchers have proposed that deficits in executive functioning may impact social functioning in individuals with ASD, given the need for individuals to cope with rapidly changing verbal and nonverbal stimuli that occur in natural social discourse, to select appropriate responses to these cues, and to hold social norms and unspoken rules of engagement on line throughout the subtle and fluid stream of changing stimuli (Bennetto et al., 1996; Gilotty et al., 2002; McEvoy, Rogers, & Pennington, 1993; Reed, 2002). Others have hypothesized that Theory of Mind, or the ability to reason about others' points of view and emotional states as separate from one's own, is closely related to or dependent upon adequate development of executive functioning skills (Benson, Sabbagh, Carlson, & Zelazo, 2013).

Given that executive functioning and social cognition are the foci of two competing theories of ASD, combined with recent views of interconnected rather than separable systems, the question of the nature of the relationship between executive functioning and social impairments seen in ASD is raised. Indeed, significant correlations have been reported between performance on executive functioning measures, including perseverative errors, and joint attention behaviors in young children with autism (Griffith, Pennington, Wehner, & Rogers, 1999; McEvoy et al., 1993). Finally, relations between performance on executive functioning tests and Theory of Mind tasks have been reported among children with autism (Ozonoff et al., 1991), though findings in typically developing children suggest that the association is developmentally based, with some types of executive functioning skills serving as a prerequisite for Theory of Mind skills (Benson et al., 2013). A model of executive functioning that has been proposed includes cognitive functions associated with abstract reasoning or "cold" cognitive functions as well as those based on motivation and emotion, or "hot" functions (Barendse et al., 2013; Zelazo, Qu, & Kesek, 2010).

As mentioned earlier, deficits in working memory in ASD emerge when the complexity of visual stimuli is increased (Minshew & Goldstein, 2001). One way to increase the complexity of visual stimuli for working memory tasks is to add an emotionally salient component. A number of previous studies have examined the use of affectively-valenced stimuli within working memory paradigms. In typically developing individuals, the addition of emotional content to working memory tasks can have an detrimental effect on working memory processes (Perlstein, Elbert, & Stenger, 2002), including allocating more attention to emotionally salient stimuli (Ohman, Flykt, & Esteves, 2001) and disrupting emotion labeling ability (Phillips, Channon, Tunstall, Hedenstrom, & Lyons, 2008).

Investigations at the neural systems level in typically developing population have yielded results that suggest distinctive activation patterns for the integration of cognition and emotion. For example, Perlstein and colleagues (2002) found that error rates were higher during the presentation of affectively valenced vs. neutral stimuli during a working memory task. Further, fMRI analyses revealed that in dorsolateral prefrontal cortex, activity was increased for pleasant stimuli relative to neutral and decreased for unpleasant stimuli, whereas the reverse pattern was found in orbitofrontal cortex. In this study, the stimuli were photographic scenes of various scenarios, not necessarily human faces. However, the connections between behavioral and neuroimaging results are questionable, given that the original task that produced the neuroimaging results had significant ceiling effects, and a separate group of participants completed a modified version of the behavioral task (but not in the scanner) for behavioral error rate analysis.

In a later study, Kensiger and Corkin (2003) found in typically developing adults that affective valence did not influence working memory performance, neither on a self-ordered pointing task nor on a backward word span task, though there was an effect of affective valence on long term recall. Others have integrated emotion and cognition and found a distributed pattern of activation in frontal (inferior, middle, and superior frontal gyri), parietal (inferior parietal lobe, intraparietal sulcus), and occipital (lingual and fusiform gyri) areas during an auditory *n*-back task in which a neutrally valenced word was spoken in various emotional tones (Rama et al., 2001), and yet others found increased right-hemisphere ventrolateral prefrontal cortex activation during *n*-back for faces vs. words (Braver et al., 2001).

Even more specific to the current study, researchers have investigated the association between working memory and recognition of facial expressions of emotion, not just general socially/emotionally-relevant stimuli, in typically developing individuals. Lopresti and colleagues (LoPresti et al., 2008) used facial expressions of emotion in a delayed match to sample task for emotions vs. identity to demonstrate differential patterns of activation. Superior temporal sulcus and inferior occipital cortex areas showed more activation in stimulus presentation vs. delayed maintenance phases, and the orbitofrontal cortex, amygdala, and hippocampus were more activated during the delay. Orbitofrontal areas demonstrated increased activation for the emotion task relative to the identity task, both during stimulus presentation and during the active maintenance phase that followed.

The classic *n*-back task, a measure of working memory, uses simple stimuli (letters, objects) as targets and non-targets (Krebs et al., 2011; Veltman, Rombouts, & Dolan, 2003). However, researchers have recently included more complex emotionally-valenced stimuli in the *n*-back task such as pictures of affectively-valenced scenes (Dohnel et al., 2008) in controls vs. individuals with mild cognitive impairment and found differing patterns of activation in the precuneus according to valence of stimuli.

Others have employed cropped photos of facial expressions as flanking distracters to simple stimuli in pediatric depression and anxiety (Ladouceur et al., 2005), 2005) and have revealed differential allocation of attention resources according to valence of emotional distracters. Schematic drawings of faces have also been included in working memory paradigms (Beneventi, Barndon, Ersland, & Hugdahl, 2007); studies using such paradigms have yielded evidence that facial feature specific working memory interaction with a general cognitive load component were associated with significant activations in prefrontal regions of the brain. Probing further, combining working memory tasks with face stimuli has been conducted in typically developing individuals. For example, investigations regarding cortical activation patterns specific to *n*-back for gray-scale faces, during which the participants were to respond to the identity of the faces, revealed significant linear increases in fusiform face area activation associated with increases in working memory load (Druzgal & D'Esposito, 2001). Neta and Whalen (2011) demonstrated differential performance and cortical activation patterns for emotion recognition vs. facial identity during 2-back performance in a typical adult sample, with better performance on the identity task, emotion task-related activation in superior temporal sulcus and inferior frontal gyrus, and identity task related activation in anterior cingulate, precuneus, and temporo-parietal junction, as well as increases in dorsolateral prefrontal cortex activity for both conditions (Neta & Whalen, 2011).

Similarly, others (Gray, Braver, & Raichle, 2002) investigated cortical activation patterns during letter vs. face 3-back tasks after inducing either positive or negative emotional states by having participants watch movie clips before task completion. Remarkably, their sample of healthy adults demonstrated no main effect of type of task, but a crossover effect of enhanced word 3-back performance with positive emotion state and impaired word 3-back performance with negative emotion state, with the opposite pattern for face 3-back performance. Furthermore, regions of interest (lateral prefrontal cortex) showed the greatest activation during the task/state combinations with enhanced performance (word-unpleasant and face-pleasant), less activation in the neutral conditions, and even less in the conditions with impaired performance (word-pleasant and face-unpleasant). In sum, a precedent for investigating the effect of emotional content on working memory process at both the behavioral and neural levels in typical and clinical populations has been established.

This recent evidence for the specificity of activation patterns during emotion-cognition integration in prefrontal regions in controls (Gray et al., 2002) provides an intriguing impetus for examining this phenomenon in ASD, given demonstrated deficits in both emotional and cognitive domains. In the ASD literature, studies using the classic *n*-back paradigm with simple stimuli (letters, geometric shapes) indicate comparable accuracy in comparison to neurotypical controls (Cui, Gao, Chen, Zou, & Wang, 2010; Koshino et al., 2005; Ozonoff & Strayer, 2001; Williams, Goldstein, Carpenter, et al., 2005). However, significant differences in reaction time (Cui et al., 2010) and reduced prefrontal activation were observed. Koshino and colleagues conducted an fMRI study in high-functioning adults with ASD using face stimuli in an *n*-back task (Koshino et al., 2008). Neuroimaging results indicated reduced left prefrontal and right superior temporal activation and less functional connectivity in the ASD group than the control group. However, the task was based on responding to facial identity recognition, not on emotion recognition, despite the fact that the stimuli consisted of emotionally expressive (not just neutral) faces Other methodological weaknesses, such as varying levels of zoom and or extraneous detail in the stimuli, may have contributed to their lack of significant findings at the behavioral level, though they did demonstrate group differences at the neural level. The current study has potential to address this gap in the literature regarding working memory specifically for emotional expressions in the ASD population

Although there is some evidence for short-term memory for faces being a weakness in ASD (Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998; Wallace, Coleman, & Bailey, 2008; Williams, Goldstein, & Minshew, 2005), no studies with ASD samples have used the *n*-back paradigm to target responses to facial expressions of emotion to directly investigate parametric variation of working memory load. Two studies have come close to this design. As described in the introduction section, Koshino and colleagues (2008) compared *n*-back performance using faces as stimuli between a sample of high-functioning individuals with ASD and full-scale and verbal IQ matched controls. However, the task was to respond to facial identity. The authors reported that there were no group differences at the behavioral level, and that both groups showed expected patterns of medial frontal gyrus and inferior frontal gyrus activation associated with working memory tasks and fusiform activation associated with face perception. However, they also found that the ASD group showed more right hemisphere lateralization of frontal activation and less activation of superior and middle gyri of the posterior temporal lobes (areas important for processing social information) than the control group.

Of note, a potential confound of Koshino et al.'s (2008) experimental task was that the facial stimuli used were emotionally expressive, though the task was a facial identification task, and there is no mention of systematic variation or controlling for this variable. If emotional expression was constant for a particular facial identity stimulus (person X is always smiling, person Y is always frowning), featural level information (e.g., frowning mouth) could have been used to perform the identity task, without recognition of the emotional expression or identity per se. Furthermore, the stimuli included other uncontrolled visual variations (e.g., differences in orientation, zoom level, or presence of eyeglasses and other articles of clothing) that could have diverted attention away from the emotionally salient aspects of the stimuli (Krebs et al., 2011).

Not only could such attentional diversion have affected the results at the behavioral level, but also at the neural level, given research that shows differing neural networks for facial identification vs. (facial) emotion perception (Calder & Young, 2005; D'Argembeau & Van der Linden, 2011; Haxby, Petit, Ungerleider, & Courtney, 2000). Neta and colleagues (2011) conducted a study similar to Koshino and colleagues (2005) using emotionally expressive faces and fMRI with healthy adults within the context of an *n*-back task, where the task also varied according to whether participants responded to facial identity or emotional expression. They found that participants were more accurate and had faster reaction times for identity than for emotion in the 2-back task. Furthermore, the emotion task elicited greater activation in the right posterior superior temporal sulcus and bilateral inferior frontal gyrus, whereas the identity task elicited greater activation in the rostral/ventral anterior cingulate cortex and bilateral precuneus, and right temporo-parietal junction. Finally, conjunction analyses revealed that bilateral dorsolateral prefrontal cortex, dorsal anterior cingulated cortex, bilateral superior parietal lobule, fusiform gyrus, and other visual areas were activated for both tasks.

1.1.4 Summary and current Study

Working memory deficits may contribute to the significant social disability high functioning individuals with ASD experience in their day-to-day lives. Clarifying both the behavioral manifestations and the neural underpinnings of these difficulties will advance our understanding of the deficits observed in real-world social interactions, and may have the potential to inform intervention approaches for individuals with ASD. Considering 1) the conflicting evidence for emotion recognition deficits in ASD, 2) lack of deficit in both verbal and nonverbal *n*-back performance, and 3) suggestions to increase task difficulty as a method to investigate working memory differences in ASD vs. typical controls, the stage is set for the current study.

The primary aim was to examine the interactive contribution of both working memory and emotion recognition integrated into a single task. This integrated task could be conceptualized as a simplified model for the process of social interaction (maintaining and updating emotionally salient stimuli). Further, it also imposes experimental constraints that permit focusing on component skills within the domains of executive functioning and social reciprocity, as related theories have been criticized for being based in domains that are too broad.

The results of the current study partially extend previous findings in an adult control population (Neta & Whalen, 2011) to adults with ASD. This study also advances the literature by including parametric variation of working memory load such that patterns of performance with increasing load can be examined. Additionally, the potential confounds in the Koshino et al. (2008) study were addressed by limiting the task to emotion recognition only, with careful and systematic variation in facial identity to preclude unintentional responding to identity instead of emotion, as well as by cropping out extraneous, non-social details in the stimuli. The results of the current study address a gap in the literature regarding working memory for socially and emotionally salient stimuli in a population of individuals with ASD, recently referred to as “hot” executive functioning. This study draws from neuropsychological theories of ASD including the executive functioning theory, the weak central coherence theory, and social cognitive theories, using a methodologically rigorous design with potential to have clinically useful applications, such as informing development of intervention strategies (Baltruschat et al., 2011).

1.2 Hypotheses

Hypotheses were formulated for accuracy data only. Previous research (Tracy, Robins, Schriber, & Solomon, 2011) has demonstrated that individuals with ASD are able to identify a target emotion accurately among a set of matches and non-matches, given sufficient time to view the stimuli (Soulieres, Mottron, Giguere, & Larochelle, 2011). Additionally, intact maintenance memory for non-verbal stimuli in ASD has also been demonstrated (Bennetto et al., 1996; Mottron, Morasse, & Belleville, 2001). Therefore, group differences on the maintenance memory (0-back) task seemed unlikely. Reaction time hypotheses were not formulated as there is insufficient basis in the extant literature. Reaction time analyses were carried out for exploratory purposes only.

1.2.1 Hypothesis 1

It was hypothesized that both groups would demonstrate lower accuracy as working memory load levels increases. More specifically, 3-back performance will be significantly less accurate than 2-back, and 2-back performance will be significantly less accurate than 1-back.

