

# Neural Correlates Of The Extreme Male Brain Theory In Adolescents With And Without Autism Spectrum Disorders

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NEURAL CORRELATES OF THE EXTREME MALE BRAIN THEORY  
IN ADOLESCENTS WITH AND WITHOUT  
AUTISM SPECTRUM DISORDERS

by

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## ABSTRACT

NEURAL CORRELATES OF THE EXTREME MALE BRAIN THEORY  
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Marquette University, 2013

The Extreme Male Brain (EMB) theory (Baron-Cohen, 2003) is a behavioral theory of autism spectrum disorders (ASD), suggesting that the triad of behavioral impairments in ASD can be conceptualized psychologically as impairment in empathizing, coupled with a superior capacity for systemizing. Despite studies of the behavioral manifestations of this theory, it lacks neurological findings, specifically evidence of less coordinated activity between the left and right hemisphere in ASD (i.e. more lateralized activity). This study attempted to investigate neural correlates of the EMB theory utilizing EEG coherence, an index of neural connectivity, to determine if a more lateralized profile exists in the brain of adolescents with ASD compared to typically developing teens. In addition, relationships among coherence values and behavioral data were explored, and group membership was predicted using a “traditional model” of ASD characteristics (social skills and ratings of autism symptomatology) and an “EMB theory model” (EEG coherence and behavioral ratings of empathizing and sympathizing). Results revealed that teenagers with ASD displayed decreased coherence between the left and right frontal lobes in the alpha and theta frequency bands, while coherence between the frontal and temporal-parietal lobes within each hemisphere did not differ from typically developing teens at any frequency band. This pattern of results suggests that teens with ASD displayed a more lateralized profile, consistent with the EMB theory. Also, increased frontal-frontal coherence at the alpha and theta frequencies was associated with increased social skills in the total sample. In addition, the EMB model and the traditional characteristics model did not differ in their ability to correctly classify the groups, as a significant difference between the percent classified by each group did not emerge. Taken together, it seems that male adolescents with ASD display a more lateralized neural profile with less connectivity between the hemispheres than their typically developing peers. This pattern provides neural support for the EMB theory of autism, while also highlighting a potentially important neural marker for ASD.

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Audrey Meyer Carson, MS

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Autism spectrum disorder (ASD) encompasses a collection of pervasive developmental disorders noted for marked impairments in a triad of behavioral domains: social development, communication, and restricted and repetitive interests and behaviors. Persons with ASD experience difficulties with the pragmatics of social interactions and communication and often display preferences for engaging in specific interests to the neglect of social opportunities and development. ASD currently affects 1 in 88 children (1 in 50 boys: CDC, 2012), a number that continues to rise. Although considered a brain-based disorder, diagnosis continues to rely on behavioral criteria (APA, 2000), as understanding of the neural substrates of the disorder lags behind. As such, marrying behavioral theories with neurobiological conceptualizations of the disorder provides an opportunity for insight into ASD.

One such behavioral theory, the Extreme Male Brain (EMB) theory of autism (Baron-Cohen, 2003) is an extension of the empathizing-systematizing (E-S) theory of psychological sex differences (Baron-Cohen, Wheelwright, Lawson, Griffin, & Hill, 2002). The EMB theory suggests that the triad of behavioral impairments in ASD can be conceptualized psychologically as impairment in empathizing, coupled with a superior capacity for systemizing. As described in the E-S theory (Baron-Cohen et al., 2002), empathizing indicates an ability to put oneself in another's position and understand how they are feeling—in a sense, to “read” the emotional climate (Baron-Cohen, 2003). This skill would be dependent on connections between the hemispheres that allow for the multi-domain integration of emotion, cognition, and behavior. Systemizing, on the other hand, indicates the drive to analyze objects and events (Baron-Cohen & Belmonte, 2005), and is more supported by local connections within each hemisphere that support a detail-

oriented processing style. Thus, in ASD, decreased connections between the hemispheres would be observed, while connections within each hemisphere would remain intact (Baron-Cohen & Belmonte, 2005). Although well researched in behavioral and biological studies, sufficient neurological findings supporting this theory are lacking. The current study will review the relevant behavioral research concerning the EMB theory, as well as discuss EEG coherence and investigate theorized neurological correlates for the EMB theory. Primarily, this study will attempt to provide neurological support for the EMB theory via a study of brain activity utilizing electroencephalogram (EEG), in order to find evidence suggesting that brain activity in ASD mimics the patterns suggested by this theory: less connected, more lateralized brain activity. Specifically, differences between EEG coherence, an index of connectivity (Nunez & Srinivasan, 2006) will be examined between adolescents with ASD and typically developing adolescents. After exploration of relationships among coherence values and behavioral data, group membership (i.e. ASD group versus the typically developing group) will be predicted utilizing EEG coherence and behavioral ratings of empathizing and systemizing.

### *Autism Spectrum Disorders*

As previously mentioned, ASD is a pervasive developmental disorders with symptoms generally identifiable prior to the third birthday (APA, 2000) and persistent throughout the lifespan. A general agreement in the literature exists regarding the presence of early cortical overgrowth (in both white and gray matter) during the first four years of life in ASD (Schumann et al., 2010; Courchesne et al., 2007). Young children with ASD have received much attention in research and as targets of intervention, due to

the consistent finding that early and intensive intervention leads to the best possible outcomes for persons with ASD (i.e., Dawson et al., 2010). As ASD is considered a brain-based disorder, it seems that early interventions hold the best opportunity to mold the young, plastic brain. However, adolescence in typically developing children has recently been targeted as a busy period of neural development, second only to the bursts of development observed in early life (Blakemore, 2008). As such, understanding this brain-based disorder in teenagers with ASD is also of interest. Teens with ASD have a unique experience in adolescence, as they must combat the typical difficulties that accompany the increasing demands of peer relationships in adolescence (Brown, 2004; Brown & Klute, 2006) while possessing core deficits that make the pragmatics of social relationships overwhelming and difficult to understand. The EMB theory of autism allows for a behavioral conceptualization of these difficulties unique to ASD as being understood primarily due to an advanced capacity for systemizing along with deficits in empathizing in ASD.

### *The Extreme Male Brain Theory of Autism*

A thorough understanding of the EMB theory requires exploration of the E-S theory (Baron-Cohen et al., 2002) and its support. The E-S theory asserts that certain brain “types” exist, based on the amount of empathizing and systematizing abilities present in the individual. The term empathizing indicates two primary abilities: attributing mental states to oneself and to others in order to make sense of one’s own and others’ actions, and conjuring emotional reactions appropriate to others’ mental states (Baron-Cohen & Belmonte, 2005). On the other hand, systemizing indicates the drive to analyze objects and events in order to understand their structure and predict future

behavior (Baron-Cohen & Belmonte, 2005). Systems include anything governed by rules that specify input-operation-output relationships, which requires an exacting eye and mind for details (Baron-Cohen, 2003). In the E-S theory, scores on empathizing and systematizing can be compared, utilizing standard deviations from the mean in order to categorize a person's brain type. A balanced brain (Type B) suggests a balanced profile, where empathizing and systematizing abilities are seen in the same proportions in an individual. In brain Type E, empathizing is one or two standard deviations higher than systemizing, whereas in brain Type S the opposite profile is observed (Baron-Cohen, 2003). Importantly, this theory suggests that the key point is the *discrepancy* between the scores, rather than absolute score. A person scoring two standard deviations above the mean on systematizing would still be classified as having a Type E brain if their empathizing scores were three standard deviations above the mean. As such, the proportions and possibility of asymmetries in ability are crucial.

*Type E Brain.* Baron-Cohen (2003) argues that females spontaneously empathize more often than males, suggesting that women are more likely than men to be classified as having a Type E brain than men. Although some debate exists as to whether women actually possess more empathy or if social desirability plays a part in the gender differences observed (Singer & Lamm, 2009; Davis, 1994), behavioral evidence for sex differences in the precursors of empathy have been found from the first moments of life. For example, female neonates were found to show a stronger interest in a face, while male neonates were more intrigued by a physical-mechanical mobile (Connellan, Baron-Cohen, Wheelwright, Batki, & Ahluwalia, 2000). In addition, at 12-months of age, girls prefer to watch a video of a person talking without volume over a video of cars

(considered a predictable mechanical system), whereas boys show the opposite preference (Lutchmaya & Baron-Cohen, 2002). One-year-old girls have also been found to display more empathic concern (visual expression of concern about another), prosocial behavior (efforts to help), and engage in more hypothesis testing (attempts to comprehend distress of another) than same-age boys (Zahn-Waxler, Robinson, & Emde, 1992). Though these differences were small in magnitude, they were consistently present in this study of differences of empathy in twins.

Girls and boys also show differences in play that provide evidence for differences in early precursors to empathy. For example, girls are less likely to engage in “roughhousing” in preschool (Rose & Rudolph, 2005), which typically involves wrestling and play fighting rather than talking, sharing, and other skills dependent on empathy. Interestingly, when examining sharing with one toy in all-girl groups, the girl who plays with the toy more than the others utilizes verbal skills, rather than physical tactics, to maneuver the toy into her hands again, showing reliance on mindreading rather than physicality to obtain the desired result (Baron-Cohen, 2003). With age, peer relationships become more complex, and sex differences in behavioral styles with peers continues to reflect girls’ strength in empathizing. For example, girls are more likely to cooperate, display prosocial behavior, and self-disclose to friends. In addition, their interactions with peers tend to involve prolonged dyadic interactions, rather than group play with recognized dominance hierarchies established through competitive play, as boys do (Rose & Rudolph, 2006). The ability to make sense of other’s actions and reciprocate emotional reactions appropriate to the situation and other’s feelings is integral in the play described as prominent in girls as opposed to boys.

In addition to play skills, sex differences emerge in other domains related to empathizing. Theory of Mind (ToM) skills—a cognitive component of empathizing that indicates an ability to understand that others have unique points of view and to be able to make predictions about other’s behavior or mental states (Baron-Cohen, 2003)—are evident in children as young as three or four years-old (Walker, 2005; Happe, 1995; Sullivan, Zaitchik, & Tager-Flusberg, 1994) and are typically investigated through false-belief tests at this age. Walker (2005) reports that three to five year-old girls displayed better ToM understanding. In first-grade, girls do seem to be more skilled at determining the intentions of others and at effectively problem-solving social issues (Putallaz, Hellstern, Sheppard, Grimes, & Glodis, 1995), and at age seven girls are better able to detect a social faux pas—an indication of better empathizing—than boys (Baron-Cohen, O’Riordan, Jones, Stone, & Plaisted, 1999). Differences of styles in communication have also been discussed, suggesting that girls and women are more cooperative, reciprocal, and collaborative in communication (e.g. Baron-Cohen, 2003).

In a more direct test of empathy skills, preadolescent girls have been found to be superior in evaluating the feelings and intentions of characters in a story (Bosacki & Astington, 1999). These early differences in ToM skills continue to contribute to empathizing skills through adulthood, as women score higher on emotion recognition tasks (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997) and are more accurate than men when asked to determine an emotion from simply looking at a person’s eyes during the “Reading the Mind in the Eyes” task (Eyes-C; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). Chapman and colleagues (2006) administered the Eyes-C and the child version of the Empathizing Quotient (EQ-C; Auyeung et al., 2009), a parent-

report of empathy, to school-age boys and girls whose mothers had undergone an amniocentesis during pregnancy, providing access to their fetal testosterone levels. Fetal testosterone levels have been found to inversely correlate with eye contact at 12-months of age (Lutchmaya, Baron-Cohen, & Raggatt, 2002) and quality of social relationships at age four, but to positively correlate with narrow interests at four years-old (Knickmeyer, Baron-Cohen, Raggatt, & Taylor, 2005). In Chapman and colleagues' (2006) study, a significant negative correlation was found between fetal testosterone and scores on the Eyes-C and EQ-C, again suggesting a biological component to empathy beginning prenatally.