1.2.2 Hypothesis 2

It was hypothesized that a significant interaction effect would be demonstrated, such that the ASD group would show lower accuracy on the 2-back condition (Hypothesis 2a) and the 3-back condition (Hypothesis 2b) than would the control group. Because demands for emotion processing are low when the task only requires detection of back-to-back targets it was not expected that 1-back condition performance would significantly differ across groups.

2 METHOD

2.1 Sample and Participant Selection

2.1.1 Sample Size

An a priori power analysis was conducted using G*Power 3.1.3 (Faul, Erdfelder, Lang, & Buchner, 2007) and indicated that 34 participants would be required for the present study design. However, further inspection of extant literature using similar experimental designs, (mixed ANOVA, also called split-plot designs) suggested that accurately estimating effect size, power, and therefore appropriate sample size is a more complex process than the G*Power program can handle (Bakeman, 2005). Furthermore, the experimental task in the current study has not yet been conducted in an ASD population, so estimates of effect size were not available to more accurately calculate the required sample size for the present design. In consultation with faculty members at Georgia State University who have expertise in research design and statistical analytic methods, it was recommended that recruiting a sample of 60 participants would be a conservative approach by doubling the rule of thumb of 5 participants per cell, and thus more than enough data points to ensure sufficient power. However, response to recruitment efforts was very low despite persistent efforts to reach out to the ASD community in both Atlanta and Miami, including increasing the compensation from $10 to $30. The dissertation committee was petitioned for permission to cease data collection after 32 controls and 19 ASD individuals had participated, and permission was granted based on preliminary analysis results and ability to address the key questions of the study. Furthermore, several published studies employed similar sample sizes, which were sufficient to reveal group differences (Cui et al., 2010; Gabig, 2008; Goldberg et al., 2005; Kana et al., 2007; Kennedy & Adolphs, 2012; Landa & Goldberg, 2005; Lopez et al., 2005; Nakahachi et al., 2006).

2.1.2 Recruitment

Participants were recruited in Atlanta, GA and Miami, FL via various strategies. These include direct emails to participants in previous studies that included ASD samples; in-person presentations at local community support groups; flyers posted at Georgia State University, the University of Miami, and distributed at Autism Society of America local chapter events and other community events targeted to individuals with developmental disabilities; messages posted on ASD community listservs; and word of mouth communication with the help of local clinicians who serve the ASD population. Participants were also recruited from the undergraduate participant pool through the web-based recruitment system (SONA) at Georgia State University, and a large database of individuals who gave permission at organizations and events related to the ASD community in the greater Atlanta area for lab members to contact them about new research studies.

2.1.3 Participants

Participants were individuals between the ages of 16 and 30 years who were diagnosed with an autism spectrum disorder and healthy controls without an autism spectrum disorder. Males and females were included. All participants were fluent and dominant in English, based on self report. All participants had either normal or corrected to normal vision. A total of 51 individuals participated in the study; 32 control and 19 with ASD. Control participants were overenrolled due to simultaneous enrollment in both Miami and Atlanta. Participants were screened for central nervous system disorders, brain tumors or injuries, and psychiatric conditions, as these have the potential to interfere with recognition of emotional expressions. Six participants' data were excluded from analyses. One participant from the ASD group demonstrated inability to comprehend the task requirements despite IQ that was within normal limits, as evidenced by poor performance on practice tasks, and was excluded from participation. One control group participant was excluded due to reported depression and obsessive-compulsive disorder. Two controls and two participants with ASD were excluded from data analyses due to response bias and inattention to the experimental task. The final sample included 29 control and 16 ASD participants. Response bias was determined by summing each participant's number of YES responses and NO responses across all conditions of the experiment, to obtain a mean and standard deviation for both. Additionally, total number of trials in which there was no response was also summed across conditions. Participants whose total number of YES, NO, or no response trials fell outside two standard deviations of the mean for the whole sample were excluded from analyses. Incidentally, the participants who were identified using this method were the same participants who demonstrated obvious signs of inattention or unwillingness to comply with instructions based on behavioral observations during data collection. See Table 2.1.3.1.

Table 2.1.3.1. Means and standard deviations for response type, to check for response bias for all enrolled participants (*n*=51).

Type of response	*M (SD)*
Number of trials with "Yes" responses	96.66 (20.45)
Number of trials with "No" responses	108.96 (16.24)
Number of trials with no response (blank)	6.46 (8.58)
Number of trials with 2 responses (2nd response same as 1st)	2.12 (8.27)
Number of trials with 2 responses (2nd response different from 1st)	1.38 (3.26)

Group characteristics (means and standard deviations) for age, years of education, verbal IQ, performance IQ, full-scale IQ, and Autism Screening Quotient (AQ) scores are presented in Table 2.1.3 2. Groups did not significantly differ on age (p=.227), years of education (p=.124), or PIQ (p=.105). Significant group differences were found in VIQ (p=.025) and AQ (p <.001). Proportions of the groups based on sex and racial identity are significantly different in the two groups (Table 2.1.3.3). Scores on IQ measures were not used as covariates, despite significant difference in verbal IQ between groups, as recent arguments against such practices provide a compelling argument for breaking with this longstanding tradition (Dennis et al., 2009).

Table 2.1.3.2. T-test results for demographics, estimates of VIQ, PIQ, FSIQ, and AQ and SCQ descriptive.

	Control (*n*=29)		ASD (*n*=16)				
Variable	*M*	*SD*	*M*	*SD*	*t*	*Df*	sig
Age (years)	20.34	3.131	21.63	3.739	-1.225	43	*p*=.227
Education (years)	14.24	2.655	13.06	1.879	1.569	43	*p*=.124
VIQ (T score)	56.34	7.911	48.69	11.394	2.389	23.16	*p*=.025*
PIQ (T score)	51.72	5.637	55.69	8.388	-1.691	22.65	*p*=.105
FSIQ (standard score)	106.76	10.858	103.75	15.665	0.683	23.14	*p*=.501
AQ (raw score) (n=41)	14.32	4.563	27.31	8.489	-5.179	15.31	*p*<.001*
SCQ (raw score) (n=10)	-	-	21.10	7.68	-	-	-

* Age is in years, education is in years, VIQ and PIQ are T-scores, FSIQ is presented as a standard score, and AQ is presented as a raw score.

Table 2.1.3.3. Proportions of sex and racial identity, by group.

	Control (*n*=29)	ASD (*n*=16)
Males	6.9%	68.8%
Females	93.1%	31.3%
African American	48.3%	0%
Asian	3.4%	0%
Caucasian	37.9%	50%
Hispanic	10.3%	31.3%
Bi- and Multi-Racial	0%	12.6%

2.2 Assessments and Measures

2.2.1 ASD symptom and IQ measures

ASD diagnosis was confirmed with Module 4 of the Autism Diagnostic Observation Scale, 2nd Edition (ADOS-2; Lord et al., 2000), which is intended for adolescents and adults who are verbally fluent. When caregivers for ASD participants were available, they completed the Social Communication Questionnaire (SCQ; Rutter, Bailey, and Lord, 2003) a 40-item, forced choice (Yes vs. No) caregiver questionnaire that queries the lifetime presence of behaviors characteristic of individuals with ASD. The SCQ is based on the diagnostic algorithm of the Autism Diagnostic Interview – Revised (ADI-R) which, along with the ADOS, is considered the gold standard for establishing new ASD diagnoses.

The ADI-R, an extensive caregiver interview that can last 45 minutes or longer and that assesses symptoms of ASD based on DSM-IV TR criteria and provides cutoff scores for diagnostic classification has, along with the ADOS, been considered gold standards for establishing new diagnoses. Although both are traditionally included in numerous published studies, most current studies tend to eliminate the ADI-R for participants with diagnosis that are already established, for feasibility reasons. Thus, the SCQ was included with the intent of using it as a proxy for the ADI-R.

All participants completed the Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), a 50-item self-report that measures the degree to which a person endorses traits associated with an ASD. The items are constructed to tap the following five areas: social skill, attention switching, attention to detail, communication, and imagination. The AQ and SCQ are not diagnostic assessments, but instead serve primarily as means to corroborate a reported history of ASD diagnosis for the ASD group. Exclusion criteria for the control group included scores above the suggested cutoff score of 26 on the AQ (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005) or 15 on the SCQ.

The Wechsler Abbreviated Scale of Intelligence, 2nd Edition (Wechsler, 2011) was administered as a brief screen to ensure adequate intellectual capacity to understand task instructions. Participants whose full-scale IQ scores were less than 70 were to be excluded. However, given that high-functioning individuals with ASD were specifically recruited, none of the participants' IQs were lower than 70.

All participants in the ASD group met criteria for an autism spectrum disorder based on the ADOS. Only 10 ASD participants had caregivers available and willing to complete the SCQ on the day of data collection. Participants who did not have a caregiver available on the day of data collection were asked to take home an SCQ form and a postage-paid envelope addressed to the PI, so that their primary caregiver could complete it and send it back to the PI. However, none of the SCQs were returned via this method. Therefore, SCQ data are missing for six participants, and thus, the SCQ was not utilized as an inclusion criterion. Of the 10 who did have completed SCQs, 8 met the suggested cutoff score of 15 as an indicator of possible ASD, though the authors of the SCQ recommend a lower threshold if other risk factors are also present. AQ data are missing for one control participant and three ASD participants, due to refusal to complete the questionnaire. The suggested cutoff score of 26 has been shown to have good discriminative validity in distinguishing neurotypical adults from those with Asperger's Disorder and high-functioning autism. (Woodbury-Smith, et al., 2005). None of the control participants' scores on the AQ exceeded this suggested cutoff. Of the 13 participants in the ASD group who completed the AQ, seven participants' scores met or exceeded the cutoff and six participants did not meet the cutoff. None of the participants were excluded on the basis of IQ scores.

2.2.2 Procedure

For both institutions where the study was conducted, approval was obtained from respective Institutional Review Boards. For many participants, all experimental testing and study questionnaires were administered in a research laboratory in the Psychology Department of Georgia State University, Atlanta, Georgia or in a private office at the University of Miami Miller School of Medicine. However, the option of completing all study related tasks in participants' homes was offered, in order to reduce the burden of finding transportation and paying for parking. Several participants, both control and ASD, chose the latter option. In all cases when study activities were conducted in participants' homes, a distraction-free environment with adequate furnishings and lighting was achieved. Total participation time was 2 ½ to 3 hours for the ASD group and 2 to 2 ½ hours for the control group (due to not completing the ADOS).

Upon arrival at the study location, the participant received an explanation of the study and consent and/or assent forms were reviewed verbally. Participants and in one case, an adult ward and his legal guardians, were given ample time to read the consent and/or assent forms, and ask questions when they arose. Participants (and legal guardian) indicated consent to participate by signing the appropriate forms. Participants completed preliminary screening and questionnaires in order to ensure that they meet both inclusion and exclusion criteria. Preliminary screening included an informal interview to collect demographic information, and to inquire about histories of psychopathology, central nervous system disease, and brain injury or tumor. Both ASD and control participants completed the AQ. Participants with ASD then completed the ADOS, while a caregiver (if available) completed the SCQ. The ADOS-2 administration was video recorded to allow the PI to review responses after data collection had been completed; these recordings were also useful in cases where consultation with the PI's mentor for ambiguous responses was required. Both groups of participants then completed the 2-subtest version of the WASI-II. Then, the experimental task and its associated practice runs were completed by both groups. The PI and other study personnel guided the participants through the practice runs in order to ensure that they understood the instructions. Practice runs for each working memory condition were completed first using cards with stimuli printed on them and then on a laptop computer. The experimental tasks were the same as the practice runs on the laptop computer, but included more trials.

After completion of the experimental tasks, the participants were debriefed and allowed to ask any questions they had about the experiment. Participants who completed study activities were given a gift card to Target worth $10 (or $30.00 if they participated after compensation was increased in attempt to increase enrollment).

2.2.3 Experimental task

The experimental task for the current study served as a model of social interaction, but with tight experimental control. The 0-back task involves viewing a target stimulus that is presented for a fixed amount of time, after which a series of other stimuli are presented. The participant must indicate which items within the series match the initial target stimulus based on a pre-determined dimension, and which do not. The 0-back condition is a slightly different measure than the 1-, 2-, and 2-back tasks, in that it measures maintenance memory or vigilance, but does not involve continual updating of the to-be-remembered information as do the 1-, 2- and 3- back conditions. The 0-back condition was included as a baseline for individual differences in emotional expression matching, but was not included in the main analysis as a key variable of interest.

Working memory was assessed using the *n*-back task. Stimuli consisted of cropped photographs of faces (Tottenham et al., 2009). The NimStim Set of Facial Expressions is widely used in both clinical and typical populations and includes a variety of facial expressions at both high and low levels of intensity, and a variety of male and female actors from various racial backgrounds. The initial validation and reliability study of the NimStim set yielded high measures; kappa = .79 across emotions and test-retest reliability was 0.84.

Neta and Whalen (2011) also utilized the NimStim Set of Facial Expressions to compare cortical activation for facial identity vs. emotion expression recognition within the context of an *n*-back task, in a sample of normal controls. The current study partially follows their design in that it includes *n*-back for emotional expression, but does not include a facial identity *n*-back condition, and it extends the findings to the ASD population. However, as Krebs et al. (2011) noted, ASD participants may be tempted to identify targets on the basis of irrelevant, peripheral features, such as hairline or the presence of an earring. Therefore, NimStim photos were cropped to eliminate as much extraneous visual information as possible to reduce this likelihood.