Lastly, the Empathizing Quotient (EQ; Baron-Cohen & Wheelwright, 2004) was designed as a quick and effective questionnaire for assessing empathy within adults and has shown that females within the general population score higher on the EQ than men (Baron-Cohen & Wheelwright, 2004) and people with ASD (Wheelwright et al., 2006). Variations of the EQ have been developed for children (Auyeung et al., 2009) and adolescents (Auyeung, Allison, Wheelwright, & Baron-Cohen, 2012) and have shown the same results: girls score higher on ratings of empathy than boys. These studies lend support to the idea that females are, on average, more likely to display empathizing behaviors than men and display behaviors associated with the Type E brain.

*Type S Brain.* Mirroring the Type E brain, Baron-Cohen (2003) suggests that more males are classified as having a Type S brain and display a drive to understand and build systems. Within the context of the E-S theory, six major systems exist that can be analyzed and/or constructed: technical systems (i.e. computers, vehicles, physics, etc.); natural systems (ecology, biology, meteorology, etc.); abstract systems (math, logic,

grammar, maps, etc.); social systems (politics, committees, groups of friends, etc.); organizable systems (encyclopedias, museums, stamp collections, etc.); and motoric systems (golf swing, finger movements required to play piano, etc.). Some of the early evidence for men being more likely to display systemizing abilities includes differences in children's play. As discussed previously, girls tend to display more sharing and prosocial behavior in play (Rose & Rudolph, 2006), whereas boys often show preferences that display an aptitude for systemizing. For example, boys as young as one year are more likely to independently select to play with toys related to systems, such as vehicles and construction blocks (Servin, Bohlin, & Berlin, 1999). In addition, this interest in systems in young children is evident in boys from pre-industrial societies, who, when asked to draw a picture, chose to draw tools and weapons—examples of more universal systems (Baron-Cohen, 2003).

In addition to these differences in early play preferences, more males tend to choose careers requiring superior skills in systemizing. For example, in 2007-2008, the vast majority of bachelor's degrees in engineering, computer and information sciences, and physical sciences and science technologies were awarded to males (National Center for Education Statistics, 2010). Although debates may emerge as to various reasons why these sex differences in these job areas may exist—including possible discrimination, stereotype threat, or societal pressures regarding gendered stereotypes—these fields focus on constructing and understanding systems, which Baron-Cohen (2003) argues could reflect a male preference for working with systems. Interestingly, variances in male scores in mathematics—an abstract system and important foundational skill for work in system-driven fields—are 10-20% greater than females, resulting in more men at either

end of the distribution of abilities. This finding suggests that men are more likely to fall within the highest range of the ability distribution in mathematics and may give an edge in systemizing abilities to a portion of men (Ceci & Williams, 2010a). Further evidence for more men possessing an aptitude for systemizing abilities is derived from robust findings that men excel in spatial ability (Voyer, Nolan, & Voyer, 2000), and even male infants between four- and five-months old have been found to mentally rotate better than same-age females (Ceci & Williams, 2010b). In addition, males tend to score higher on tasks utilizing systemizing such as directional cues when reading maps and in map-making (Kimura, 2000; Galea & Kimura, 1993) or predicting movement of levers from studying mechanical diagrams (Lawson, Baron-Cohen, & Wheelwright, 2004).

Interestingly, a study reporting neurological sex differences also supports the idea that on average men are more likely to be systemizers. Cheng and colleagues (2006) investigated sex differences in the mirror neuron system by examining *mu* suppression in the primary motor cortex. *Mu* suppression provides an index of the engagement of the mirror neuron system—activated not only when one performs an action, but also when watching others’ perform actions—which has been hypothesized to play an important role in humans’ ability to understand another’s actions. Cheng et al. (2006) reported that men in their study displayed smaller *mu* suppression to a hand performing a motor action, but showed greater *mu* suppression to moving dots. The authors suggest that men may be treating the moving dots as an object—perhaps a part of a system—which would be more likely to trigger response in the premotor cortex, whereas women were not.

As with empathizing abilities, a succinct self-report questionnaire for assessing systemizing was established: the Systemizing Quotient (SQ; Baron-Cohen, Richler,

Bisarya, Gurunathan, & Wheelwright, 2003). The SQ shows the expected sex differences, with men scoring higher on the SQ than women and persons with ASD scoring higher than both typically developing men and women (Baron-Cohen et al., 2003; Wheelwright et al., 2006). These results were also replicated in a sample of college students, with men more likely to be classified as having a Type S brain and to display more systemizing abilities, as evidenced by higher scores on block design tasks (Carroll & Chiew, 2006). The SQ has also been adapted for children (Auyeung et al., 2009) and adolescents (Auyeung et al., 2012.) and has shown similar results. Taken together, systemizing abilities seem to be more likely to be developed within males than females, with men more likely to be classified as having a Type S brain.

*The Extreme Male Brain.* Within this conceptualization, ASD can be understood as an extreme variant of the typical male brain with superior strengths in systematizing coupled with a decreased capacity for, or even deficit in, empathizing. Roots for this conceptualization of ASD stem back to Hans Asperger who wrote: “The autistic personality is an extreme variant of male intelligence. Even within the normal variation, we find typical sex differences in intelligence . . . In the autistic individual, the male pattern is exaggerated to the extreme” (Asperger, 1944, as cited in Baron-Cohen, 2003, p. 149). Results of behavioral tasks suggest this pattern, with persons with ASD performing more poorly on various measures of empathizing. For example, persons with ASD score lower than men (who score lower than women) on various tests of ToM, including asking persons to read emotionality from only looking at someone’s eyes (Baron-Cohen et al., 2001a) and recognizing social faux pas (Baron-Cohen et al., 1999). Adults with ASD also score lower on the Friendship Questionnaire—which asks about individual

differences about preferences for closeness and quality of friendships and interacting with others for the sake of interacting—than men (who score lower than women; Baron-Cohen & Wheelwright, 2003). Lastly, persons with high-functioning ASD or Asperger's Syndrome (regardless of sex) score significantly lower on the EQ (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004) than typically developing women and men. These results suggest agreement with an exaggerated male profile, as men, on average, score lower than women on these tests related to constructs of empathy.

In addition to differences in empathizing, persons with ASD can be described as being excellent systemizers. A part of the diagnostic criteria for autism (APA, 2000), the restricted and repetitive interests of persons with ASD often involve closed-systems, such as trains, computers, or bird migration patterns. In addition, the presence of lining up behaviors, such as lining up toys in a specific manner rather than displaying creative play (Baron-Cohen, 2003), is another diagnostic consideration in ASD that indicates a preference for systems. Also, children with Asperger Syndrome score well above expected for their mental age on tests of intuitive physics, which ask participants to infer the cause of a non-agent's movement and draws upon traits associated with systemizing, but lower than expected for their mental age on tests of intuitive psychology, where the cause of an agent's movement is inferred and utilization of empathizing abilities are required (Baron-Cohen, Wheelwright, Spong, Scahill, & Lawson, 2001). Persons with ASD also have been shown to have superior detailed local perception, a prerequisite for systemizing, as they score higher than males (who score higher than females) on the Embedded Figures Test (Jolliffe & Baron-Cohen, 1997). This task requires exceptional attention to detail in order to perform well. In addition, persons with ASD have been

shown to have faster and more accurate attention to detail than males (and females) on visual search tasks (O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001), again suggesting a strength in characteristics of systemizing in persons with ASD. Lastly, persons with ASD also score significantly higher on the SQ than control groups (Baron-Cohen et al., 2003), once again displaying this strength in systemizing abilities in comparison to typically developing males and females.

*Coherence: An Index of Neural Connectivity*

Given that ASDs are conceptualized as brain-based disorders, the gap between the neurobiology of ASD and behavioral theories must be addressed. The assemblage of atypicalities in social functioning, communication, and stereotyped behaviors in ASD suggests, from a neurobiological perspective, a large-scale dysfunction of the association cortex that does not impact primary motor and sensory cortex (Minshew & Williams, 2007). In addition, a growing literature supports the notion that neural connectivity—referring generally to the coordination or integration of brain regions—is compromised in ASD (see Wass, 2011, for a recent review), though various theories exist regarding exactly how this connectivity has diverged from typical development. Currently, general consensus has supported the idea that aberrant connectivity in ASD is marked by short-range over-connectivity coupled with long-range under-connectivity (Wass, 2011; Casanova & Trippe, 2009; Minshew & Williams, 2007; Courchesne & Pierce, 2005). More specifically, structural evidence from post mortem histological studies of persons with ASD has found irregularities in minicolumns: “radially oriented arrangements of cellular elements, which have a stereotypical morphometry and are distributed throughout the cortex” (Casanova & Trippe, 2009, p. 1433). Findings suggest that minicolumns in

persons with ASD are more numerous, densely packed, and narrow, while maintaining the same number of cells per minicolumn (Casanova et al., 2002a; Casanova et al., 2002b; Casanova et al., 2006a, Casanova et al., 2006b), indicating that disruptions exist at a cellular level which may lead to excessive local connectivity.

In addition, abnormalities in long-range connectivity have been studied via functional magnetic resonance imaging (fMRI), diffusion tensor imaging (DTI), and EEG. For example, an fMRI study by Kleinmans and colleagues (2008) reported decreased functional connectivity in ASD in areas associated with the “social brain,” particularly during a face-processing task. Anderson and colleagues (2011) also found decreased long-range, interhemispheric connectivity (measured by fMRI) in areas associated with behavioral abnormalities in autism, including the sensorimotor cortex, anterior insula, fusiform gyrus, superior temporal gyrus, and superior parietal lobe. Recent work (Assaf et al., 2010; Monk et al., 2009; Weng et al., 2010) has focused on underconnectivity in the default mode network in ASD, which includes the posterior cingulate cortex, retrosplenial cortex, lateral parietal cortex/angular gyrus, medial prefrontal cortex, superior frontal gyrus, temporal lobe, and parahippocampal gyrus. This network has been shown to be active during passive resting states, as well as during cognitive processes associated with deficits in ASD, such as autobiographical memory, future prospection, and ToM. Although some conflicting results exist (i.e. Monk et al., 2009 also reported some areas of stronger connectivity), reports show a tendency for decreased connectivity in the default network in ASD as compared to typically developing controls (Assaf et al., 2010; Weng et al., 2010). In addition, more severe social difficulties (from parent-report on the SRS and clinician ratings on the ADOS—

both measures to be discussed in more detail below) were associated with weaker connectivity in the default network (Assaf et al., 2010; Weng et al., 2010), as were more severe restricted and repetitive interests (Weng et al., 2010). Criticisms of fMRI research on connectivity include the use of a few regions of interest in order to investigate connectivity (Wass, 2011), which could miss other regions of activity, as well as its insufficient temporal accuracy especially during tasks (Spear, 2010).