The NimStim set includes photos of 43 male and female actors from a range of racial backgrounds. The stimulus set depicts closed- and opened-mouth versions of happy, sad, angry, fearful, calm, and neutral. Surprise is also included, but only has the opened-mouth version. This yields a total of 688 stimuli. The current study only included the closed-mouth versions of each of the emotions, to control for perceptual differences across the different emotions, such as toothiness. Thus, the surprise expression was excluded, because there is no closed mouth version. Neutral expression was also not included, as some studies have demonstrated that neutral is often construed as a negative emotion (Tottenham et al., 2009). The calm expression was used in place of neutral. This subset of photos contains a total of 258 stimuli, depicting six emotions from 43 different actors. With this number of stimuli available, it was possible to ensure that no one stimulus was repeated in any of the experimental trials. However, some of the stimuli that were used in the experimental trial were part of either the practice tasks on paper or on the laptop. None of the practice stimuli appeared in the experimental block with which it was paired. Stimulus duration was 2000 ms, following the design of studies that closely resemble the proposed study in that they included NimStim faces in an *n*-back task based on emotion (rather than identity) (Levens & Gotlib, 2010; Neta & Whalen, 2011). Inter-stimulus Interval (ISI) was 1000 ms, as most of the *n*-back studies in related literature using facial stimuli used this interval (Cohen et al., 1997; du Boisgueheneuc et al., 2006; Hideya Koshino et al., 2008). Target to non-target ratio was 1:1 in order to allow sufficient opportunity for behavioral responses to targets to be measured, which ensures adequate power for repeated measures designs, as in other behavioral studies with similar design (Ozonoff & Strayer, 2001; Phillips et al., 2001).

First, all participants completed an emotion matching practice task, to ensure adequate emotional expression identification skills to complete more difficult delayed-match-to-sample (0-back), and working memory tasks (1-, 2-, and 3-back). Stimuli printed on cards, one for each of the six emotions, were displayed in a single row on the table in front of the participant, to represent multiple choice options. Then the PI or lab assistant presented another stimulus that matched one of the multiple choices displayed in front of the participant, in terms of emotional expression. The participant was asked to select from the multiple choices which one had the same emotional expression as the one the PI/lab assistant was presenting (target emotion). This was repeated for each of the six emotions. In some instances, target emotion cards matched one of the multiple choices in terms of facial identity but not in terms of emotional expression. This allowed the PI/lab assistant opportunity to point out that though the same actors may be seen in the experiment, the task was to match based on emotional expression. Only one participant from the ASD group had significant difficulty on this task, and therefore, was excluded from participation. All other participants were able to complete this practice task successfully.

Participants then completed practice and experimental trials for the 0-back task. This is a delayed match-to-sample, or maintenance memory task, conducted to ensure that participants had the ability to hold an emotional expression in memory for a short period of time. First, a practice version was completed with stimuli printed on cards. A target emotion was presented for approximately 2000 ms, and the participant was prompted to remember the emotional expression. Then subsequent stimulus cards were presented one by one, whereas the participant replied YES if the one they were viewing had the same emotional expression as the target emotion initially presented, or replied NO if it was not the same emotion. If the participant made a mistake, the task was paused and the target emotion was presented again briefly so that the participant was allowed to give a second response. This process was repeated with each of the six emotions as target emotions. There were 10 trials per emotion block, with the target emotion appearing three times within each emotion block. The order in which the stimuli were presented within a block was randomized. None of the participants made more than two errors per emotion block and when a mistake was made, participants provided the correct response on their second chance.

Next, a practice run for the 0-back condition was completed on the laptop. The participant's attention was directed to written instructions on the screen. Instructions were also read aloud to the participants. The instructions read: "Look at this face. Remember the ***emotion*** on this face. On the rest of the faces, press the YES button if it has the same ***emotion*** as the first face or press the NO button if it is not the same ***emotion***." Then, the target stimulus disappeared from the screen and a new face appeared with the prompt at the bottom of the screen than read “YES – same ***emotion*** as the first face. NO – not the same ***emotion*** as the first face.” The YES key was labeled on the right side of the keyboard (/) and the NO key was on the left (z). The stimulus and prompt remained on the screen until the participant selected their response, after which they both disappeared. A new stimulus appeared, again with the prompt at the bottom of the screen. After responding to this trial, subsequent trials appeared without the prompt, and for a fixed length of time of 2000 ms with an interstimulus interval (blank screen) of 1000ms. Participants were warned that the remainder of the stimuli would “flash on the screen quickly” so that they would be prepared to respond. The continuous stream of stimuli proceeded at that rate regardless of whether or not the participant registered a response. For the majority of participants, it took a few trials to become accustomed to the pace of trial presentation, such that by the end of the first emotion block, all were responding during the 3000 ms stimulus + interstimulus interval period. The order in which the practice 0-back emotion blocks was fixed: 1) angry, 2) happy, 3) sad, 4) fearful, 5) disgust, and 6) calm. The practice 0-back run on the laptop took approximately 3 minutes to complete.

Participants then completed the 0-back experiment on the laptop. For each emotion block, 10 targets and 10 non-targets (two each of the five non-target emotions) were presented in random order within each emotion block. Again, the order in which the target emotion blocks were presented was fixed (see above). Stimulus presentation time was again 2000 ms with a 1000 ms blank-screen interstimulus interval. The 0-back run took approximately six minutes to complete.

Participants then completed each of the remaining working memory load conditions twice. With three working memory load condition, (1-back, 2-back, and 3-back), each performed twice, there were six blocks, presented in two runs (A and B), with a short break in between runs. A practice task with stimuli printed on cards, as well as a short practice task on the laptop computer was completed before each of the six experiment blocks. The practice on cards was discontinued if the participant responded correctly to three consecutive trials. For participants who made errors, the practice task was paused, and the target stimulus was briefly re-presented so that the participant could see the nature of their mistake. The purpose of the practice with cards was to exclude participants who were unable to achieve roughly 70 percent correct for the practice trials on cards. However, this was usually not the case for the 1- and 2-back conditions. Participants in both groups had considerable difficulty with the 3-back condition, though data collection ensued in order to evaluate systematically the value of including such a difficult condition for future studies in this population. After the first few participants' data were collected, it became apparent that the practice task with stimuli on cards was highly redundant for the 2nd run, as the participants clearly understood the task demands, even if they felt they did not perform well, for example, on the 3-back condition. So, for the 2nd run, the practice on cards was eliminated, whereas the practice on the laptop was performed for both runs. As described above, none of the stimuli in the practice tasks (cards + laptop) appeared in its associated experimental block.

The order in which the working memory load conditions were presented was pseudorandomized by creating two runs (Run A and Run B), neither of which started with the most difficult condition, the 3-back. The run order was counterbalanced within groups such that half of the control participants were presented with Run A first and the other half were presented with Run B first; the same was done for the ASD group. Each block included 18 targets and 18 non-targets, with three stimuli for each of the emotions within a block, which yields a total of 36 stimulus presentations within a block. This number also ensures that the ratio of target to non-target is 1:1, thereby ensuring that the possibility of both "YES" and "NO" responses occurred an equal number of times within a block. For a depiction of the experimental design and task, see Figures 2.2.3.1 and 2.2.3.2.

0-back practice, experiment				
Run A	**Block 1a**	**Block 2a**	**Block 3a**	
	Practice with stimuli from 3b	Practice with stimuli from 1a	Practice with stimuli from 2a	
	1-back	**3-back**	**2-back**	Total
	18 targets & 18 non-targets	18 targets & 18 non-targets	18 targets & 18 non-targets	108 stimuli
	3 each of the 6 emotions	3 each of the 6 emotions	3 each of the 6 emotions	
Run B	**Block 1b**	**Block 2b**	**Block 3b**	
	Practice with stimuli from 3a	Practice with stimuli from 1b	Practice with stimuli from 2b	
	2-back	**1-back**	**3-back**	
	18 targets & 18 non-targets	18 targets & 18 non-targets	18 targets & 18 non-targets	108 stimuli
	3 each of the 6 emotions	3 each of the 6 emotions	3 each of the 6 emotions	

Figure 2.2.3.1 Experimental design

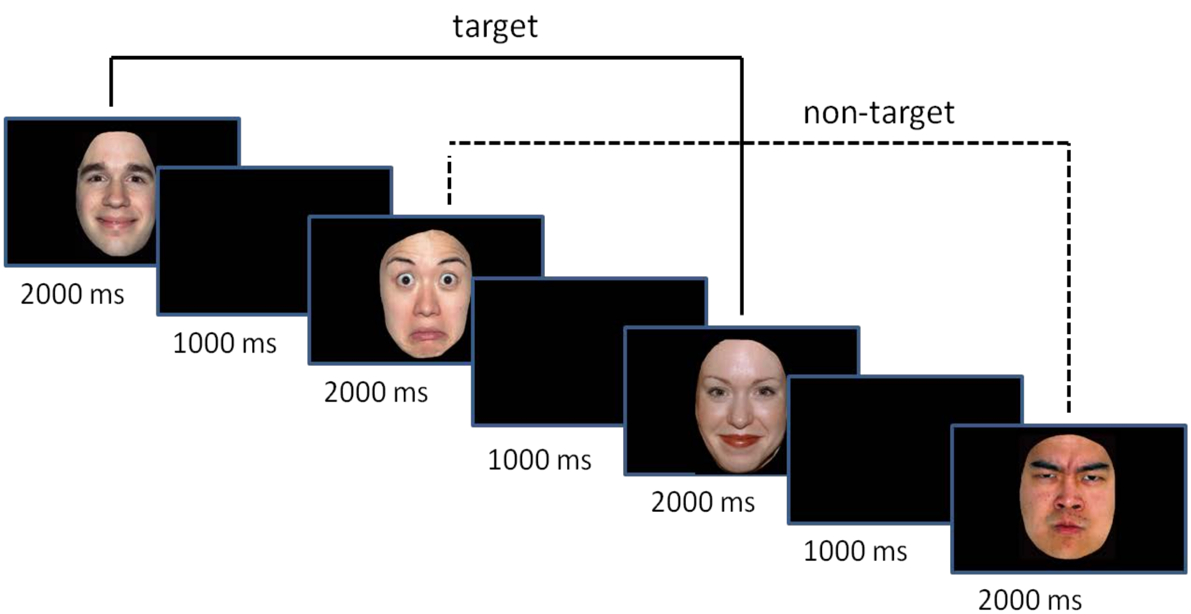

Figure 2.2.3.2. A depiction of the 2-back condition with cropped NimStim examples.

Participant data were double-entered, once in SPSS and once in Microsoft Excel and then exported to SPSS in order to detect and rectify data-entry errors. The data were analyzed using SPSS version 18. A mixed ANOVA with group as the between group variable and working memory load as the repeated measures variable was conducted. Two sets of analyses were conducted: one with accuracy level as the dependent variable and one with reaction time as the dependent variable. Post-hoc *t*-tests were conducted when appropriate.

3 RESULTS

3.1 Variables

Independent variables included group and working memory load. The between-group variable consisted of two levels: ASD and controls. The repeated-measures variable consisted of working memory load levels: 1-back, 2-back, and 3-back. Accuracy level calculated as percent correct responses served as the primary dependent variable. Accuracy level was operationalized as the total number of correct responses, divided by total number of trials for which participants responded (correct + incorrect) x 100. Correct responses (YES for targets + NO for non-targets) and incorrect responses (NO for targets + YES for non-targets) were summed across the Run A and Run B blocks for each working memory load to create a composite accuracy level percentage. Trials with no response were not included in this calculation. Reaction time data were also collected and analyzed for exploratory purposes. Reaction time was operationalized as the average time from stimulus onset to response across all correct response trials within a working memory load condition (Run A and Run B) to create a composite reaction time, presented in milliseconds. Means and standard deviations by group and working memory load are presented in Table. 3.1.1. Performance in terms of accuracy level and reaction time across working memory load levels is presented in figures 3.1.1 and 3.1.2.

Table 3.1.1 Means and standard deviations of percent correct, reaction time, and no response trials by working memory load and group.

		Control (*n*=29)	ASD (*n*=16)	Total (*n*=45)
% Correct *M (SD)*	0-back	82.23 (5.70)	71.73 (10.98)	78.49 (9.36)
	1-back	80.65 (5.45)	68.40 (13.20)	76.30 (10.66)
	2-back	75.92 (10.87)	61.18 (8.51)	70.68 (12.28)
	3-back	64.61 (10.69)	56.00 (7.72)	61.55 (10.51)
	1- +2- +3-back	73.73 (7.79)	61.86 (8.66)	69.51 (9.85)
Reaction Time (ms) *M (SD)*	0-back	938.80 (124.12)	1023.03 (175.70)	968.77 (148.28)
	1-back	986.79 (148.91)	991.91 (135.02)	988.61 (142.59)
	2-back	1073.64 (167.86)	1033.23 (185.14)	1059.27 (173.20)
	3-back	1100.70 (210.05)	962.95 (247.58)	1051.72 (231.13)
	1- +2- +3-back	1053.71 (158.21)	1341.44 (162.65)	1033.20 (160.40)
No Response (raw) *M (SD)*	0-back	3.21 (4.92)	5.25 (12.86)	3.93 (8.53)
	1-back	1.00 (1.39)	1.2 (1.74)	1.07 (1.50)
	2-back	1.76 (3.28)	1.4 (2.41)	1.64 (2.99)
	3-back	2.45 (3.19)	1.27 (2.19)	2.05 (2.92)
	1- +2- +3-back	5.21 (6.11)	3.87 (5.83)	4.75 (5.98)

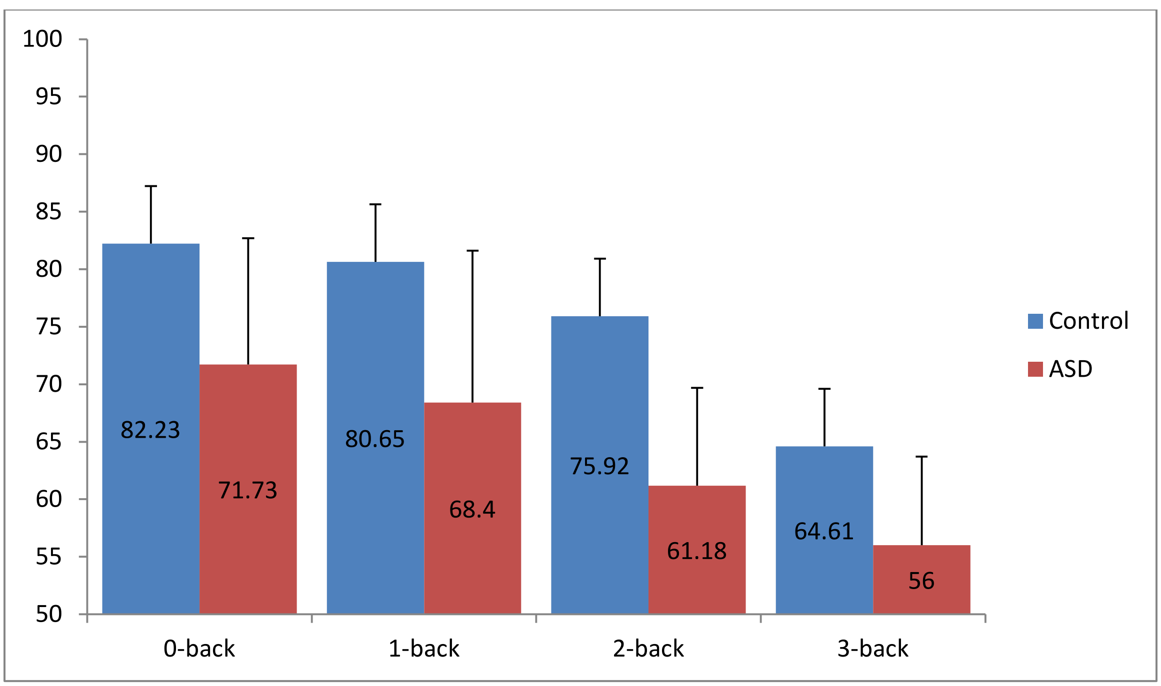

Figure 3.1.1. Mean accuracy level by group and working memory load.

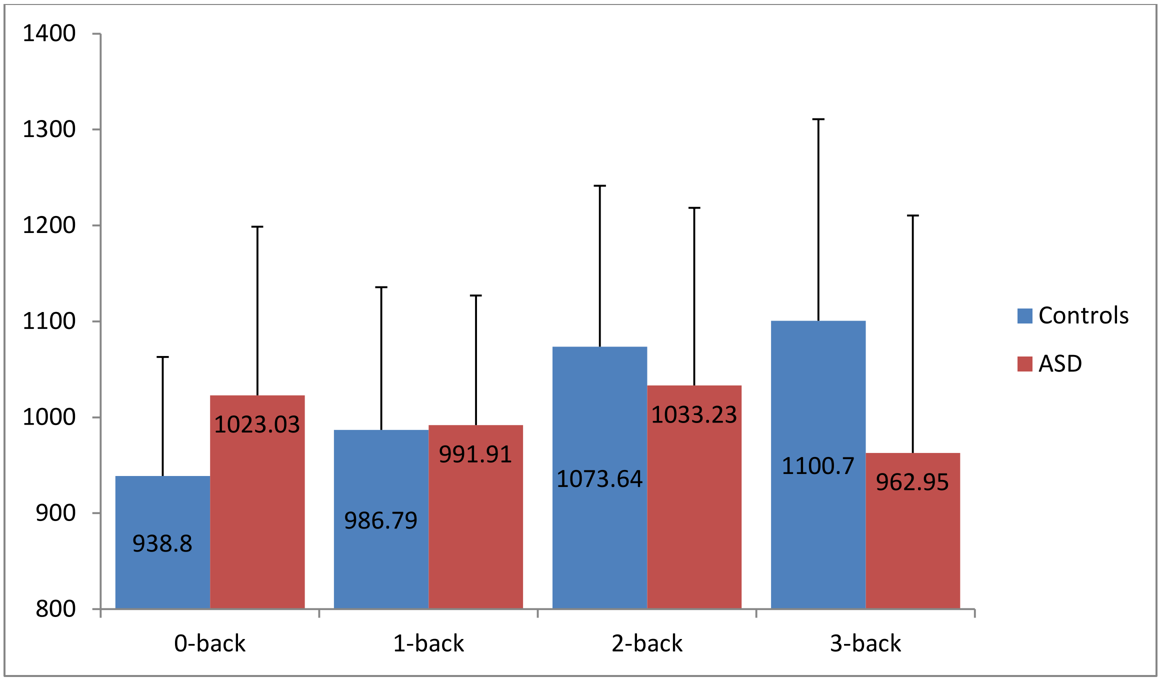

Figure 3.1.2. Mean reaction time by group and working memory load.

3.2 Accuracy Level Results

An independent samples *t*-test was conducted to test for a significant difference in accuracy level between groups on the 0-back task. The normality assumption for 0-back distribution within each group was checked and met. Levene's test was conducted to check the assumption of homogeneity of variance in the two groups. Results were significant indicating that variance in the 0-back condition was significantly higher in the ASD than the control group, F (1, 43) = 12.949, p=.001. Results of the independent samples *t*-test (corrected for equal variances not assumed) of accuracy level for the 0-back task revealed a significant group difference, t (19.562) = 3.564, p=.002, d=1.2, with the control group having significantly higher accuracy level. This was not predicted.

Differential patterns of performance, both within and between groups, were investigated using a 2 x 3 mixed design ANOVA to investigate main effects of group and working memory load, plus interaction effects on accuracy level for 1-, 2-, and 3-back conditions. The assumption of normality of distribution of scores within groups was met for all conditions except one. The distribution of accuracy level for the controls in the 1-back condition was non-normal. Given that factorial ANOVA is robust to violations of this assumption and that all other distributions were normal, data transformations were not performed. Specific to the requirements of a repeated measures mixed design ANOVA, the assumption of sphericity was checked via a Mauchly's test and was met and Sidak correction method (an alternative to Bonferroni correction, used to preserve power) for multiple comparisons was applied. There was a significant main effect of group on accuracy level, F (1, 43) = 22.16, p<.001, *partial* η^2= 0.34, with the ASD group (M=61.86, SD=8.66) having a significantly lower accuracy level when collapsing across all working memory load conditions than controls (M=73.73, SD=7.79). There was also a significant main effect of working memory load, collapsing across both groups on percent correct F (2, 86) = 52.09, p<.001, *partial* η^2= 0.62. Contrasts revealed significant decreases in accuracy for the entire sample as working memory load increased. The mean accuracy for 1-back (M=76.30, SD=10.66) was significantly higher than for 2-back (M=70.68, SD=12.28), F (1,43) = 19.57, p<.001, *partial* η^2 = .313, and mean 2-back accuracy level was significantly higher than 3-back (M=61.55, SD=10.51), F (1,43) = 34.269, p<.001, *partial* η^2 = .444. There was no significant interaction effect of Group x Working Memory load on accuracy level, F (2, 86)=2.43, p=.094, *partial* η^2 = .053. See tables 3.2.1 and 3.2.2 for results.

Table 3.2.1 Between subjects effects for percent correct as DV.

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
Intercept	1	2889.34	p<.001	.985	1.00
GROUP	1	22.16	p<.001	.340	.996
Error	43	196.83			

Table 3.2.2. Within subjects effects for percent correct as DV.

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
WM LOAD	2	52.09	p<.001	.548	1.00
WM LOAD* GROUP	2	2.43	p=.094	.053	.477
Error	86	40.37			

In order to explore the relationship between maintenance memory for emotional expression, as measured by the 0-back task, and working memory (1-, 2-, and 3-back tasks), partial correlations were conducted, controlling for the effect of group. Positive correlations between 0-back and each of the working memory tasks were revealed. Strong positive relationships were found between 0-back and 1-back accuracy levels (r=.597, p<.001) and between 0-back and 2-back (r=.413, p=.005), whereas a moderate positive relationship between 0-back and 3-back was observed (r=.306, p=.044). See table 3.2.5.

Table 3.2.3. Partial correlations between 0-back and each of 1-, 2- and 3-back, controlling for group.

	Partial r (2-tailed)	*Sig*	*df*
1-back	.597	*p*<.001	42
2-back	.413	*p*=.005	42
3-back	.306	*p*=.044	42

To investigate possible differences between in the relationship between maintenance memory and working memory accuracy further, data were analyzed separately by groups. In the control group, none of the working memory load condition accuracy levels was significantly correlated with 0-back accuracy. However, for the ASD group, the 1-back and 2-back levels, but not the 3-back, working memory load accuracy level, were significantly, positively, and strongly correlated with 0-back accuracy. See Table 3.2.6.

Table 3.2.4. Pearson correlations between 0-back and each of 1-, 2- and 3-back, separately by group.

		Pearson's r (2-tailed)	Sig
Control	1-back	.356	*p*=.058
	2-back	.279	*p*=.143
	3-back	.289	*p*=.116
ASD	1-back	.699	*p*=.003*
	2-back	.675	*p*=.004*
	3-back	.401	*p*=.123

Due to these significant correlations within the ASD group, a repeated-measures ANOVA with 0-back as a covariate was conducted for the ASD group. For exploratory purposes, the same analysis was conducted for the control group. Results for the ASD group, indicate that the main effect of *n*-back level was non-significant, after covarying for 0-back performance F (2,28) =.447, p =.644, *partial* η^2*=.031.* Similarly for the control group, the main effect of *n*-back level was also non-significant after covarying for 0-back performance F (2,54) =.469, p =.628, *partial* η^2*=.017..*

Table 3.2.5. Control group repeated-measures ANOVA of *n*-back level with 0-back as covariate.

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
n-back level	2	.469	.628	.017	.123
n-back level * 0-back	2	.121	.886	.004	.068
Error	54				

Table 3.2.6. ASD group repeated-measures ANOVA of *n*-back level with 0-back as covariate.

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
n-back level	2	.447	.644	.031	.116
n-back level * 0-back	2	2.080	.144	.129	.391
Error	28				

Closer inspection of the distribution of scores and the changes from 1-back, to 2-back, to 3-back reveals that performance changes were highly variable. Most control participants (n=19, 65.5%) demonstrated the expected linear, downward trend in accuracy as the working memory load increased, whereas some control group participants (n=7, 24.1%) performed more accurately on 2-back than 1-back and others (n=3, 10.3%) were more accurate on the 3-back condition than on the 2-back condition. In the ASD group, there were also some (n=4, 25%) who were more accurate on 2-back than 1-back and some (n=3, 18.8%) whose 3-back performance was more accurate than their 2-back. Whereas the control group's 3-back accuracy performance exhibited high variability in comparison to its 1-back performance (3-back SD almost twice the SD for 1-back), the opposite pattern is seen in the ASD group, with more variability in 1-back than 3-back accuracy performance. It is also notable that several control (n=5, 17%) and ASD (n=6, 37.5%) participants performed at near-chance levels of accuracy (<55% accuracy) in the 3-back condition. See Figures 3.2.1 and 3.2.2.