Another method for studying connectivity, EEG coherence can inform behavioral theories, as it provides understanding as to how different brain regions associated with certain behaviors interact. Briefly, EEG is a non-invasive method of measuring the waveforms associated with the electrical activity in the brain. The signal is believed to originate in the gray matter of the cerebral cortex, generating from the ionic current flow in the apical dendrites of pyramidal cells (Rippon, 2006). Currently, waveforms of five different ranges are commonly reported and discussed in EEG literature, including: delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-45 Hz; Blinkowska & Durka, 2006). These frequency bands are thought to represent a different level of conscious awareness, though the understanding of the type of information processing and behavioral associations with each frequency band remains limited and a current focus of research. Each frequency can also be analyzed in terms of EEG power or EEG coherence. Power analysis allows for measurement of the magnitude of the neural signal at a given frequency band (Hughdahl, 1995; Rippon, 2006), whereas coherence analysis provides an index of connectivity that estimates the level of synchronization between neural populations. Synchronized neural activity is reflected as high coherence values and indicates functional cortical connectivity between two areas,

while low coherence values indicate that two brain regions are acting independently (Murias, Webb, Greenson, & Dawson, 2007; Nunez & Srinivasan, 2006). Notably, EEG coherence reflects synchronized connectivity, not brain activity, e.g. two brain regions may show dampened activity, but still be highly synchronized and show high coherence values.

Studies of EEG coherence in ASD are limited and are better equipped to provide insight into long-range connectivity, as EEG records cortical activity through the skull making reports of specific, dense brain regions difficult (Spear, 2010). Still, Murias and colleagues (2007) reported a novel study of EEG coherence in adults with ASD during an eyes-closed resting state, finding reduced coherences in short-distance electrode pairs in the alpha frequency (8-12 Hz) in the frontal regions, as well as increased coherences in the theta frequency (3-6 Hz) at short-distance frontal and left temporal electrode pairs. In addition, Murias et al. (2007) reported reduced EEG coherence in the alpha frequency in long-range connections across the whole brain. Another study of EEG coherence in children ages 6-11 found evidence of global underconnectivity in ASD during an eyes-closed, resting state (Coben et al., 2008). The authors report decreased alpha coherence between the left and right hemispheres of the temporal lobe, as well as reduced coherence in delta (1.5-3.5 Hz) and theta (3.5-7.5 Hz) frequencies within each hemisphere. Lastly, previous work by the author (Carson, Gregor, Scheidt, & Van Hecke, in preparation) found evidence of reduced EEG coherence between the left and right frontal lobes in ASD, suggesting decreased long-range connectivity between the hemispheres. However, this work did not find evidence of global, reduced long-range connectivity. Analysis of intra-hemispheric coherence between the left frontal and parietal-temporal lobe, as well

as right frontal and parietal-temporal lobe, did not show group differences in coherence. Although previous work seems to include activity both within the hemispheres *and* between the hemispheres when discussing “long-range connectivity,” this last study (Carson et al., in preparation) suggests that differences may arise in long-range connectivity within the hemispheres (i.e. intra-hemispheric coherence: left frontal lobe to left parietal-temporal lobe) versus between the hemispheres (i.e. inter-hemispheric: left frontal lobe to right frontal lobe), indicating a need to better demarcate types of long-range connectivity and their specific disruptions, if any, in ASD.

In fact, another body of literature exists suggesting that long-range connectivity between the hemispheres may be disrupted in ASD on both a structural and functional level. The corpus callosum (CC) is the largest and most principal white matter structure in the brain, consisting of 200 million axons connecting the left and right hemispheres of the brain. In ASD, the CC has become an area of interest, considering its involvement in inter-hemispheric transfer of sensory information relevant to multiple cognitive processes (e.g. Schulte et al., 2005; Pollman et al., 2004; Mathias et al., 2004). The CC plays a primary role in the integration of a variety of functions, as its task is to seamlessly incorporate the functions of the hemispheres of the brain, including memory storage and retrieval, attention and arousal, language, and the integration of a variety of sensory fields (Giedd, 2008). Studies of the CC in ASD have reported abnormalities; for example, three- and four-year-old children with ASD have been found to have smaller CC than typically developing controls when accounting for the increase in ASD cerebral volume (Boger-Megiddo et al., 2006). Further, when the ASD group was divided into a group with autism and a group with PDD-NOS (considered a less severely affected group), the

group with autism had significantly smaller CC than the control group, while comparisons between the PDD-NOS group and control group yielded only trends towards significance. Additionally, pre-adolescent boys with autism were found to have reduced total area of the CC, as well as significant thinning within the genu and splenium regions of the CC, when compared to typically developing controls (Vidal et al., 2006).

Interestingly, the genu connects fibers in the orbitofrontal cortex, an area associated with understanding social and emotional cues (Mah, Arnold, & Grafman, 2004), as well as the ability to guess about another's mental state (ToM; Sabbagh, 2004).

Two other studies (Keary et al., 2009; Alexander et al., 2007) of the CC in autism with wide age ranges (ages 8-45 and ages 7-33, respectively) demonstrate similar findings of reduced CC size, further suggesting a general trend for reduced CC in ASD across the lifespan. Interestingly, persons with developmental absence (agenesis) of the CC (AgCC) display difficulties with social communication and social interaction in ways that overlap with the diagnostic criteria for ASD (Paul et al., 2007; Brown & Paul, 2000), suggesting the crucial role the CC has in allowing the coordination of various brain regions for social interactions.

### *Neurological Correlates of the EMB Theory*

Proposed neural profiles of the Type E and Type S brains types help to bridge the gap between behavioral implications and neurological evidence of the EMB theory.

Within this framework, it is expected that a Type E brain would display increased connectivity across the brain and a Type S brain would display decreased connectivity between the two hemispheres (Baron-Cohen & Belmonte, 2005). The behavioral differences between men and women, especially those pertaining to language, have been

suggested to be due to these differing patterns of neural activation. Specifically, during language tasks, women have been shown to display more bilateral activation in the inferior frontal gyrus (i.e. Baxter et al., 2003; Clements et al., 2006) and posterior areas of the middle/superior temporal gyrus (i.e. Kansaku, Yamaura, & Kitazawa, 2000; Phillips, Lowe, Lurito, Dziedzic, & Mathews, 2001). This bilateral activation could indicate that more neural resources are devoted to language processing in women, whereas men are more likely to rely on the left hemisphere (i.e. Clements et al., 2006). These findings have also been replicated in children (Burman, Bitan, & Booth, 2008).

Additional support for the idea that women (and thus, the Type E brain) present with more bilateral activation includes evidence from female stroke patients, who have been found to experience less impairment after lesions of the left hemisphere than men (McGlone, 1980). Additionally, Sowell and colleagues (2007) reported that in a sample of typical adults, women had increased gray matter thickness in the left and right temporal and parietal cortices, which could contribute to the female advantage in language tasks, as these areas are involved in language production. In addition, this study reported the women's cortices in the right hemisphere were especially thicker in comparison to men, which they indicate is usually non-dominant for language. This increased cortical thickness could indicate a better connected brain with additional resources for use during language skills or other behaviors associated with these areas, including empathizing skills as the temporal and parietal cortices are the location of the proposed "social brain" circuit (Adolphs, 2001; Brothers, 1990). As seen in persons with AgCC (Paul et al., 2007; Brown & Paul, 2000), connections between the hemispheres play a crucial role in social behaviors, suggesting that those with higher empathizing

skills would have richer, more developed connections between the two hemispheres. Indeed, empathy has been found to activate brain areas that integrate information from a variety of neural sources in a typical sample (Ochsner et al., 2004). Thus, it seems that utilization of empathy requires the coordination of various brain regions, including between the hemispheres. The Type E brain would then be expected to display increased connectivity between the hemispheres, while the Type S brain would show the opposite pattern.

A theoretical connectionist model suggested by Lewis and Elman (2008) explored the idea of cortico-cortical connectivity and brain size and provides further insight into the neurological correlates of the EMB theory. Their model suggests that connectivity between the hemispheres may be impacted within physically larger brains, especially those with accelerated brain growth. Their model found that larger brains rely more on local connections within each hemisphere, which require fewer neural resources to sustain computationally and physically. Given that only a (somewhat) finite amount of neural resources exist within the brain and that long-distance connections require more resources to develop, a larger brain adapts by relying increasingly on connectivity within each hemisphere. Interestingly, in the general population, men have consistently been found to have greater total brain volume (Gur et al., 1999; Nopoulos et al., 2000; Goldstein et al., 2001). This finding is evident from the first few months of life (Gilmore et al., 2007), with larger gray and white matter volumes found in newborn males compared to newborn females. Connecting this finding to the EMB theory, males may allocate more resources to short-range connections due to their larger brain size, resulting in a neurological profile that is more lateralized. Indeed, a study of healthy adults found

that connection length (i.e. the physical length of connection fibers) in the CC was negatively correlated with degree of connectivity, suggesting that cortical networks are optimized to conserve neural resources (Lewis, Theilmann, Sereno, & Townsend, 2009). As larger brains tend to have longer fibers (Braitenberg, 2001), these findings also suggest that enlarged brain size may contribute to disrupted connectivity between the hemispheres. Further, children with ASD as young as two have been shown to have greater cerebral volume than typically developing children (Hazlett et al., 2005), though this initial overgrowth seems to slow, as group differences in brain size disappears in adolescence (Redcay & Courchesne, 2005). Still, this initial overgrowth may contribute to different connectivity patterns developing in ASD (Wass, 2011), as discussed in Lewis and Elman's (2008) connectionist model. Specifically, it may be that neural development in ASD is especially predisposed to develop functional connections which rely on increased local connectivity, in part due to their larger brain size in childhood. This altered connectivity would result in an extreme profile of the typical male brain with significantly decreased connectivity between the hemispheres.

In fact, larger brains have been found to show increased connectivity within the hemispheres relative to connectivity between the hemispheres (Luders, Narr, Zaidel, Thompson, and Toga, 2006), which fits within the framework of the EMB theory as a Type S brain would be expected to show decreased inter-hemispheric connectivity. Gender differences evident in Luders and colleagues' (2006) study showed that women had decreased asymmetry across the CC compared to men, suggesting that women have thicker, more pronounced connections between the hemispheres. Lastly, a recent study by Chou, Cheng, Chen, Lin, and Chu (2011) analyzed white matter microstructure in men

and women, correlating their results to the EQ and SQ. Their results support the EMB theory of autism, in that scores on the EQ in females, but not males, were positively correlated with more ordered neural structure (fractional anisotropy in white matter) in areas associated with the social brain (inferior parietal lobule and superior temporal gyrus). In addition, scores on the SQ in males, but not females, were found to be positively correlated with fractional anisotropy in areas associated with the analytic brain (occipital gyrus and postcentral gyrus; Baron-Cohen & Belmonte, 2005). Chou and colleagues (2011) also reported that women were found to have white matter microstructure better suited for communications across the hemispheres (greater fractional anisotropy associated with decreased radial diffusivity), which they suggest could be the foundation for greater empathizing skills in women. These findings provide more direct evidence for neural support of the EMB theory, though studies relating functional connectivity to the behavioral presentations associated with the EMB theory are needed. Work by Carson and colleagues (in preparation) suggested a pattern of decreased communication between the hemispheres, but intact communication within the hemispheres from a study of EEG coherence in adolescents with and without ASD. However, this study lacks behavioral evidence to link this pattern of neural activity to the EMB theory. Thus, this study aims to explore connections between EEG coherence and measures of empathizing and systemizing in groups of adolescents with and without ASD. More specifically, the aims of the present study are:

- I. To examine whether EEG coherence differs between adolescents with ASD and typically developing adolescents.