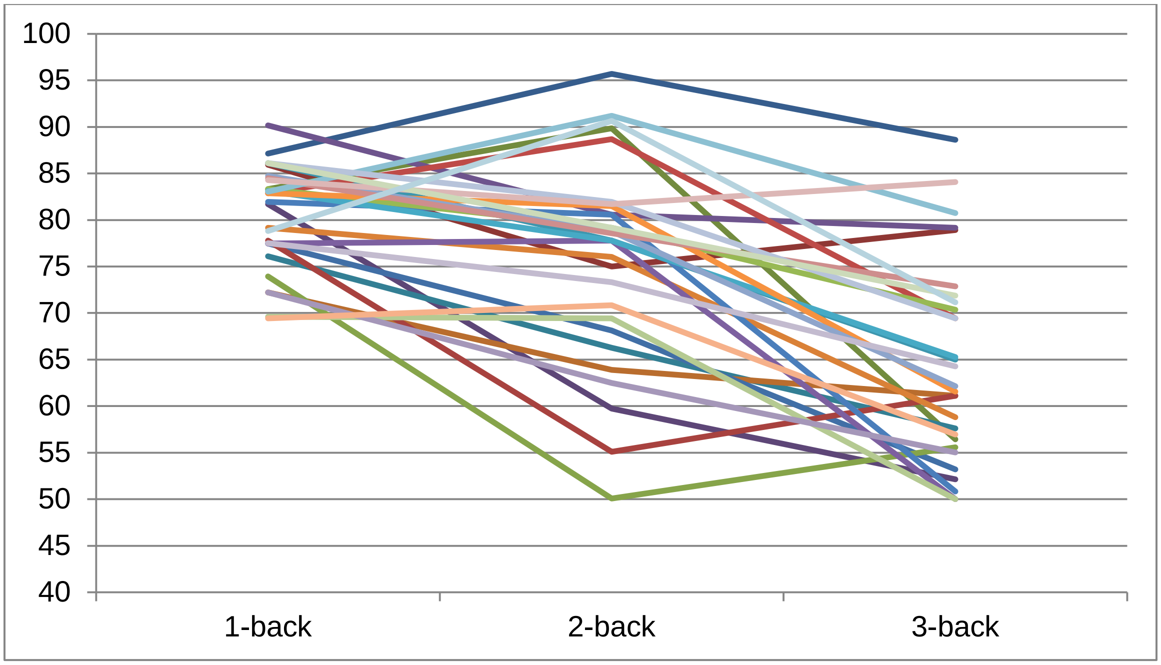

Figure 3.2.1. Individual control group participants' accuracy (% correct) performance change from 1-back, to 2-back, to 3-back

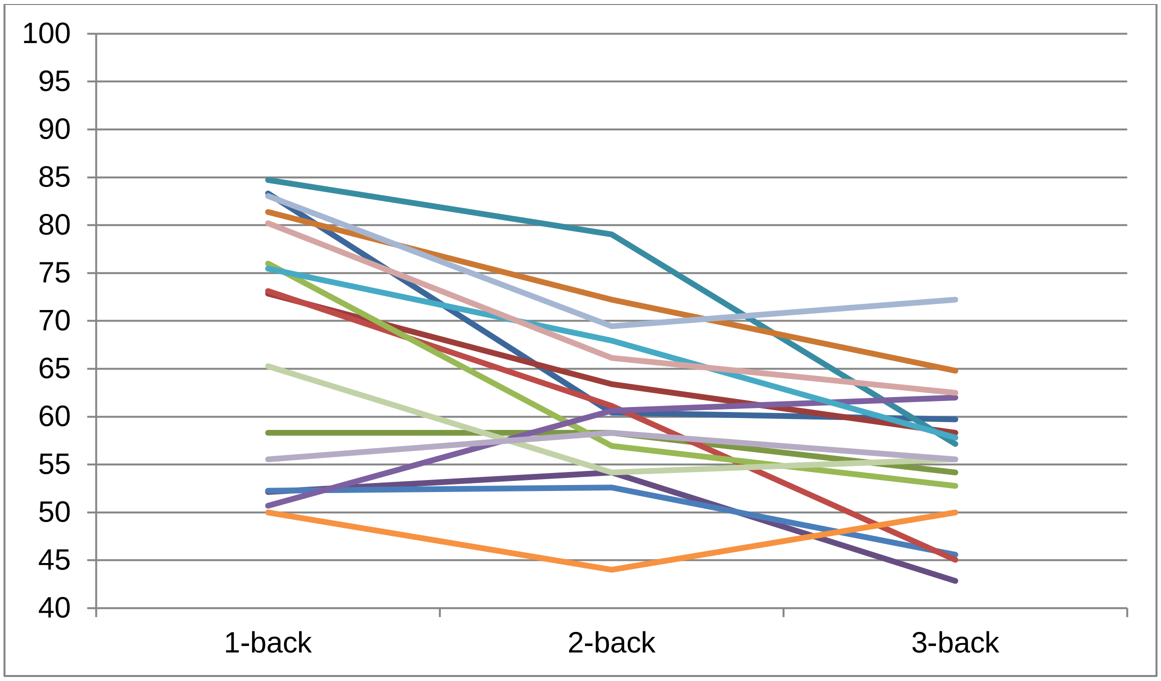

Figure 3.2.2. Individual ASD group participants' accuracy (% correct) performance change from 1-back, to 2-back, to 3-back.

Given that the control group's VIQ (*M*=56.34, *SD*=7.911) was significantly higher than the ASD group's (*M*=48.69, *SD*=11.394), Pearson correlations were calculated between VIQ and each of the task conditions for each group separately. VIQ was not significantly correlated with accuracy performance on any of the task conditions for the control group (all *p*s>.05). In the ASD group, VIQ was only significantly correlated with 2-back performance (*r*=.648, *p*=.007).

Table 3.2.7. Pearson correlations between VIQ (T-score) and each task condition.

	Control (N=29)		ASD (N=16)	
	r (2-tailed)	*Sig*	*r* (2-tailed)	*Sig*
0-back	.262	.170	.432	.095
1-back	.356	.248	.364	.166
2-back	.266	.163	.648	.007
3-back	.230	.231	.426	.100

3.3 Reaction Time Results

Reaction times for correct trials only were included in the analyses; reaction times for trials on which the participants responded incorrectly were excluded. An independent *t*-test was conducted for the 0-back task. Assumptions of normally distributed scores and homogeneity of variance was met for both groups. Results indicated that the difference between groups in reaction time was not significant for the 0-back task (see Table 3.3.3). Differential patterns of performance, both within and between groups with reaction time as the dependent variable were investigated using a 2 x 3 mixed design ANOVA. The assumption of normally distributed scores within groups was met for all conditions. The sphericity assumption was met for the main effect of group, but was not met for working memory load. Therefore, the Greenhouse-Geisser correction method was applied to the main effect of working memory load condition. There was no significant main effect of group on reaction time overall, F (1,43) = 1.34, p=.253, *partial* η^2= .03. In contrast, there was a significant main effect of working memory load, F (1.703, 3.56), p=.04, *partial* η^2= 0.076. Contrasts revealed that reaction times for 1-back (*M*=988.61, *SD*=142. 59) were significantly faster than reaction times for 2-back (*M*=1059.27, *SD*=173.20), F (1, 43), *p*=.007, *partial* η^2=.160. However, 2-back reaction times were not significantly different from 3-back reaction times (*M*=1051.72, *SD*=231.13), F (1, 43), p=.311, *partial* η^2=.024. Finally, a significant interaction effect for group x working memory load was found, F (1.703, 73.217), *p*=.02, *partial* η^2= .094. See tables 3.3.1 and 3.3.2 for results.

Table 3.3.1. Between subjects effects for reaction time as DV.

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
Intercept	1	1697.04	*p*<.001	.975	1.00
GROUP	1	1.34	*p*=.253	.03	.205
Error	43				

Table 3.3.2. Within subjects effects for reaction time as DV.

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
WM LOAD	1.703	3.56	*p*=.04	.076	.597

WM LOAD* GROUP	1.703	4.46	*p*=.02	.094	.700
Error	73.217				

Post-hoc independent samples *t*-tests were conducted to explore simple main effects, to see for which working memory load condition(s) the group difference in reaction time was significant. Results were not significant for any of the working memory load conditions, meaning that the two groups did not differ significantly in reaction time within any of the working memory levels (see Table 3.3.3).

Table 3.3.3. Independent samples t-tests for between group differences for each working memory load.

				95% Confidence Interval	
Variable	*Df*	*t*	*Sig*	*Lower*	*Upper*
1-back	43	-.114	.910	-95.697	85.456
2-back	43	.745	.460	-69.919	149.744
3-back	43	1.976	.055	-2.839	278.343

Repeated measures ANOVAs were conducted to determine whether reaction times for any of the working memory load conditions differed, within each group separately. For the control group, the sphericity assumption was not met, so the Greenhouse-Geisser correction method was applied, and the Sidak correction method (a less conservative alternative to Bonferroni correction that preserves power) for multiple comparisons was applied. The results indicate that the control group's increase in reaction time from 1- to 2-back was significant, F (1,28) = 13.455, *p*=.001, *partial* η^2*.325*, but the increase from 2- to 3-back was not significant, F (1,28) = 1.247, *p*=.274, *partial* η^2*.043*. (See Table 3.3.4). For the ASD group, neither was the increase in reaction time from 1- to 2-back F (1, 15) = .784, *p*=.390, *partial* η^2*=.050,* nor was the decrease from 2- to 3-back significant (see Table 3.3.5).

Table 3.3.4. Repeated measures ANOVA for control group reaction time comparisons from 1- to 2 and from 2- to 3-back

Variable	*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*

WM Load	1- to 2-back	1	13.455	.001	.325	.943
	2- to 3-back	1	1.247	.274	.043	.190
Error	1- to 2-back	28				
	2- to 3-back	28				

Table 3.3.5. Repeated measures ANOVA for ASD group reaction time comparisons from 1- to 2 and from 2- to 3-back

Variable		*Df*	*F*	*Sig*	*Partial* η^2	*Observed Power*
WM Load	1- to 2-back	1	.784	.390	.050	.132
	2- to 3-back	1	3.795	.070	.202	.446
Error	1- to 2-back	15				
	2- to 3-back	15				

The near chance-level accuracy performance in the ASD group for the 3-back condition raises the question of whether these participants found this condition particularly difficult and subsequently did not put forth much effort on this particular condition. One way to investigate this possibility would be to assume that increased effort as evidenced by increased reaction time, results in higher accuracy. This would suggest positive correlations between reaction time and accuracy, particularly for the more difficult conditions. This was not the case (see Table 3.3.6). The possibility that the ASD group's faster rate of responding is an indicator of low effort, or giving up because the task was simply too difficult cannot be ruled out. Another way to interpret the pattern of reaction time across the working memory load conditions is that the ASD group did not utilize a strategized approach to their responses, as evidenced by lack of significant differences in reaction time across the working memory load conditions, whereas the control group increased effort by slowing down when the difficulty of the task increased to a certain point, as evidenced by a significant increase in reaction time from 1- to 2-back conditions. The lack of significance in the control group's increase from 2- to 3-back may be evidence that they too, gave up on the 3-back condition.

Table 3.3.6. Pearson correlations for accuracy (%correct) and reaction time, by working memory load and group.

Group	WM Load	Pearson's r (2-tailed)	*Sig.*

Control	0-back	*r*=-.140	*p*=.468
	1-back	*r*=.254	*p*=.185
	2-back	***r*=.434**	***p*=.019**
	3-back	*r*=.328	*p*=.083
ASD	0-back	*r*=-.068	*p*=.802
	1-back	***r*=.588**	***p*=.017**
	2-back	*r*=.262	*p*=.327
	3-back	*r*=.211	*p*=.432

4 DISCUSSION

4.1 Results Discussion

The purpose of the study was to investigate working memory for facial expression of emotion in ASD. This was accomplished by using the *n*-back task with cropped photographs from validated set of facial expression stimuli, NimStim (Tottenham et al., 2009). The task served as an experimental model of a social interaction, in that it requires short-term memory and moment-to-moment updating (working memory) of socially and emotionally relevant information. This kind of skill has been referred to as “hot” executive functioning, as opposed to “cool” executive functioning which involves various aspects of cognitive control for abstract, decontextualized information (Barendse et al., 2013; Zelazo et al., 2010).

The results of the current study suggest that participants with ASD were able to recognize and remember emotional expressions over short periods of time, as evidenced by better than chance-level accuracy on the 0-back task. However, the ASD group did so with significantly less accuracy than control individuals, in contrast to expectations. Despite previous findings of intact ability to recognize the basic facial expressions (Adolphs et al., 2001; Jones et al., 2011) without time constraints and intact short-term visual memory for objects (Blair, Frith, Smith, Abell, & Cipolotti, 2002; Boucher & Lewis, 1989), the current results suggest that short-term memory for facial expressions when the stimulus exposure time is limited is impaired in young adults with ASD.

As expected, both controls and participants with ASD demonstrated progressively poorer accuracy with increasing difficulty of the task. Both groups had significant difficulty with the most challenging condition, the 3-back, as evidenced by near chance-level (defined as <55% accuracy) performance either as a group (ASD) or by several individual participants within the group (ASD and controls). It appears that extension of the *n*-back with facial expressions of emotion to the 3-back level constitutes too difficult a task to yield meaningful results, at least with the exposure time of 2 s. It is unknown whether or not increasing exposure time would facilitate performance at this level of working memory load.

Those in the ASD group had significant difficulty maintaining and conducting moment-to-moment updating of emotional expressions. Contrary to expectation, participants with ASD did not perform as accurately as controls in the 1-back condition. The 1-back level of the task requires less specificity in emotion recognition, as it can be successfully completed by merely detecting when two of the same emotions appear back-to-back rather than by rapidly identifying and maintaining memory of multiple exact emotions. Thus, it can be argued that the 1-back, similar to the 0-back , is not a true test of working memory, in that it does not demand as much manipulation as the 2- and 3-back do. The results suggests that even at the 1-back level, participants with ASD already demonstrate deficits, more than two standard deviations below the control group's mean. Thus, it was not surprising that the ASD group also performed significantly less accurately than the control group in the 2-back condition as well. Further, the finding that the ASD group demonstrated poor performance at the least challenging level, the 1-back, with 1 SD below group mean being near chance level, as well as at the 2-back level, suggests a floor effect for *n*-back when the task requires judgments about facial expressions, for individuals with ASD. In contrast, the control group performed relatively well at the 2-back level, whereas like the ASD group, their performance in the 3-back condition approached chance-level accuracy rates, which suggests a floor effect for typically developing individuals at the 3-back level.

The demonstrated pattern of accuracy performance stands in stark contrast to the lack of group differences in the Koshino et al. (2008) study of 0-, 1- and 2-back for facial identity in individuals with ASD vs, neurotypical controls. In the current study, group differences were found at even the lowest *n*-back load condition. The current study's ASD group accuracy performance from 0-, 1-, and 2-back for emotional expression ranged from 72% to 61% correct, whereas Koshino et al.'s (2008) ASD group's accuracy performance for facial identity ranged from 96% to 87.5% correct. Control groups' performance in these two studies also reveal a similar pattern, with poorer performance for emotional expression 0-, 1-, and 2-back (82% to 76% correct) than for facial identity 0-, 1-, and 2-back (96% to 84% correct). Thus, across both ASD and control participants, accuracy levels in the current study are lower than what has been found in the only other study using faces in an n-back task in an ASD sample. Further, Cui et al. (2010) reported ASD group accuracy performance on 1- and 2-back for digits ranged from 89% to 69% correct and Williams et al.'s (2005) finding that error rates were so low in *n*-back for geometric for participants in both ASD and control groups that the authors did not pursue analyses for accuracy data. In sum, the results appear to indicate that the n-back incorporating judgments of emotional expression is more difficult than *n*-back for facial identity or other stimuli such as geometric shapes or letters. One possible explanation regarding the current study's findings of much lower accuracy than in other studies is that the current study's task involved systematic variation of both facial identity and emotional expression. Previous studies provide evidence of asymmetrical influence of facial identity on recognition of emotional expression but not vice versa (D'Argembeau & Van der Linden, 2011; Schweinberger & Soukup, 1998). In the current study, the systematic variation of facial identity within across all working memory tasks (no repetition of any actor/expression combination was repeated within any of the 1-, 2-, and 3-back blocks) was an approach to address confounds in the Koshino et al. (2008) study, where participants may have been able to successfully recognize facial identity based on differences in emotional expression and other extranous details (person X has glasses and is always smiling, person Y has a tie and is not smiling). However, including variations in facial identity, even though it was done in a systematic manner, may have unintentionally introduced an added layer of categorical judgment to the task that was required to be suppressed in order to respond to emotional expression only. Doing so may have increased the difficulty significantly more than if facial identity were to have been held constant across all tasks.

Inspection of the pattern of individual participants' performance across the three working memory load conditions within just the control group, revealed a curious finding. Several control participants were more accurate in the 2-back condition than they were in the 1-back condition, and a few were more accurate in the 3-back than the 2-back condition. This same pattern was found in the ASD group, for a small subset of participants. It could be interpreted that participants were caught "off guard" by the difficulty of the task in the 1-back condition, and subsequently resolved to increase effort for 2-back task, which thereby increased their accuracy. However, the order of working memory load condition was pseudorandomized and the run order was counterbalanced within groups. In other words, half of the group actually completed the 2-back as their very first experimental condition, and the other half completed the 1-back first. Thus, any order effect should have been eradicated by the counterbalanced administration. Further, of those who demonstrated this curious finding, approximately half were from the group whose first task was the 1-back and half were for the other group, the one that completed the 2-back first (the 3-back was not administered to any participant as a first task). This suggests that the task order does not impact performance. Alternatively, the 2-back may have been more interesting and engaging for some participants, prompting increased effort and higher accuracy for those individuals.

Correlations between baseline maintenance or vigilance memory (0-back) and each of the working memory load conditions were also examined to explore the relationship between working memory and emotion recognition further, and findings were significant. When repeated-measures ANOVA covarying for 0-back performance were run for each group separately, the main effects of *n*-back level were no longer significant. This finding indicates that the accuracy level performance patterns seen in the current study are attributable in large part to underlying difficulty in maintenance or vigilance memory for facial expressions, and less so to working memory per se.

The reaction time analyses also revealed interesting and informative results. Though the main effects paint a picture of comparable reaction time between groups for all conditions combined, and the expected significant increase in reaction time as working memory load increased, the post-hoc analyses to explore significant interaction effects further reveal a more interesting picture. There were no group differences in reaction time within any given working memory load condition. This is consistent with the findings of Koshino and colleagues (2008), but stands in contrast to other findings of significantly slower reaction times in the ASD group (Cui et al., 2010; Williams, Goldstein, Carpenter, et al., 2005). Within group analyses for the control group revealed that the increase in reaction time from 1- to 2-back was significant, but from 2- to 3-back was not significant. In contrast, for the ASD group, neither the increase from 1- to 2-back nor from 2- to 3-back was significant. This pattern of results seems to suggest that the control group applied a strategy of slower, more careful responding as the difficulty of the task increased, whereas the ASD group did not demonstrate this strategy, but rather responded to each of the levels with the same amount of consideration and effort.

The executive functioning theory, places the primacy of dysfunction solidly within the cognitive domain. However, this theory has been criticized with the argument that executive functioning is a broad domain composed of separable, component skills, each of which may or may not be disrupted in ASD. That being said, the vast majority of researchers who seek to investigate the viability of this theory seem to either take a domain-general approach or at best, compares results from tasks that include verbal vs. nonverbal stimuli. These tasks are often abstract and do not contain overtly social or emotional features, and have been referred to as "cool" executive functioning (Zelazo et al., 2010).

In contrast to the executive functioning theory, the social-cognitive theories of ASD focus more on social deficits, which are present early in development. This argument is rooted in the fact that humans are fundamentally social beings and our very survival depends on learning from social interactions in our environment, both directly and indirectly. The ability to deduce information from multiple sources that is often consistent but sometimes inconsistent, in our interactions provides a richness that is unique to the human experience. Facial expressions of emotion are one such type of stimuli and, generally speaking, are universally displayed and understood (Darwin, 1955; Ekman, 1973). For both of these theories, studies have produced equivocal results, with some demonstrating intact abilities and some revealing clear deficits.

Historically, cognition and emotion were regarded as separate entities in psychological research, though some researchers have investigated emotion-cognition integration and have found intriguing neural activation patterns that are entirely distinct from the expected additive activation patterns of two separate areas associated with each domain alone. Successful social interactions depend on fluid negotiation of attention resources and the ability to continually update those various sources of information, in order to formulate an appropriate response, according to the demands of the situation. This ability to maintain and manipulate information over short periods of time is considered working memory. Indeed, at the behavioral level, some have suggested successful adaptive and social functioning depends on adequate executive functioning skills (Gilotty et al., 2002; McEvoy et al., 1993). This brings us back to the idea of working memory skills required to negotiate successfully the myriad cues within a social interaction, particularly when facial expressions change from moment to moment and one must be capable of maintaining and updating that information. Executive functioning as applied to tasks that involve motivational or affective aspects have been referred to as “hot” executive functioning (Zelazo et al., 2010), which has gained little attention in terms of research on the ASD population. Gaining a better understanding about “hot” executive functioning has the potential to inform interventional approaches to social skills training programs.

The extant literature leaves several questions unanswered, which the present study addresses. For example, if individuals are specifically instructed to pay attention to the emotional expression and all other social cues are eliminated, can individuals with ASD maintain representations of those expressions over short periods of time, much like what is required in a social interaction when expressions are transient and variable? Furthermore, can they update, from moment to moment, changes in emotional expression, over the course of time? If so, what is the limit of that ability to continually update and maintain that information? This kind of specific emotion-cognition integration task has been investigated in ASD, but the focus was on the neural activation patterns rather than on behavioral differences (Koshino et al., 2008). Also, the stimuli employed in the task were less than ideal for the ASD population, as they included many extraneous details that had high potential to pull for distracted responses, given the propensity for local, over global processing in ASD, and directing attention to non-social, non-emotional aspects of visual scenes. Yet other studies have used more methodologically rigorous approaches, but have not applied the study to individuals with ASD (Neta and Whalen, 2011). In the current study, I aimed to address these questions.

The present findings stand in contrast to those from other studies that have demonstrated comparable ability to recognize emotional expressions by individuals with ASD vs. controls (Adolphs et al., 2001; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Weng et al., 2011). However, as Kennedy and Adolphs (2012) posited, subtle differences in specificity of and reliability in recognizing facial expressions may be magnified when the stimuli are constrained in some way, so as to be more akin to naturalistic interactions, for example by limiting exposure time or by using dynamic faces. The current findings appear to support that hypothesis. An alternative explanation to the current findings of poorer performance in the ASD group on each and every task condition, could be an overall difference in processing speed, which has been previously demonstrated in other studies (Mayes & Calhoun, 2008; Oliveras-Rentas et al., 2012); Schmitz, Daly & Murphy, 2007). However, the lack of group differences in reaction time, suggests that this is an insufficient explanation for the pattern of findings. Another alternative explanation to the current findings may be a more basic deficit in sustained visual attention in the ASD group. However, exploratory analyses revealed that the groups did not significantly differ in number of trials to which they failed to register a response. Finally, the ASD group's consistently poorer performance across all tasks could be explained by a failure to use a verbally-mediated strategy to augment their working memory performance. Indeed, the control group's verbal IQ was significantly higher than the ASD group's, but the lack of significant correlations between verbal IQ and any of the task conditions in the control group argues against this explanation.

The current findings include demonstrated deficits in maintenance memory for emotional expressions, despite previous findings of intact performance on the two separately. The aim of the current study was to investigate performance on a task that simultaneously draws on both emotion recognition and working memory skills, also called "hot" executive functioning. However, underlying foundational difficulty in short-term memory for emotional expressions was discovered. Therefore, inferences regarding true working memory that requires not only short-term maintenance or vigilance memory, but also moment to moment updating of that information are not easily made.

With regard to the two major theories of ASD described in the literature review sections, the executive functioning theory and the social-cognitive theory, the pattern of results presented here seem to provide some evidence in support of the latter, given evidence in the literature for intact *n*-back performance in ASD for non-social/non-emotional stimuli, or "cool" executive functioning. Though previous research failed to reveal group differences in ASD vs. controls using a task of "hot" executive functioning (Koshino et al., 2008), the findings may have been confounded due to the possibility of the ASD group performing the task using a strategy of recognizing visual stimuli via non-face details, which limits interpretation of the results as evidence for intact working memory for faces in ASD. The current study eliminated such extraneous non-face details such that participants were limited to only socially/emotionally relevant information to perform the task, which makes the task more likely to be a measure of "hot" executive functioning. However, the interpretation of the current findings are also limited with regard to working memory for emotional expression, or "hot" executive functioning due to the high degree of difficulty introduced by varying facial identity and emotion expression simultaneously. Thus, the ASD group's difficulty at the most basic level of maintenance or vigilance for emotional expression (0-back and arguably, 1-back) precludes firm conclusions regarding the more challenging, working memory conditions (2- and 3-back). Finally, the current study furthers our knowledge regarding the difficulties individuals face in interacting socially in the world when there are multiple sources of information, which change from moment to moment, and place significant demands on not only cognitive but also social skills, which are not always separate, either behaviorally or neutrally.

4.2 Limitations

The current study's findings are limited by significant differences in race and sex between the control and ASD groups. Almost half of the control group members were African American, whereas none of the ASD group were. Race was not systematically controlled in the set of stimuli used for the experimental tasks. Given extant literature on own-race bias in facial identity recognition (Meissner & Brigham, 2001), it is possible that own-race bias may have an impact on emotion recognition, and could explain some of the results of the current study.

The control group was almost exclusively female, despite efforts to recruit males, whereas over half of ASD group was male. Notably, the composition of the ASD group is not unexpected given established sex ratio differences in the general population; however, it proved difficult to recruit a sex-matched sample of controls. Potential sex differences in emotion recognition accuracy and efficiency may explain some of the results, but were not explored as part of the current study.

Another limitation is underpowered interaction analyses, despite utilizing a sample size that is comparable to other similar studies that have yielded significant behavioral results (Cui et al., 2010; Gabig, 2008; Goldberg et al., 2005; Kana et al., 2007; Landa & Goldberg, 2005; Lopez et al., 2005; Nakahachi et al., 2006). However, the small effect size for the interaction term in the accuracy level analysis suggests that it is unlikely that the results would have achieved significance for the group by working memory load interaction had several more participants' data been collected. Additionally, repeated-measures ANOVA is an effective method to compensate for small sample sizes.

4.3 Future Directions

Future studies may benefit from the methodological approach of using a validated set of facial expressions that is consistent in terms of orientation and zoom but that has extraneous details removed as is done in the present study, in order to explore potential differing neural activation patterns between individuals with ASD and controls for maintenance or vigilance memory for emotional expressions. Also, investigations of "hot" executive functioning in ASD focusing on other component processes, such as inhibition (which has been shown to be intact in ASD for "cool" stimuli) for socially or emotionally relevant information may shed light on higher-order social interaction difficulties that are the hallmark of ASD. Additionally, studies of intervention approaches may consider limiting working memory tasks to 0-, 1-, and 2-back conditions, as training for success on 3-back conditions may prove to be fruitless and frustrating, particularly for complex visual stimuli.

Future investigations may extend the current findings and how they may generalize to real-world social interaction in individuals with ASD. For example, the relationship between social interaction scores on the ADOS or other ASD-specific measures and performance on tasks designed to measure "hot" executive function may be informative. Also, "hot" executive function task performance may serve as a pre- and post-intervention measure for social skills training programs. Future studies may include more fine-grained analyses to investigate the effect of affective valence, sex of the model in the stimulus, or the match/mismatch of the race of the stimulus model and the participant on accuracy or reaction time, given the extant literature for these kinds of investigations in the typically developing population.

5 REFERENCES

Adolphs, R., Sears, L., & Piven, J. (2001). Abnormal Processing of Social Information from Faces in Autism. *Journal of Cognitive Neuroscience, 13*(2), 232.