- II. To examine relationships between behavioral measures and EEG coherence between the frontal lobes.
- III. To determine the best predictors of group membership within the sample by analyzing how EEG coherence and behavioral indicators of the EMB theory contribute to group membership, in comparison to how parent reports of social skills and characteristics associated with autism contribute to group membership.

The hypotheses that will be tested in the current study are as follows:

- Ia. Adolescents with ASD will show decreased coherence between the frontal lobes in comparison to typically developing adolescents in alpha, beta, theta, delta, and gamma bands.
- Ib. EEG coherence within the left frontal and temporal-parietal lobes will not differ between adolescents with ASD and typically developing adolescents in alpha, beta, theta, delta, and gamma bands (Carson et al., in preparation).
- Ic. EEG coherence within the right frontal and temporal-parietal lobes will not differ between adolescents with ASD and typically developing adolescents in alpha, beta, theta, delta, and gamma bands (Carson et al., in preparation).
- IIa. EEG coherence between the frontal lobes will be positively correlated with empathizing capabilities (i.e. the EQ).
- IIb. EEG coherence between the frontal lobes will be negatively correlated with severity of autism (i.e. the AQ).
- IIc. EEG coherence between the frontal lobes will be positively correlated with social skills, and thus negatively correlated with the total score of the SRS.

- IId. EEG coherence between the frontal lobes will be negatively correlated with systematizing capabilities (i.e. the SQ).
- IIIa. Group membership (ASD vs. TYP) will be accurately determined from the following predictors: systematizing capabilities (i.e. SQ scores), empathizing capabilities (i.e. EQ scores), and EEG coherence between the frontal lobes.
- IIIb. Group membership (ASD vs. TYP) will be accurately determined from the following predictors: parent report of social skills (i.e. total score of the Social Responsiveness Scale) and characteristics associated with autism (i.e. AQ scores).
- IIIc. Group membership will be more accurately determined from the following predictors: systematizing capabilities (i.e. SQ scores), empathizing capabilities (i.e. EQ scores), and EEG coherence between the frontal lobes, in comparison to membership predicted by parent report of social skills and characteristics of autism.

## Method

Data collection for this study was reviewed and continuously approved by the Marquette University Internal Review Board (IRB). Data was collected with collaboration from Amy Van Hecke's, Ph.D., laboratory, which included financial support from the Autism Society of Southeastern Wisconsin (ASSEW).

### *Participants*

Sixty-one male adolescents, ages 11-15, were recruited for participation in this study. Thirty-two typically developing male adolescents were recruited via flyers and online advertisements. Typically developing teens had no history of ASD or a sibling with ASD. In addition, their caregiver completed the Autism Spectrum Screening Questionnaire (ASSQ; Ehlers, Gillberg, & Wing, 1999) and Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001), in order to ensure the absence of a diagnosis on the autism spectrum and other behavioral concerns.

Twenty-nine male adolescents with ASD were recruited for participation in the Marquette University Program for the Enrichment and Education of Relational Skills (PEERS). PEERS is a social skills group aimed at teaching high-functioning adolescents with ASD how to make and keep friends (Laugeson, Frankel, Mogil, & Dillon, 2009). As a part of their participation in PEERS, community diagnoses for teens with ASD are confirmed via administration of the Autism Diagnosis Observation Schedule (ADOS: Lord, Rutter, DiLavore, & Risi, 1999), Module 3 or 4, which is appropriate for children aged 11 to 15 who are able to speak in competent, full sentences. The ADOS is

considered a gold standard among autism diagnostic tools and recommended for use in research (Tanguay, 2000).

All participants were required to speak relatively well, in English, in full sentences and to have at least one parent agree to participate as well. Adolescents were administered the Kaufman Brief Intelligence Test (KBIT: Kaufman & Kaufman, 1990) to ensure their intelligence quotient (IQ) scores were above or equal to 70. This cutoff was established as the IQ criteria for participation in PEERS and, for continuity, was utilized with the control group as well. The K-BIT was normed on over 2,000 children and had good internal consistency (IQ composite: .94) and test-retest reliability (.92-.95).

One typically developing participant was excluded due to an elevated internalizing subscale on the CBCL. Left-handed subjects (three in the TYP group and three in the ASD group) were not included in the analysis, due to concerns of possible lateralization effects on coherence values. Therefore, the final samples included 28 adolescents in the TYP group and 26 adolescents in the ASD group, for a total sample size of 54.

Medication use was noted for all participants using the following classifications: 1) none, 2) medications to treat attention problems, 3) medications to treat mood disorders, and 4) multiple medications. Statistically significant differences were noted between the groups for medication use, with none of the TYP group reporting taking medications for behavior or mood [ $t(52) = -5.785, p < .001$ ]. In the ASD group, ten teens reportedly took no medication, three teens were on medications for attention problems, six teens were on medications to treat mood disorders, and seven teens were taking

multiple medications. No statistically significant differences were found for age, IQ, or race/ethnicity (see Table 1).

Table 1. *Descriptive Statistics*

Variable	ASD Group		TYP Group	
	Mean	SD	Mean	SD
Age (years)	12.85	1.32	13.00	1.47
IQ	101.58	18.36	107.25	13.99
AQ Total*	32.62	6.56	13.39	5.21
EQ Total*	16.46	7.58	43.64	13.82
SQ Total	36.27	13.94	34.68	17.15
SRS Total*	101.50	21.75	24.25	16.46
Delta Frequency Band				
Frontal-Frontal	.215	.112	.261	.122
Left Frontal-Temporal	.333	.143	.325	.100
Right Frontal-Temporal	.266	.106	.273	.114
Theta Frequency Band				
Frontal-Frontal	.470	.225	.612	.180
Left Frontal-Temporal	.453	.178	.452	.124
Right Frontal-Temporal	.366	.158	.401	.105
Alpha Frequency Band				
Frontal-Frontal*	.500	.256	.734	.224
Left Frontal-Temporal	.455	.165	.514	.157
Right Frontal-Temporal	.408	.187	.448	.177
Beta Frequency Band				
Frontal-Frontal	.284	.137	.361	.141
Left Frontal-Temporal	.310	.104	.311	.078
Right Frontal-Temporal	.247	.082	.290	.092
Gamma Frequency Band				
Frontal-Frontal	.280	.151	.333	.078
Left Frontal- Temporal	.262	.087	.275	.136
Right Frontal-Temporal	.206	.086	.220	.090

*Note.* Frontal-Frontal= Coherence values from frontal lobe electrodes F3 and F4. Left Frontal-Temporal= Coherence values from frontal lobe electrode F3 and Temporal electrode T5. Right Frontal-Temporal= Coherence values from frontal lobe electrode F4 and Temporal electrode T6. IQ = KBIT total score. AQ = Autism Quotient total score. EQ = Empathizing Quotient total score. SQ = Systemizing Quotient total score. SRS= Social Responsiveness Scale total score. \* denotes statistically significant difference between the group means at  $p < .005$ .

Females were excluded from analysis due to the significantly lower numbers of female participants with ASD in the PEERS program. As boys are four times more likely to be diagnosed with ASD than girls (Kogan et al., 2009), this gender difference in participants is not unusual.

### *Procedures*

Participants with ASD were recruited through the Marquette University PEERS program and were naïve to the PEERS intervention, meaning at the time of data collection they had not received the intervention. Recruitment of typically developing adolescents occurred via online advertising. Study information was posted on Craigslist.org and local family websites, such as Milwaukee moms.com. A description of the study was disseminated to the Marquette community on two occasions via a weekly email update sent to students, faculty, and staff. In addition, flyers describing the study were posted in the community, including in grocery stores, coffee shops, and other public areas. Finally, a collaboration with a doctoral student in the Biomedical Engineering Department, whereby participants recruited are able to participate in both research protocols, with overlapping information (i.e. KBIT scores) shared between the two investigators, was established. This relationship was approved by the Marquette University Institutional Review Board (IRB).

For typically developing adolescents, interested families contacted the study author in order to set up an appointment via the contact information provided on recruitment materials. For adolescents with ASD, participation in the current study was conducted through the required research component for PEERS and did not require additional testing or participation.

All participants completed consent and assent forms. For participants with ASD, the measures and procedures described were collected in accordance with the procedures approved by the Marquette University IRB as a part of the larger Marquette University PEERS study. For all participants, following the consent procedure, parents completed behavioral questionnaires: ASSQ (Ehlers et al., 1999), the CBCL (Achenbach & Rescorla, 2001), the Adolescent Empathy Quotient (EQ; Auyeung et al., 2012), the Adolescent Systemizing Quotient (SQ; Auyeung, et al., 2012), the Adolescent Autism Spectrum Quotient (AQ; Baron-Cohen, Hoekstra, Knickmeyer, & Wheelwright, 2006), and the Social Responsiveness Scale (SRS; Constantino, 2005). While the parent completed behavioral questionnaires, the typically developing group participated in the KBIT and the participants with ASD participated in the KBIT and ADOS. Upon completion of behavioral testing, teens were accompanied by their parents to Dr. Van Hecke's research laboratory to complete the EEG. Adolescents were asked to sit quietly in a comfortable chair facing a 19-inch presentation video monitor.

EEG net application began by the experimenter first asking the participant to remove any jewelry (ears, neck, bracelet, face jewelry) and hair accessories. A 64 channel EGI HydroCell Sensor Net (Electrical Geodesics, Eugene, OR) was used. After soaking the net in electrolyte solution, net application began. The examiner placed the EEG net on the participants' heads. All impedances were maintained at or below 50 kOhm and a CZ reference was utilized during recording. After ensuring the child was comfortable, EEG data collection began during an alert, eyes-open condition. A total of three minutes of continuous EEG was collected.

### *Measures*

*Adolescent Empathy Quotient (EQ) and Adolescent Systemizing Quotient (SQ).*

The Adolescent EQ and SQ (Auyeung et al., 2012) were developed as adolescent versions of the Empathy Quotient (Baron-Cohen & Wheelwright, 2004) and Sympathy Quotient (Baron-Cohen et al., 2003), self-report questionnaires assessing empathy and systemizing. The Adolescent EQ and SQ contain a list of statements about situations, experiences, and interests where empathizing and systemizing are required and asks parents to rate how strongly they agree with each statement about their adolescent with a Likert scale format. The Adolescent EQ and SQ show well-established variability, internal consistency (EQ:  $\alpha = 0.96$ ; SQ:  $\alpha = 0.90$ ) and test retest reliability (EQ:  $r = 0.83$ ,  $p < 0.001$ ; SQ:  $r = 0.84$ ,  $p < 0.001$ ; Auyeung et al., 2012). Additionally, the current sample also demonstrated good reliability and internal consistency on both the EQ (EQ total:  $\alpha = 0.94$ ) and the SQ (SQ total:  $\alpha = 0.89$ ). Akin to patterns observed in children and adults, adolescent girls scored higher on the EQ than adolescent boys, who scored higher than adolescents with ASD (Auyeung et al., 2012). Adolescents with ASD scored highest on the SQ, followed by teenage boys then teenage girls (Auyeung et al., 2012).

*Adolescent Autism Spectrum Quotient (AQ).* The Adolescent AQ (Baron-Cohen et al., 2006) was developed as an adolescent version of the Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), a quick and quantitative self-report measure for assessing the number of autistic traits a person possesses. The Adolescent AQ is completed by parents of teens, asking them to rate how much they agree with 50 statements about their teens using a Likert scale. Five areas are assessed with ten questions each: social skill, attention switching, attention to detail, communication, and imagination. Cronbach's  $\alpha$  coefficients for each group were all in

the range 0.6-0.9, suggesting the measure has reasonable construct validity. This measure also has good test-retest reliability and was shown to distinguish between typically developing teens and adolescents with ASD (Baron-Cohen et al., 2006). In the current sample, excellent internal consistency was found on the AQ (AQ total:  $\alpha = .922$ )

*Social Responsiveness Scale (SRS)*. The SRS (Constantino, 2005) consists of 65 items that measure social awareness, reciprocal social communication, social anxiety, social information processing, and autistic traits. The SRS produces t-scores for six subscales: Social Awareness, Social Cognition, Social Communication, Social Motivation, Autistic Mannerisms, and Total Score. T-scores above 76 are indicative of a diagnosis of autism and atypical development in that area. The scale was normed by gender and age on a sample of more than 1,600 4-18-year-old children. The scale exhibits good reliability and validity, with all scales reporting  $\alpha > .70$  in published samples (Constantino et al., 2003), as well as the current sample (SRS total:  $\alpha = .98$ ).

#### *Data Preparation*

EEG signals from 64 channels were amplified and digitized at a sampling rate of 1000 samples per second using an EGI (Electrical Geodesics, Inc., Eugene, OR) Geodesic EEG System, Net Amps 300. Raw EEG data was transferred from the EGI system used to collect data to the Scan 4.3 program (Neuroscan, Inc., Charlotte, NC). All preparation and analysis of the EEG data was conducted within the Neuroscan 4.3 Edit program. Data was re-referenced offline to an average reference configuration and was high pass filtered at .3-50 Hz. Any segments of continuous EEG data with movement, muscle activity, and eye artifact were identified manually and rejected from analyses using information from electro-oculogram channels. Artifact-free data was then epoched

into 1-second segments (1024 points). A Fast Fourier Transform with a Hanning window of 1-second width and 50% overlap between consecutive windows was used to average artifact-free epochs for both conditions. A minimum of 30 artifact-free epochs (or 30 seconds of continuous EEG) was necessary in order for a participant's data to be included in analyses. Average spectral power (microvolts squared) was computed by summing the power in the 0-4 Hz (delta), 4-8 Hz (theta), 8-12 Hz (alpha), 12-30 Hz (beta), and 30-50 Hz (gamma) bins. Coherence was then calculated based on delta, theta, alpha, beta, and gamma values within the Scan 4.3 program's coherence transform (Neuroscan, Inc., Charlotte, NC). Coherence is a linear correlation coefficient that primarily estimates the amount of synchronization between any two data channels (Nunez & Srinivasan, 2006). Coherence values range between 0 and 1. A coherence value of 1 indicates a high level of connectivity, or relatedness, between the two electrodes. A coherence value of 0, however, indicates the two electrodes are not related. Further, a coherence of 0.5 in one frequency band, for example, indicates that at this frequency, 50 percent of the variance in one channel can be explained by the other channel (Nunez & Srinivasan, 2006). Three pairs of electrodes were selected (10-20 standard locations): a left frontal lobe electrode (F3) and a right frontal lobe electrode (F4); a left frontal lobe electrode (F3) and a left temporal-parietal lobe electrode (T5); and finally a right frontal lobe electrode (F4) and a right temporal-parietal lobe electrode (T6). All statistical analyses were conducted using the SPSS 20.0 General Linear Model (SPSS, Inc., 2011) program.

## Results

Descriptive statistics are presented in Table 1. As stated previously, the final sample sizes included 28 adolescents in the TYP group and 26 adolescents in the ASD group, for a total sample size of 54. All variable distributions were examined for skewness, kurtosis, and sphericity, when applicable. Coherence values were determined to be skewed; therefore, data were normalized by calculating the square root and performing a Fisher z-transform of these values (Coben et al., 2008). After transformation, all skewness values were within acceptable limits. Kurtosis values suggested that all coherence values demonstrated a platykurtic distribution.

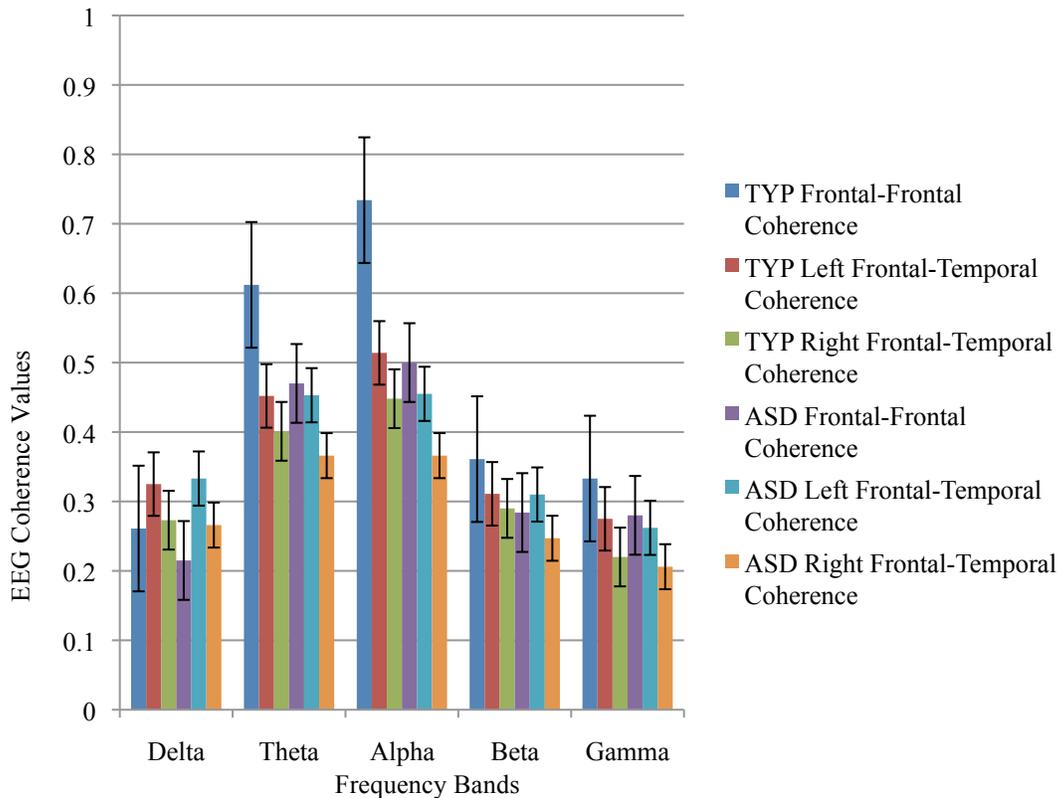
### *Results of the First Set of Hypotheses: Differences in Coherence Between Groups*

To examine the first set of hypotheses—regarding differences in coherence between the adolescents with ASD (ASD) and typically developing adolescents (TYP)—a three-way, mixed analysis of variance (ANOVA) was conducted. The coherence value (ranging from 0 to 1) served as the dependent variable. For independent variables, diagnosis (ASD or TYP) was utilized as the between groups factor, coherence electrode pairing (frontal-frontal; left frontal-left temporal-parietal; and right frontal-right temporal-parietal) was utilized as a three-level within-groups factor, and frequency band (gamma, delta, theta, alpha, and beta) was utilized as a five-level within-groups factor. Initially, participants' IQ scores from the KBIT and medication use were included as covariates. However, when these variables were included in the models, the results did not differ from those cited below. Therefore, K-BIT scores and medication use were not

included as covariates in the final model in order to preserve power. The Huynh-Feldt correction was utilized when violations of sphericity were noted.

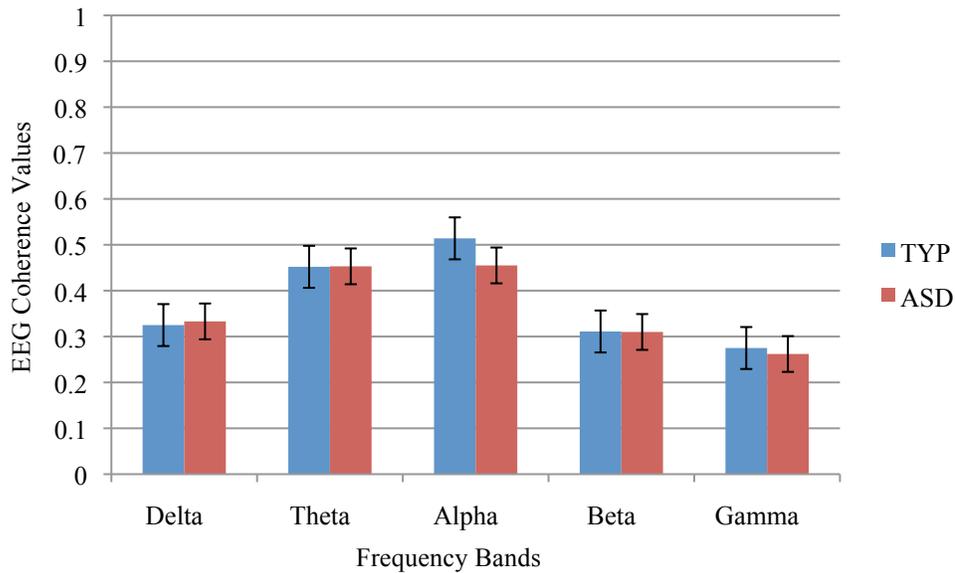
Results of the repeated measures ANOVA found significant main effects of frequency band ( $F(3.697, 192.235) = 44.589, p = .001, \text{partial } \eta^2 = .462$ ) and electrode pair ( $F(2, 104) = 92.215, p = .001, \text{partial } \eta^2 = .639$ ). A marginally significant main effect for diagnosis was also found ( $F(1,52) = 3.821, p = .056$ ). Significant two-way interactions were also found for electrode pair x frequency band ( $F(4.538, 235.973) = 48.324, p = .001, \text{partial } \eta^2 = .482$ ), electrode pair x diagnosis ( $F(2, 104) = 3.576, p = .031, \text{partial } \eta^2 = .064$ ), and frequency band x diagnosis ( $F(3.697, 192.235) = 3.803, p = .007, \text{partial } \eta^2 = .068$ ). Finally, results of the repeated measure ANOVA indicated a significant three-way interaction: frequency band x electrode pair x diagnosis ( $F(4.538, 235.973) = 4.493, p = .001, \text{partial } \eta^2 = .08$ ). Follow-up analyses were conducted on the three-way interaction to obtain a better understanding of group differences (see Figure 1).