Baddeley, A. (2003). Working Memory: Looking Back and Looking Forward. *Nature Reviews Neuroscience, 4*(10), 829-839.

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods, 37*(3), 379-384. doi: 10.3758/bf03192707

Baltruschat, L., Hasselhorn, M., Tarbox, J., Dixon, D. R., Najdowski, A. C., Mullins, R. D., & Gould, E. R. (2011). Addressing working memory in children with autism through behavioral intervention. *Research in Autism Spectrum Disorders, 5*(1), 267-276. doi: 10.1016/j.rasd.2010.04.008

Banko, E. M., Gal, V., & Vidnyanszky, Z. (2009). Flawless visual short-term memory for facial emotional expressions. *Journal of Vision, 9*(1). doi: 10.1167/9.1.12

Barendse, E. M., Hendriks, M. P. H., Jansen, J. F. A., Backes, W. H., Hofman, P. A. M., Thoonen, G., . . . Aldenkamp, A. P. (2013). Working memory deficits in high-functioning adolescents with autism spectrum disorders: neuropsychological and neuroimaging correlates. *Journal of Neurodevelopmental Disorders, 5*. doi: 10.1186/1866-1955-5-14

Barnard, L., Muldoon, K., Hasan, R., O'Brien, G., & Stewart, M. (2008). Profiling executive dysfunction in adults with autism and comorbid learning disability. *Autism, 12*(2), 125-141. doi: 10.1177/1362361307088486

Baron-Cohen, S. (1991). The theory of mind deficit in autism: How specific is it? *British Journal of Developmental Psychology. Special Issue: Perspectives on the child's theory of mind: II, 9*(2), 301-314.

Baron-Cohen, S., Golan, O., & Ashwin, E. (2009). Can emotion recognition be taught to children with autism spectrum conditions? *Philosophical Transactions of the Royal Society B-Biological Sciences, 364*(1535), 3567-3574. doi: 10.1098/rstb.2009.0191

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: Evidence from very high functioning adults with autism or Asperger Syndrome. *Journal of Child Psychology and Psychiatry, 38*(7), 813-822.

Baron-Cohen, S., Ring, H. A., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., & Williams, S. C. R. (1999). Social intelligence in the normal and autistic brain: an fMRI study. *European Journal of Neuroscience, 11*(6), 1891-1898. doi: 10.1046/j.1460-9568.1999.00621.x

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" test revised version: A study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 42*(2), 241-251. doi: 10.1017/s0021963001006643

Bauminger, N., & Kasari, C. (1999). Brief report: Theory of mind in high-functioning children with autism. *Journal of Autism and Developmental Disorders, 29*(1), 81-86.

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., & Minshew, N. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia, 44*(1), 110-129.

Beneventi, H., Barndon, R., Ersland, L., & Hugdahl, K. (2007). An fMRI study of working memory for schematic facial expressions. *Scandinavian Journal of Psychology, 48*(2), 81-86. doi: 10.1111/j.1467-9450.2007.00536.x

Bennetto, L., Pennington, B. F., & Rogers, S. J. (1996). Intact and impaired memory functions in autism. *Child Development, 67*(4), 1816-1835.

Benson, J. E., Sabbagh, M. A., Carlson, S. M., & Zelazo, P. D. (2013). Individual Differences in Executive Functioning Predict Preschoolers' Improvement From Theory-of-Mind Training. *Developmental Psychology, 49*(9), 1615-1627. doi: 10.1037/a0031056

Blair, R. J. R., Frith, U., Smith, N., Abell, F., & Cipolotti, L. (2002). Fractionation of visual memory: Agency detection and its impairment in autism. *Neuropsychologia, 40*(1), 108-118.

Boucher, J., & Lewis, V. (1989). Memory impairments and communication in relatively able autistic children. *Journal of Child Psychology and Psychiatry, 30*(1), 99-122.

Braver, T. S., Barch, D. M., Kelley, W. M., Buckner, R. L., Cohen, N. J., Miezin, F. M., . . . Petersen, S. E. (2001). Direct comparison of prefrontal cortex regions engaged by working and long-term memory tasks. *Neuroimage, 14*(1), 48-59. doi: 10.1006/nimg.2001.0791

Brock, L. L., Rimm-Kaufman, S. E., Nathanson, L., & Grimm, K. J. (2009). The contributions of 'hot' and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Childhood Research Quarterly, 24*(3), 337-349. doi: 10.1016/j.ecresq.2009.06.001

Calder, A. J., & Young, A. W. (2005). Understanding the Recognition of Facial Identity and Facial Expression. *Nature Reviews Neuroscience, 6*(8), 641-651. doi: 10.1038/nrn1724

Cambridge Cognition Cognition. (1996). CANTAB_. Cambridge, England: Cambridge Cognition Limited.

Celani, G., Battacchi, M. W., & Arcidiacono, L. (1999). The understanding of the emotional meaning of facial expressions in people with autism. *Journal of Autism and Developmental Disorders, 29*(1), 57-66. doi: 10.1023/a:1025970600181

Cohen, J. D., Perlstein, W. M., Braver, T. S., Nystrom, L. E., Noll, D. C., Jonides, J., & Smith, E. E. (1997). Temporal dynamics of brain activation during a working memory task. *Nature, 386*(6625), 604-608.

Constantino, J. N., Davis, S. A., Todd, R. D., Schindler, M. K., Gross, M. M., Brophy, S. L., . . . Reich, W. (2003). Validation of a brief quantitative measure of autistic traits: Comparison of the social responsiveness scale with the autism diagnostic interview-revised. *Journal of Autism and Developmental Disorders, 33*(4), 427-433. doi: 10.1023/a:1025014929212

Critchley, H. D., Daly, E. M., Bullmore, E. T., Williams, S. C. R., Van Amelsvoort, T., Robertson, D. M., . . . Murphy, D. G. M. (2000). The functional neuroanatomy of social behaviour - Changes in cerebral blood flow when people with autistic disorder process facial expressions. *Brain, 123*, 2203-2212.

Cui, J. F., Gao, D. G., Chen, Y. H., Zou, X. B., & Wang, Y. (2010). Working Memory in Early-School-Age Children with Asperger's Syndrome. *Journal of Autism and Developmental Disorders, 40*(8), 958-967. doi: 10.1007/s10803-010-0943-9

D'Argembeau, A., & Van der Linden, M. (2011). Influence of Facial Expression on Memory for Facial Identity: Effects of Visual Features or Emotional Meaning? *Emotion, 11*(1), 199-208. doi: 10.1037/a0022592

Darwin, C. (1955). *The expression of the emotions in man and animals*. Oxford England: Philosophical Library.

Dawson, G., Meltzoff, A. N., Osterling, J., & Rinaldi, J. (1998). Neuropsychological correlates of early symptoms of autism. *Child Development, 69*(5), 1276-1285.

Dawson, G., Webb, S. J., & McPartland, J. (2005). Understanding the Nature of Face Processing Impairment in Autism: Insights From Behavioral and Electrophysiological Studies. *Developmental Neuropsychology, 27*(3), 403-424.

De Sonneville, L. M. J., Verschoor, C. A., Njiokiktjien, C., Op het Veld, V., Toorenaar, N., & Vranken, M. (2002). Facial identity and facial emotions: Speed, accuracy, and processing strategies in children and adults. *Journal of Clinical and Experimental Neuropsychology, 24*(2), 200-213.

Dennis, M., Francis, D. J., Cirino, P. T., Schachar, R., Barnes, M. A., & Fletcher, J. M. (2009). Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *Journal of the International Neuropsychological Society, 15*(3), 331-343. doi: 10.1017/s1355617709090481

Deruelle, C., Rondan, C., Gepner, B., & Tardif, C. (2004). Spatial Frequency and Face Processing in Children with Autism and Asperger Syndrome. *Journal of Autism and Developmental Disorders, 34*(2), 199-210. doi: 10.1023/B:JADD.0000022610.09668.4c

Dohnel, K., Sommer, M., Lbach, B., Rothmayr, C., Meinhardt, J., & Hajak, G. (2008). Neural correlates of emotional working memory in patients with mild cognitive impairment. *Neuropsychologia, 46*(1), 37-48. doi: 10.1016/j.neuropsychologia.2007.08.012

Druzgal, T. J., & D'Esposito, M. (2001). Activity in fusiform face area modulated as a function of working memory load. *Cognitive Brain Research, 10*(3), 355-364.

du Boisgueheneuc, F., Levy, R., Volle, E., Seassau, M., Duffau, H., Kinkingnehun, S., . . . Dubois, B. (2006). Functions of the left superior frontal gyrus in humans: a lesion study. *Brain, 129*, 3315-3328. doi: 10.1093/brain/awl244

Ekman, P. (1973). Universal facial expressions in emotion. *Studia Psychologica, 15*(2), 140-147.

Engle, R. W., Kane, M. J., Tuholski, S. W., Miyake, A., & Shah, P. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex *Models of working memory: Mechanisms of active maintenance and executive control.* (pp. 102-134). New York, NY US: Cambridge University Press.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191..

Frith, U. (1989). Autism and "theory of mind". In C. Gillberg (Ed.), *Diagnosis and treatment of autism* (pp. 33-52). New York, NY: Plenum Press.

Frith, U., Morton, J., & Leslie, A. M. (1991). The cognitive basis of a biological disorder: Autism. *Trends in Neurosciences, 14(10)[160]*, 433-438.

Gabig, C. S. (2008). Verbal Working Memory and Story Retelling in School-Age Children With Autism. *Language Speech and Hearing Services in Schools, 39*(4), 498-511. doi: 10.1044/0161-1461(2008/07-0023)

Garcia-Villamisar, D., Rojahn, J., Zaja, R. H., & Jodra, M. (2010). Facial emotion processing and social adaptation in adults with and without autism spectrum disorder. *Research in Autism Spectrum Disorders, 4*(4), 755-762. doi: 10.1016/j.rasd.2010.01.016

Gauthier, I., Curran, T., Curby, K. M., & Collins, D. (2003). Perceptual interference supports a non-modular account of face processing. *Nature Neuroscience, 6*(4), 428-432. doi: 10.1038/nn1029

Gilotty, L., Kenworthy, L., Sirian, L., Black, D. O., & Wagner, A. E. (2002). Adaptive skills and executive function in autism spectrum disorders. *Child Neuropsychology. Special Issue: Behavior Rating Inventory of Executive Function (BRIEF), 8*(4), 241-248.

Golan, O., Baron-Cohen, S., & Golan, Y. (2008). The 'Reading the Mind in Films' Task [Child Version]: complex emotion and mental state recognition in children with and without autism spectrum conditions. *Journal of Autism & Developmental Disorders, 38*(8), 1534-1541.

Goldberg, M. C., Mostofsky, S. H., Cutting, L. E., Mahone, E. M., Astor, B. C., Denckla, M. B., & Landa, R. J. (2005). Subtle Executive Impairment in Children with Autism and Children with ADHD. *Journal of Autism and Developmental Disorders, 35*(3), 279-293.

Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America, 99*(6), 4115-4120. doi: 10.1073/pnas.062381899

Griffith, E. M., Pennington, B. F., Wehner, E. A., & Rogers, S. J. (1999). Executive functions in young children with autism. *Child Development, 70*(4), 817-832.

Happe, F., Booth, R., Charlton, R., & Hughes, C. (2006). Executive function deficits in autism spectrum disorders and attention-deficit/hyperactivity disorder: Examining profiles across domains and ages. *Brain and Cognition, 61*(1), 25-39.

Harms, M. B., Martin, A., & Wallace, G. L. (2010). Facial emotion recognition in autism spectrum disorders: A review of behavioral and neuroimaging studies. *Neuropsychology Review, 20*(3), 290-322. doi: 10.1007/s11065-010-9138-6

Hauck, M., Fein, D., Maltby, N., Waterhouse, L., & Feinstein, C. (1998). Memory for faces in children with autism. *Child Neuropsychology, 4*(3), 187-198.

Haxby, J. V., Petit, L., Ungerleider, L. G., & Courtney, S. M. (2000). Distinguishing the functional roles of multiple regions in distributed neural systems for visual working memory. *Neuroimage, 11*(5), 380-391.

Hill, E. L., & Bird, C. M. (2006). Executive processes in Asperger syndrome: Patterns of performance in a multiple case series. *Neuropsychologia, 44*(14), 2822-2835.

Hobson, R. P., Ouston, J., & Lee, A. (1988). Emotion recognition in autism: coordinating faces and voices. *Psychological Medicine, 18*(4), 911-923.

Hughes, C., & Russell, J. (1993). Autistic Childrens Difficulty with Mental Disengagement from an Object - Its Implications for Theories of Autism. *Developmental Psychology, 29*(3), 498-510.

Jolliffe, T., & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? *Journal of Child Psychology and Psychiatry, 38*(5), 527-534.

Jones, C. R. G., Pickles, A., Falcaro, M., Marsden, A. J. S., Happe, F., Scott, S. K., . . . Charman, T. (2011). A multimodal approach to emotion recognition ability in autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 52*(3), 275-285. doi: 10.1111/j.1469-7610.2010.02328.x

Joseph, R. M., McGrath, L. M., & Tager-Flusberg, H. (2005). Executive Dysfunction and Its Relation to Language Ability in Verbal School-Age Children With Autism. *Developmental Neuropsychology, 27*(3), 361-378.