Figure 1. Results of First Repeated Measures ANOVA



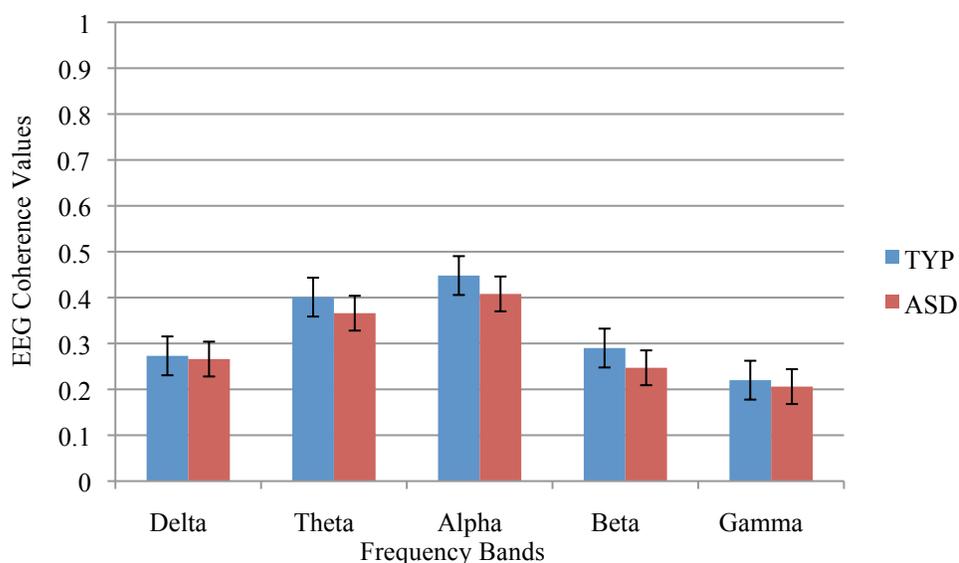
For follow-up analyses, three separate two-way repeated measures ANOVAs were conducted to investigate differences between the groups at various frequency bands in each electrode pairing: left frontal-temporal, right frontal-temporal, and frontal-frontal. Each repeated measure ANOVA utilized coherence value as the dependent variable, and for independent variables, diagnosis served as the between groups factor with frequency band (gamma, delta, theta, alpha, and beta) as a five-level within-groups factor. The first repeated measures ANOVA investigated the left frontal-temporal electrode pairing (see Figure 2). Results indicated a significant main effect for frequency band ( $F(3.299, 171.543) = 51.740, p = .001, \text{partial } \eta^2 = .499$ ) and a non-significant two-way interaction for frequency band x diagnosis ( $F(3.299, 171.543) = 1.037, p = .382, \text{partial } \eta^2 = .020$ ).

Figure 2. *Results of Repeated Measures ANOVA: Left Frontal-Temporal Electrode Pairing.*



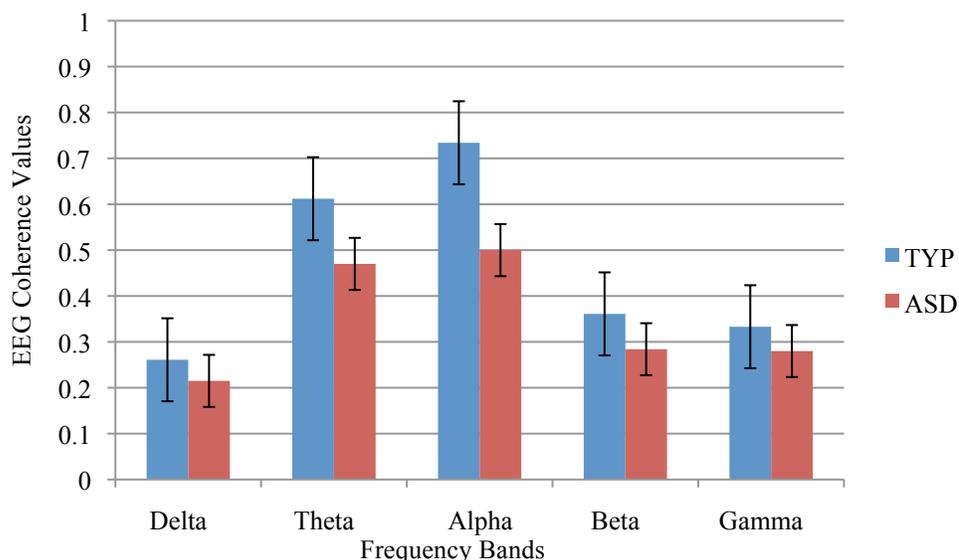
The second repeated measures ANOVA investigated the right frontal-temporal electrode pairing, which revealed similar results to the left frontal-temporal pairing. A significant main effect for frequency band ( $F(2.978, 154.857) = 57.996, p = .001$ , partial  $\eta^2 = .527$ ) and a non-significant two-way interaction for frequency band x diagnosis ( $F(2.978, 154.857) = 0.479, p = .696$ , partial  $\eta^2 = .009$ ) were found (see Figure 3).

Figure 3. Results of Repeated Measures ANOVA: Right Frontal-Temporal Electrode Pairing.



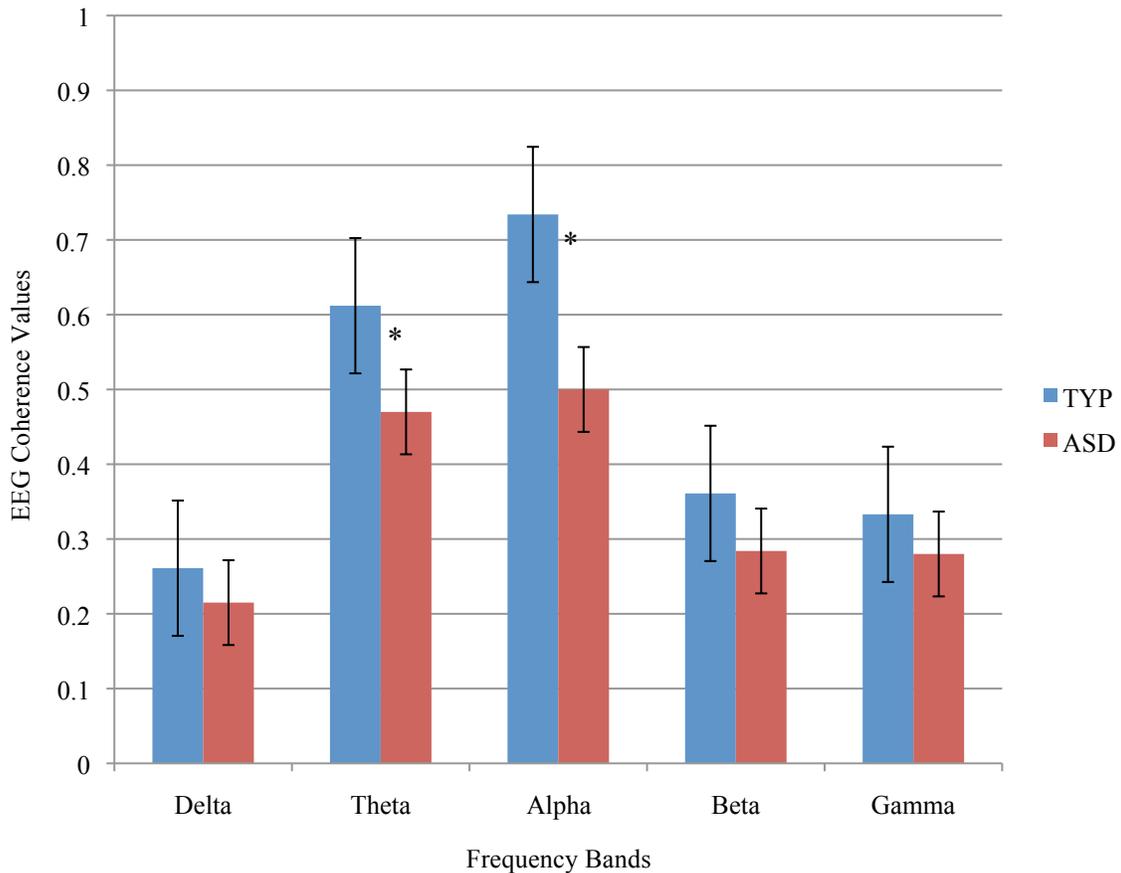
Lastly, the third repeated measures ANOVA investigated the frontal-frontal coherence electrode pairing. Results revealed a significant main effect for frequency ( $F(3.014, 156.715) = 109.923, p = .001, \text{partial } \eta^2 = .679$ ), as well as a significant two-way interaction between frequency band and diagnosis ( $F(3.014, 156.715) = 6.298, p = .001, \text{partial } \eta^2 = .108$ ). These results indicate that differences in coherence between the typically developing adolescents and teens with ASD were only found in the frontal-frontal electrode pair (see Figure 4).

Figure 4. Results of Repeated Measures ANOVA: Frontal-Frontal Electrode Pairing.



As the frontal-frontal electrode pairing yielded a significant two-way interaction, independent samples t-tests were conducted on this pairing in order to better understand group differences in frontal-frontal coherence at various frequencies. Utilizing a corrected p-value of  $p = .01$  for multiple tests, no significant differences were found between the groups in the following frequency bands: delta ( $t(51.991) = 1.465, p = .149$ ), beta ( $t(51.877) = 2.055, p = .045$ ), and gamma ( $t(50.997) = 1.313, p = .195$ ). Significant differences did emerge between adolescents with ASD ( $M = .47, SD = .22$ ) and typically developing adolescents ( $M = .61, SD = .18$ ) in the theta frequency band ( $t(47.942) = 2.544, p = .01$ ). Significant differences also were found between adolescents with ASD ( $M = .50, SD = .26$ ) and typically developing adolescents ( $M = .73, SD = .22$ ) in the alpha frequency band ( $t(49.838) = 23.561, p = .001$ ). These results indicate that typically developing teens have significantly higher frontal-frontal coherence in the theta and alpha bands than teens with ASD (see Figure 5).

Figure 5. *Results of Independent Samples T-Test: Frontal-Frontal Coherences.*



\* denotes significant group difference at  $p < .01$ .

In summary, the data supported aspects of hypothesis (Ia), in that adolescents with ASD demonstrated decreased coherence between the frontal lobes in comparison to typically developing adolescents in alpha and theta bands, but not also delta, beta, and gamma bands. In addition, the data supported hypotheses (Ib) and (Ic), as typically developing teens and teens with ASD did not differ in coherence values between the left frontal and left temporal-parietal lobes or between the right frontal and right temporal-parietal lobes.

*Results of the Second Set of Hypotheses: Relations of Coherence and Behavioral Characteristics*

The second set of hypotheses investigated whether behavioral indicators of EMB theory and parent report of social skills and characteristics associated with autism were related to EEG coherence. Frontal-frontal coherence was chosen for the focus of this analysis, given the significant group differences in this coherence measure from Hypothesis 1 analyses. As several skewed distributions emerged in the data, Spearman correlations were computed, in order to examine associations among coherence values between the left and right frontal lobes (beta, alpha, theta, delta, and gamma), behavioral indicators of the EMB theory (SQ and EQ), social skills ratings (SRS-Total Score), and characteristics associated with autism (AQ) in the entire sample. A corrected  $p$ -value of  $p = .01$  was utilized. Results of the correlation of the whole sample indicated that frontal-frontal coherence at the alpha frequency was significantly negatively correlated with SRS total score ( $r = -.356, n = 54, p = .008$ ). In addition, results of the correlation of the whole sample revealed a significant negative correlation between frontal-frontal coherence at the theta frequency and SRS total score ( $r = -.342, n = 54, p = .01$ ). Thus, increased frontal-frontal coherence at the alpha and theta frequencies are associated with increased social skills per parent report in the total sample. In addition, the entire sample revealed a trend toward a negative correlation between frontal-frontal coherence in the alpha frequency and AQ total score ( $r = -.293, n = 54, p = .032$ ), meaning that increased frontal-frontal coherence at the alpha frequency was marginally associated with less characteristics of autism per parent report. See Table 2.

Table 2. *Spearman's Rho Correlations for Total Sample: Frontal-Frontal Coherence and Behavioral Data.*

Variable	Empathizing Quotient	Systemizing Quotient	Autism Quotient	SRS Total Score
Delta F5.F6 Coherence	.081	-.152	-.127	-.109
Theta F5.F6 Coherence	.214	-.158	-.248	-.342*
Alpha F5.F6 Coherence	.214	-.241	-.293	-.356**
Beta F5.F6 Coherence	.086	-.104	-.129	-.186
Gamma F5.F6 Coherence	.162	-.031	-.154	-.197

*Note.* \* =  $p < .01$ , \*\* =  $p < .005$ . N = 54. F5.F6 = frontal-frontal coherence between the left electrode (F5) and right electrode (F6) in the frontal lobes.

Additional Spearman's correlations were computed for each group; however, no significant correlations emerged within either the adolescents with ASD or the typically developing adolescents. See Table 3 and Table 4.

Table 3. *Spearman's Rho Correlations for ASD Group: Frontal-Frontal Coherence and Behavioral Data.*

Variable	Empathizing Quotient	Systemizing Quotient	Autism Quotient	SRS Total Score
Delta F5.F6 Coherence	.112	-.087	-.272	-.121
Theta F5.F6 Coherence	-.199	-.161	-.100	-.023
Alpha F5.F6 Coherence	-.234	-.071	.109	.022
Beta F5.F6 Coherence	-.158	-.022	.184	.113
Gamma F5.F6 Coherence	-.272	-.003	.183	.116

Note. \* =  $p < .01$ , \*\* =  $p < .005$ . N = 28. F5.F6 = frontal-frontal coherence between the left electrode (F5) and right electrode (F6) in the frontal lobes.

Table 4. *Spearman's Rho Correlations for TYP Group: Frontal-Frontal Coherence and Behavioral Data.*

Variable	Empathizing Quotient	Systemizing Quotient	Autism Quotient	SRS Total Score
Delta F5.F6 Coherence	-.206	-.159	.290	.239
Theta F5.F6 Coherence	.113	-.162	.149	-.244
Alpha F5.F6 Coherence	-.234	-.348	.192	.170
Beta F5.F6 Coherence	-.271	-.206	.169	.081
Gamma F5.F6 Coherence	.094	-.093	-.117	-.182

Note. \* =  $p < .01$ , \*\* =  $p < .005$ . N = 26. F5.F6 = frontal-frontal coherence between the left electrode (F5) and right electrode (F6) in the frontal lobes.

In summary, the results of the correlation did not support hypotheses (IIa) and (IIc), as frontal-frontal coherence was not positively correlated with empathizing

capabilities (i.e. the EQ), nor was frontal-frontal coherence negatively correlated with systematizing capabilities (i.e. the SQ). The data did support aspects of hypotheses (IIb) and (IIc), in that frontal-frontal coherence in the alpha frequency was negatively correlated with severity of autism [i.e. the AQ; hypothesis (IIb)] and frontal-frontal coherence in the alpha and theta frequencies were positively correlated with social skills [negatively correlated with the total score of the SRS; hypothesis (IIc)].

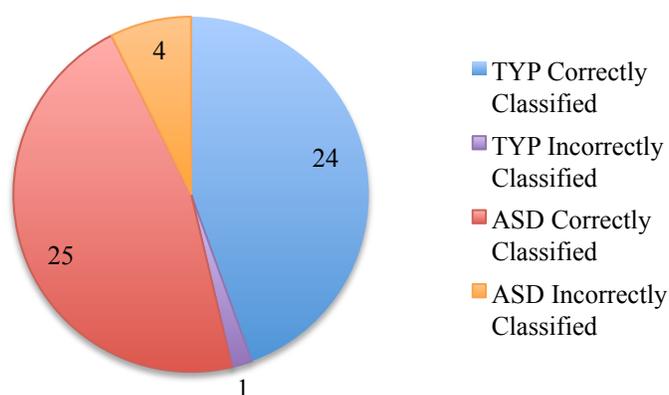
*Results of the Third Set of Hypotheses: Predictors of Group Membership*

In order to examine whether EEG coherence, EMB behavioral characteristics, or classic social skills and autism symptoms were associated with group membership, two discriminant function analyses were conducted. First, a discriminant function analysis was done to examine the accuracy of behavioral indicators of the EMB theory as predictors of group membership. Predictor variables were entered in one step and included the total scores on the EQ and SQ, as well as EEG coherence between the left and right frontal lobe at all five frequencies. The two groups being compared were typically developing teens ( $N = 28$ ) and teens with ASD ( $N = 26$ ). The chi-square for this discriminant function was statistically significant ( $\chi^2(7) = 55.487, p = .001$ ) and had a canonical correlation of .826; thus, it was highly related to group membership. Overall, the prediction of group membership was quite good; Wilks's  $\Lambda$ , which is analogous to  $1 - \eta^2$  or the percentage of variance in the discriminant scores that is *not* explained by group membership, was .32. Thus, 68% of the variance in discriminant scores was due to between-group differences. Overall, 90.7% of the subjects were correctly classified by the discriminant analysis (24 correctly classified as typically-developing, 1 incorrectly classified as typically developing, 25 correctly classified as ASD, and 4 incorrectly

classified as ASD; see Figure 6). Using the arbitrary cutoff of .50 to decide which of the standardized discriminant coefficients are large (Warner, 2008), only two of the predictor variables had large coefficients for the standardized discriminant function: EQ (.973) and frontal-frontal coherence in the alpha frequency (.640). The other predictor values had small standardized discriminant coefficients (SQ = .037; delta frontal-frontal coherence = -.114; theta frontal-frontal coherence = -.118; beta frontal-frontal coherence = .158; and gamma frontal-frontal coherence = -.160) .

Figure 6. *Discriminant Analysis for the EMB Theory Model: Number Correctly and Incorrectly Classified for Each Group.*

**EMB Theory Model: Number Correctly and Incorrectly Classified**

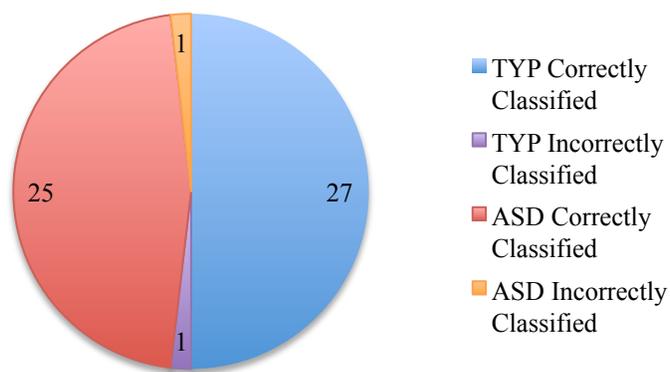


The second discriminant analysis examined the accuracy with which group membership was determined from the following predictors: parent report of social skills (i.e. total score of the Social Responsiveness Scale) and characteristics associated with autism (i.e. AQ scores). As before, predictor variables were entered in one step, and the two groups being compared were typically developing teens ( $N = 28$ ) and teens with ASD ( $N = 26$ ). The chi-square for this discriminant function was statistically significant ( $\chi^2(2) = 86.218, p = .001$ ) and had a canonical correlation of .903; thus, it was highly related to

group membership. Overall, the prediction of group membership was quite good; Wilks's  $\Lambda$  was .18. Thus, 82% of the variance in discriminant scores was due to between-group differences. Overall, 96.3% of the subjects were correctly classified by the discriminant analysis (27 correctly classified as typically-developing, 1 incorrectly classified as typically developing, 25 correctly classified as ASD, and 1 incorrectly classified as ASD; see Figure 7). Using the arbitrary cutoff of .50 to decide which of the standardized discriminant coefficients are large (Warner, 2008), only SRS total score had a large coefficient for the standardized discriminant function: SRS = .793). The other predictor value had a small standardized discriminant coefficient (AQ = .287). Finally, to determine if a significant difference existed between the percent correctly classified by the discriminant analyses (i.e. the 90.7% correctly predicted via the indicators of EMB theory model and the 96.3% correctly predicted via the parent-reported social skills and characteristics of autism model) a z-test was performed on the proportions. Results indicate that a significant difference did not exist between these two percentages ( $z = 1.18, p = .24$ , two-tailed).

Figure 7. *Discriminant Analysis for the Traditional Characteristics Model: Number Correctly and Incorrectly Classified for Each Group.*

**Traditional Characteristics Model: Number Correctly and Incorrectly Classified**



Thus, support was found for hypotheses (IIIa) and (IIb), as both discriminant function analysis models accurately predicted group membership (90.7% correctly predicted via the indicators of EMB theory model and 96.3% correctly predicted via the parent-reported social skills and characteristics of autism model). Hypothesis (IIIc) was not supported, as a significant difference did not emerge between the two models.

## Discussion

This study investigated neural correlates of the Extreme Male Brain (EMB) theory by investigating EEG coherence, traditional behavioral characteristics of ASD, and behavioral indicators of the EMB theory in adolescent males with and without ASD. Results of the first hypothesis, investigating EEG coherence between the groups, revealed group differences in frontal inter-hemispheric coherence. Teens with ASD demonstrated significantly lower coherence between the left and right frontal lobes in the alpha and theta frequencies than the typically developing group. In contrast, long-distance intra-hemispheric EEG coherence between the frontal and temporal-parietal lobes did not differ between the groups at any frequency, suggesting that connectivity within each hemisphere does not deviate from typical development in this sample. These results are similar to the author's previous findings in a different sample of 8-12 year-old males and females (Carson et al., in preparation), which also found no differences in intra-hemispheric connectivity between the left and right frontal and temporal-parietal lobes but reduced inter-hemispheric coherence in the frontal lobes. Murias et al. (2007) also reported decreased alpha coherence in long-distance connections in adults with ASD. These findings suggest an important distinction between inter-hemispheric long-distance connectivity and intra-hemispheric long-distance connectivity may exist in ASD, warranting further exploration.

Further, male teens with ASD displaying decreased inter-hemispheric alpha and theta connectivity in the frontal lobes as compared to typically developing male teens is suggestive of a more lateralized profile in ASD, particularly considering that intra-hemispheric connectivity within each hemisphere (left and right frontal to temporal-

parietal coherence) did not differ between the groups. These neural findings indicate support for the EMB theory, in that they demonstrate a more lateralized profile in ASD, at least at the alpha and theta frequencies. Indeed, these results correspond to recent studies of typically developing men and women, which have revealed anatomical and functional differences in neural organization and connectivity that suggest dimorphic organization of the brain in men and women. For example, parasagittal asymmetries in the CC were examined between healthy men and women, with men showing more pronounced and significant asymmetry in the CC, particularly in the anterior body (Luders et al., 2006). The authors suggest that differences between the sexes are reflected in the organization and distribution of callosal fibers.