Kana, R. K., Keller, T. A., Minshew, N. J., & Just, M. A. (2007). Inhibitory control in high-functioning autism: Decreased activation and underconnectivity in inhibition networks. *Biological Psychiatry, 62*(3), 198-206.

Kennedy, D. P., & Adolphs, R. (2012). Perception of emotions from facial expressions in high-functioning adults with autism. *Neuropsychologia, 50*(14), 3313-3319. doi: 10.1016/j.neuropsychologia.2012.09.038

Klin, A., Sparrow, S. S., de Bildt, A., Cicchetti, D. V., Cohen, D. J., & Volkmar, F. R. (1999). A normed study of face recognition in autism and related disorders. *Journal of Autism and Developmental Disorders, 29*(6), 499-508. doi: 10.1023/a:1022299920240

Koshino, H., Carpenter, P. A., Minshew, N. J., Cherkassky, V. L., Keller, T. A., & Just, M. A. (2005). Functional connectivity in an fMRI working memory task in high-functioning autism. *Neuroimage, 24*(3), 810-821. doi: 10.1016/j.neuroimage.2004.09.028

Koshino, H., Kana, R. K., Keller, T. A., Cherkassky, V. L., Minshew, N. J., & Just, M. A. (2008). fMRI investigation of working memory for faces in autism: Visual coding and underconnectivity with frontal areas. *Cerebral Cortex, 18*(2), 289-300.

Krebs, J. F., Biswas, A., Pascalis, O., Kamp-Becker, I., Remschmidt, H., & Schwarzer, G. (2011). Face Processing in Children with Autism Spectrum Disorder: Independent or Interactive Processing of Facial Identity and Facial Expression? *Journal of Autism and Developmental Disorders, 41*(6), 796-804. doi: 10.1007/s10803-010-1098-4

Ladouceur, C. D., Dahl, R. E., Williamson, D. E., Birmaher, B., Ryan, N. D., & Casey, B. J. (2005). Altered emotional processing in pediatric anxiety, depression, and comorbid anxiety-depression. *Journal of Abnormal Child Psychology, 33*(2), 165-177. doi: 10.1007/s10802-005-1825-z

Lahaie, A., Mottron, L., Arguin, M., Berthiaume, C., Jemel, B., & Saumier, D. (2006). Face Perception in High-Functioning Autistic Adults: Evidence for Superior Processing of Face Parts, Not for a Configural Face-Processing Deficit. *Neuropsychology, 20*(1), 30-41.

Landa, R. J., & Goldberg, M. C. (2005). Language, Social, and Executive Functions in High Functioning Autism: A Continuum of Performance. *Journal of Autism and Developmental Disorders, 35*(5), 557-573.

Levens, S. M., & Gotlib, I. H. (2010). Updating Positive and Negative Stimuli in Working Memory in Depression. *Journal of Experimental Psychology-General, 139*(4), 654-664. doi: 10.1037/a0020283

Lezak, M. D., Howieson, D. B., Loring, D. W., Hannay, H. J., & Fischer, J. S. (2004). *Neuropsychological assessment (4th ed.)*. New York, NY US: Oxford University Press.

Liss, M., Fein, D., Allen, D., Dunn, M., Feinstein, C., Morris, R., . . . Rapin, I. (2001). Executive functioning in high-functioning children with autism. *Journal of Child Psychology and Psychiatry, 42*(2), 261-270.

Lopez, B. R., Lincoln, A. J., Ozonoff, S., & Lai, Z. (2005). Examining the Relationship between Executive Functions and Restricted, Repetitive Symptoms of Autistic Disorder. *Journal of Autism and Developmental Disorders, 35*(4), 445-460.

LoPresti, M. L., Schon, K., Tricarico, M. D., Swisher, J. D., Celone, K. A., & Stern, C. E. (2008). Working memory for social cues recruits orbitofrontal cortex and amygdala: A functional magnetic resonance imaging study of delayed matching to sample for emotional expressions. *Journal of Neuroscience, 28*(14), 3718-3728. doi: 10.1523/jneurosci.0464-08.2008

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Jr., Leventhal, B. L., DiLavore, P. C., . . . Rutter, M. (2000). The Autism Diagnostic Observation Schedule--Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders, 30*(3), 205-223.

Luna, B., Minshew, N. J., Garver, K. E., Lazar, N. A., Thulborn, K. R., Eddy, W. F., & Sweeney, J. A. (2002). Neocortical system abnormalities in autism: An fMRI study of spatial working memory. *Neurology, 59*(6), 834-840.

McEvoy, R. E., Rogers, S. J., & Pennington, B. F. (1993). Executive function and social communication deficits in young autistic children. *Journal of Child Psychology and Psychiatry, 34*(4), 563-578.

Meissner, C. A., & Brigham, J. C. (2001). Thirty years of investigating the own-race bias in memory for faces - A meta-analytic review. *Psychology Public Policy and Law, 7*(1), 3-35. doi: 10.1037/1076-8971.7.1.3Minshew, N. J., & Goldstein, G. (2001). The pattern of intact and impaired memory functions in autism. *Journal of Child Psychology and Psychiatry, 42*(8), 1095-1101.

Morris, R. G., Rowe, A., Fox, N., Feigenbaum, J. D., Miotto, E. C., & Howlin, P. (1999). Spatial working memory in Asperger's syndrome and in patients with focal frontal and temporal lobe lesions. *Brain and Cognition, 41*(1), 9-26.

Mottron, L., Morasse, K., & Belleville, S. (2001). A study of memory functioning in individuals with autism. *Journal of Child Psychology and Psychiatry, 42*(2), 253-260.

Nakahachi, T., Iwase, M., Takahashi, H., Honaga, E., Sekiyama, R., Ukai, S., . . . Takeda, M. (2006). Discrepancy of performance among working memory-related tasks in autism spectrum disorders was caused by task characteristics, apart from working memory, which could interfere with task execution. *Psychiatry and Clinical Neurosciences, 60*(3), 312-318.

Neta, M., & Whalen, P. J. (2011). Individual differences in neural activity during a facial expression vs. identity working memory task. *Neuroimage, 56*(3), 1685-1692. doi: 10.1016/j.neuroimage.2011.02.051

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology-General, 130*(3), 466-478. doi: 10.1037/0096-3445.130.3.466

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging. *Human Brain Mapping, 25*(1), 46-59. doi: 10.1002/hbm.20131

Ozonoff, S. (1997). Components of executive function in autism and other disorders. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 179-211). New York, NY: Oxford University Press.

Ozonoff, S., & Jensen, J. (1999). Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders, 29*(2), 171-177.

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology and Psychiatry, 32*(7), 1081-1105.

Ozonoff, S., South, M., & Provencal, S. (2005). Executive Functions. In F. R. Volkmar, A. Klin, R. Paul & D. Cohen (Eds.), *Handbook of Autism and Developmental Disorders* (3 ed., pp. 606-627). Hoboken, NJ: John Wiley & Sons Inc.

Ozonoff, S., & Strayer, D. L. (1997). Inhibitory function in nonretarded children with autism. *Journal of Autism and Developmental Disorders, 27*(1), 59-77.

Ozonoff, S., & Strayer, D. L. (2001). Further evidence of intact working memory in autism. *Journal of Autism and Developmental Disorders, 31*(3), 257-263.

Ozonoff, S., Strayer, D. L., McMahon, W. M., & Filloux, F. (1994). Executive function abilities in autism and Tourette syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry, 35*(6), 1015-1032.

Pelphrey, K. A., & Carter, E. J. (2008). Charting the typical and atypical development of the social brain. *Development and Psychopathology, 20*(4), 1081-1102. doi: 10.1017/s0954579408000515

Perlstein, W. M., Elbert, T., & Stenger, V. A. (2002). Dissociation in human prefrontal cortex of affective influences on working memory-related activity. *Proceedings of the National Academy of Sciences of the United States of America, 99*(3), 1736.

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature Reviews Neuroscience, 9*(2), 148-158. doi: 10.1038/nrn2317

Philip, R. C. M., Whalley, H. C., Stanfield, A. C., Sprengelmeyer, R., Santos, I. M., Young, A. W., . . . Hall, J. (2010). Deficits in facial, body movement and vocal emotional processing in autism spectrum disorders. *Psychological Medicine, 40*(11), 1919-1929. doi: 10.1017/s0033291709992364

Phillips, L. H., Channon, S., Tunstall, M., Hedenstrom, A., & Lyons, K. (2008). The role of working memory in decoding emotions. *Emotion, 8*(2), 184-191. doi: 10.1037/1528-3542.8.2.184

Rama, P., Martinkauppi, S., Linnankoski, I., Koivisto, J., Aronen, H. J., & Carlson, S. (2001). Working memory of identification of emotional vocal expressions: An fMRI study. *Neuroimage, 13*(6), 1090-1101. doi: 10.1006/nimg.2001.0777

Reed, T. (2002). Visual perspective taking as a measure of working memory in participants with autism. *Journal of Developmental and Physical Disabilities, 14*(1), 63-76.

Russell, J., Jarrold, C., & Henry, L. (1996). Working memory in children with autism and with moderate learning difficulties. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 37*(6), 673-686.

Russell, J., Jarrold, C., & Hood, B. (1999). Two intact executive capacities in children with autism: Implications for the core executive dysfunctions in the disorder. *Journal of Autism and Developmental Disorders, 29*(2), 103-112.

Russo, N., Flanagan, T., Iarocci, G., Berringer, D., Zelazo, P. D., & Burack, J. A. (2007). Deconstructing executive deficits among persons with autism: Implications for cognitive neuroscience. *Brain and Cognition, 65*(1), 77-86. doi: 10.1016/j.bandc.2006.04.007

Schweinberger, S. R., & Soukup, G. R. (1998). Asymmetric relationships among perceptions of facial identity, emotion, and facial speech. *Journal of Experimental Psychology-Human Perception and Performance, 24*(6), 1748-1765. doi: 10.1037//0096-1523.24.6.1748

Sheslow, D., & Adams, W. (1990). WRAML: Wide range assessment of memory and learning. Wilmington, DE: Jastak Assessment Systems.

Soulieres, I., Mottron, L., Giguere, G., & Larochelle, S. (2011). Category induction in autism: Slower, perhaps different, but certainly possible. *Quarterly Journal of Experimental Psychology, 64*(2), 311-327. doi: 10.1080/17470218.2010.492994

Steele, S. D., Minshew, N. J., Luna, B., & Sweeney, J. A. (2007). Spatial working memory deficits in autism. *Journal of Autism and Developmental Disorders, 37*(4), 605-612. doi: 10.1007/s10803-006-0202-2

Szatmari, P., Tuff, L., Finlayson, A. J., & Bartolucci, G. (1990). Asperger's Syndrome and autism: Neurocognitive aspects. *Journal of the American Academy of Child & Adolescent Psychiatry, 29*(1), 130-136.

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., . . . Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168*(3), 242-249.

Tracy, J. L., & Robins, R. W. (2008). The automaticity of emotion recognition. *Emotion, 8*(1), 81-95. doi: 10.1037/1528-3542.8.1.81

Tracy, J. L., Robins, R. W., Schriber, R. A., & Solomon, M. (2011). Is Emotion Recognition Impaired in Individuals with Autism Spectrum Disorders? *Journal of Autism and Developmental Disorders, 41*(1), 102-109. doi: 10.1007/s10803-010-1030-y

Veltman, D. J., Rombouts, S., & Dolan, R. J. (2003). Maintenance versus manipulation in verbal working memory revisited: an fMRI study. *Neuroimage, 18*(2), 247-256. doi: 10.1016/s1053-8119(02)00049-6

Wallace, S., Coleman, M., & Bailey, A. (2008). An investigation of basic facial expression recognition in autism spectrum disorders. *Cognition & Emotion, 22*(7), 1353-1380. doi: 10.1080/02699930701782153

Wechsler, D. (1997b). Wechsler Adult Intelligence Scale-Third EditionSan Antonio, TX: The Psychological Corporation

Weng, S. J., Carrasco, M., Swartz, J. R., Wiggins, J. L., Kurapati, N., Liberzon, I., . . . Monk, C. S. (2011). Neural activation to emotional faces in adolescents with autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 52*(3), 296-305. doi: 10.1111/j.1469-7610.2010.02317.x

Williams, D. L., Goldstein, G., Carpenter, P. A., & Minshew, N. J. (2005). Verbal and Spatial Working Memory in Autism. *Journal of Autism and Developmental Disorders, 35*(6), 747-756.

Williams, D. L., Goldstein, G., & Minshew, N. J. (2005). Impaired memory for faces and social scenes in autism: Clinical implications of memory dysfunction. *Archives of Clinical Neuropsychology, 20*(1), 1-15.

Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening adults for asperger syndrome using the AQ: A preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders, 35*(3), 331-335. doi: 10.1007/s10803-005-3300-7

Zelazo, P. D., Qu, L., & Kesek, A. C. (2010). Hot executive function: Emotion and the development of cognitive control. In S. D. Calkins & M. A. Bell (Eds.), *Child development at the intersection of emotion and cognition.* (pp. 97-111). Washington, DC US: American Psychological Association.

Zinke, K., Fries, E., Altgassen, M., Kirschbaum, C., Dettenborn, L., & Kliegel, M. (2010). Visuospatial Short-Term Memory Explains Deficits in Tower Task Planning in High-Functioning Children with Autism Spectrum Disorder. *Child Neuropsychology, 16*(3), 229-241. doi: 10.1080/09297040903559648