Further, recent studies of the typical brain, using a large, international, multi-site sample, have indicated that females display a more connected brain than males (Tomasi & Volkow, 2012a), in that females have greater local functional connectivity when controlling for total brain volume, gray matter, white matter, and age. A study utilizing this same sample (Tomasi & Volkow, 2012b) found that male brains showed increased rightward lateralization in short-range connections as compared to females. Though females displayed greater leftward lateralization in the inferior frontal cortex, this finding was the only instance where women showed greater lateralization than men in this sample. These results further suggest that the typical male brain is less connected and more lateralized than the typical female brain. Findings from the current study suggest that the brain in ASD may indeed be an extreme variant of the typical male brain, with the current sample of adolescent males displaying a more lateralized profile than the typical male brain. Future studies should investigate whether differences in inter-

hemispheric EEG coherence differs between typically developing males and females, in order to determine if the findings reported in this study support the idea that brain activity in ASD is an extreme variant of the typical *male* brain, as opposed to the typical brain.

Additionally, relating behavioral measures to neural activity was an important aspect of exploring the relationship between the behavioral characteristics of the EMB theory and underlying brain activity. Yet, no significant correlations emerged between the EQ and SQ and frontal-frontal coherence at any frequency in the total sample ASD group, or TYP group. It may be that a lack of power related to sample size resulted in no significant relationships emerging. Further study and replication are warranted in order to better understand the relationship between behavioral measures of the EMB theory and inter-hemispheric coherence. However, results of the current study did reveal that parental report of social skills in the total sample emerged as being significantly related to coherence at the alpha and theta frequencies, meaning that better social skills were correlated with higher inter-hemispheric frontal coherence at the alpha and theta frequencies in the total sample. Interestingly, when correlations were conducted within each sample, no significant relationships emerged in either group, which, again, may be due to a lack of power related to sample size. Replication with a larger sample is needed in order to fully understand the relationship between frontal-frontal coherence and social skills; however, better social skills was related to higher frontal-frontal coherence in the whole sample, suggesting an important relationship between neural activity in this region and social skills, the hallmark deficit of ASD.

Despite results of the correlational analysis, further support for the EMB theory was found in the results of the discriminant analyses in this study, as the “EMB model”

(i.e. EEG coherence between the left and right frontal lobes at all five frequencies, as well as empathizing and systemizing characteristics) correctly predicted 90.7% of the cases into their appropriate group (ASD vs. TYP). It seems that relying upon the EMB theory resulted in a high rate of accuracy in predicting teens with ASD, with only one teen with ASD being inaccurately classified as typically developing. The “traditional characteristics model” (i.e. parent rating of social skills and characteristics associated with autism), on the other hand, did accurately predict a larger percent of cases (96.3%), but this percent classified was not significantly different from the EMB model. Examination of the results of the discriminant analysis reveal that the traditional characteristics model demonstrated decreased type I error, in that the traditional characteristics model had fewer false positives with only one typically developing teen being incorrectly classified in the ASD group, versus four typically developing teens being incorrectly classified in the ASD group in the EMB model. Whether increased sample size would see a reduction in this type I error in the EMB model is uncertain, but should be examined in future studies.

Another possible explanation may be that the EMB model is more sensitive to the broad autism phenotype (BAP), which describes behaviors observed in relatives of persons with ASD that mirror symptom domains of autism, but are milder in their manifestation (Losh et al., 2009). Though exclusion criteria in the current study resulted in no members of the typically developing group having a sibling with autism, extended family history was not noted. Future studies could further explore this idea that the EMB theory is sensitive to the BAP. Overall, it appears that the EMB model is a viable model for classifying teens with ASD versus typically developing teens. Interestingly, when

examining coefficients in the EMB model, EQ and frontal-frontal coherence in the alpha frequency emerge as the largest coefficients in this discriminant analysis, further indicating the importance of alpha coherence in both typical development and in ASD.

The emergence of significant differences in inter-hemispheric frontal-frontal coherence in specific frequency bands (alpha and theta), rather than all five bands, leads to questions about the significance of these frequency bands with regards to known functional associations. To date, a firm literature on coherence frequency bands and their related functions has yet to be established, and a search of electronic databases resulted in few studies associating coherence in specific frequency bands with specific behaviors or functions. However, some evidence suggests that alpha EEG coherence in frontal regions may be related to working memory functions in typical development (i.e. Sauseng et al., 2005), and one study (Mathewson et al., 2012) reported that decreased alpha coherence in posterior regions was related to decreased attention to detail, as reported on the AQ, in adults with ASD. Though this study did not report differences in frontal regions, it does provide evidence that alpha coherence may continue to differ in ASD into adulthood. The current study contributes to this literature of relating behavioral characteristics to activity in varying frequencies, in that, as discussed previously, inter-hemispheric frontal coherence in the alpha and theta frequencies was related to better social skills in the total sample. This literature remains in its infancy, requiring further investigation before a more thorough understanding of the relationship between the different coherence frequency bands and various processes or behaviors can be achieved.

Although an understanding of coherence frequency bands and their related functions/behaviors is not well established, a broader literature exists for the functional

significance of the different frequency bands when examining EEG power. Rather than exploring connectivity between various electrodes like EEG coherence, EEG power is believed to reflect brain activity, specifically the electric potential differences in neuronal dendrites from transmembrane currents in the gray matter of cerebral cortex. Different EEG frequencies are thought to reflect the activity of distributed systems, which could either be wide-spread or local, and may work together as various functional processes demand (Rippon, 2006). Both theta and alpha rhythms have been found to be related to specific cognitive processes. Theta may serve as an index of hippocampal activity and be related to the limbic system; as such, theta activity has been related to memory performance (i.e. Rohm et al, 2001; Klimesch et al., 1997, 2001; Burgess & Gruzelier, 1997). Indeed, a study of children with dyslexia found that successful task performance is related to increases in theta in frontal regions (Rippon & Brunswick, 1998, 2000). Additionally, alpha activity has been associated with thalamocortical networks and is also associated with memory functions (Rippon, 2006). For example, those performing more successfully on memory tasks demonstrate higher alpha activity than bad performers (Klimesch, 1997). Although the current study examined EEG coherence during an eyes-open, resting condition, it is interesting to consider that these frequencies necessary for a vital human process (memory) are demonstrating atypical patterns in EEG coherence in teens with ASD.

Alpha and theta activity have also been interpreted as reflecting top-down processing or internal mental activity in typical development (von Stein & Sarnthein, 2000). Taken in consideration with results of the current study—which investigated EEG coherence in an eyes-open, resting state—it could be that teens with ASD are less well

“connected” at rest and not as engaged in top-down processing as typically developing teens. Although von Stein and Sarnthein’s (2000) suggestion relates to EEG power, and not EEG coherence specifically, it may be that the cortex in teens with ASD may not be as active as seen in typical development.

Looking forward, the pattern of increased lateralization in the teens with ASD could potentially suggest an important neural marker for ASD. Specifically with regards to typical developmental changes in EEG coherence, Barry and colleagues (2004) reported that typical children (ages 8-12) demonstrate a significant increase in alpha frequencies in frontal regions at age ten, and both alpha and theta coherence showed a significant linear increase from age 8 to age 12 in frontal regions (delta frequencies also showed this increase). Developmentally, it appears that increases in alpha and theta frequencies are expected at this age. Though the scope of the current study did not include developmental changes in coherence in ASD, results of this study did indicate that teens with ASD are already lagging behind in this region of neural connectivity. Indeed, this decreased connectivity as compared to typically developing peers may be evident as early as toddlerhood. Dinstein and colleagues (2011) found decreased inter-hemispheric connectivity in the inferior frontal gyrus and superior temporal gyrus in toddlers with ASD in a fMRI study comparing toddlers with ASD to language-delayed and control toddlers during sleep. Additionally, a negative correlation existed between autism severity and inferior frontal gyrus synchronization, indicating a link between behavioral characteristics and neural activity may exist early in development (Dinstein et al., 2011). Taken together, increased lateralization, as marked by decreased inter-

hemispheric connectivity in the frontal lobes, could potentially serve as a neural marker for ASD, providing neural support for the behavioral diagnosis of a brain-based disorder.

Although the current study offers many exciting possibilities for understanding the underlying neurology of ASD, it does present with limitations. Although this study recruited a relatively large sample in comparison to previously published studies of EEG coherence in ASD (i.e. Murias et al., 2007; Mathewson et al., 2012), potential concerns with power emerged, including issues with non-significant correlations when examining groups individually. A larger sample size may have allowed for a more clear understanding of associations between behavioral ratings and EEG coherence. Also, in utilizing EEG, temporal accuracy and a non-invasive method of measuring brain activity were gained, which is particularly helpful in studying teens with ASD. However, EEG limits findings to surface cortical activity and cannot lend insight into the deeper, subcortical connections in the brain. As this field is emerging, a lack of appropriate comparison groups also exists, as many of the other EEG studies in ASD are conducted with adults. Further, no other studies (to this author's knowledge) have explicitly tested the neurological underpinnings of the EMB theory of ASD, leading to a lack of supporting literature for these findings. However, this literature may be developing, as this author's previous work did demonstrate similar findings of lateralized activity in ASD (Carson et al., in preparation). Also, this study exclusively focused upon a sample of boys; however, studies comparing EEG coherence in typically developing males and females is important for establishing neural correlates of the EMB theory. Though some research suggests that typically developing men may show more lateralized neural activity than typically developing women (i.e. Tomasi & Volkow, 2012a; Luders et al.,

2006), these studies should be replicated utilizing EEG coherence and in the context of a study investigating the EMB theory, specifically. Additionally, social behavior was measured based on parent report, which may offer a more subjective view of social functioning than other methods, such as more objective, in vivo observations of social behavior.

In conclusion, results of this study indicate a more lateralized neural profile in teen boys with ASD, demonstrating less connectivity between the hemispheres in the frontal lobes than typically developing peers, and that this connectivity was related to social skills. These results suggest agreement with the Extreme Male Brain theory of autism (Baron-Cohen, 2003), providing preliminary evidence that neural underpinnings for this behavioral theory exist. Further, discriminant analysis demonstrated that the EMB theory predicts group membership as accurately as a traditional model, using ratings of social skills and characteristics associated with autism, though it does present with greater type I error. The EMB theory, therefore, emerges as an interesting behavioral theory of ASD which now has supporting neural evidence. Clinically, this profile of persons with ASD being superior systemizers, with a deficit in empathizing, could provide particularly useful. Current therapies for persons with ASD already utilize strengths in systemizing to support deficits in empathizing (including applied behavioral analysis and demonstrated in books, such as Temple Grandin and Sean Barrow's *The Unwritten Rules of Social Relationships: Decoding Social Mysteries through the Unique Perspectives of Autism*, 2005). This study now indicates that further work in this area should be done in order to determine if increased lateralization in ASD could be utilized as a neural marker for ASD. Preliminary studies (Dinstein et al., 2011; Carson et al., in

preparation; and this current study) suggest that this area warrants further exploration, as identifying a unique neural marker in ASD has important clinical implications. For example, behavioral interventions could attempt to target the neural atypicalities in ASD, attempting to change the course of brain development in ASD. Van Hecke and colleagues' work (in press) demonstrates that neural changes in lateralization as a result of a behavioral intervention are possible in teens with ASD. The lateralized profile found in this study could potentially serve as a marker of change in future studies. Future studies could look to replicate these findings, both in teens and in older and younger age groups, as well as find ties to behavioral rating scales, which the current study was unable to do in each group. Still, this study offers an important contribution to the existing literature on the understanding of brain activity in ASD, suggesting that teens with ASD display a unique neural profile of increased lateralization, consistent with the EMB theory of autism.

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