MOTOR RESONANCE IN ADOLESCENTS AND YOUNG ADULTS WITH AUTISM SPECTRUM DISORDER

by

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A DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2011

ABSTRACT

Motor resonance is motor activation that occurs in the body when one observes or thinks about movement. Motor resonance is thought to assist in automatic imitation, the development of language (i.e., watching others speak helps a person learn to move their mouth to form the words), the development of empathy (i.e., watching others get hurt makes a person automatically flinch), and the development of motor ability (i.e., watching someone ride a bike should help a person ride it later), all of which have been reported to be impaired in persons with Autism Spectrum Disorder (ASD). Thus, the phenomenon of motor resonance may relate in important ways to the social, language, affective, and motor atypicalities commonly observed in persons with ASD. The present study used social stimuli (e.g., videos of hand movements), nonsocial stimuli (e.g., videos of a tire spinning), and language stimuli (e.g., sentences about movement) to examine the presence of motor resonance in individuals with ASD. Tweny-six individuals with ASD and 26 age-and-IQ-matched individuals with typical development (between the ages of 16 and 30) completed a motor resonance computer game in which each video or sentence portrayed a clockwise or counter-clockwise movement. Participants were instructed to respond to the stimuli by rotating a joystick either clockwise or counter-clockwise in response to a colored square presented on the screen. Because motor resonance facilitates responses in the same direction as the observed movement (congruent condition) and inhibits responses in the opposite direction of the observed movement (incongruent condition), quicker congruent responses compared to incongruent responses indicate the presence of motor resonance. The results indicated that individuals with ASD demonstrated a similar pattern of motor resonance compared

to individuals with typical development. However, the degree of motor resonance was negatively correlated with current social symptom severity of the ASD group, suggesting that those with more severe social ASD symptoms demonstrated less motor resonance. Contrary to hypotheses, motor resonance was not related to empathy in either group. However, postural sway in persons with ASD was related to both empathy and autism symptom severity.

DEDICATION

This dissertation is dedicated to my family, close friends, and mentors. Thank you.

LIST OF ABBREVIATIONS AND SYMBOLS

ASD	Autism spectrum disorders
TD	Typical development
PDD-NOS	Pervasive Development Disorder- Not Otherwise Specified
ADHD	Attention Deficit/Hyperactivity Disorder
WASI	Wechsler Abbreviated Scale of Intelligence
FSIQ	Full scale intelligence quotient
IQ	Intelligence quotient
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders-IV
ADI-R	Autism Diagnostic Interview- Revised
ADOS-G	Autism Diagnostic Observation Scale- General
SRS	Social Responsiveness Scale
BAPQ	Broader Autism Phenotype Questionnaire
RBS-R	Repetitive Behavior Scale- Revised
EQ	Empathy Quotient
EMG	Electromyography
MNS	Mirror Neuron System
ICC	Intraclass correlation coefficient
RT	Reaction time
ms	Milliseconds
df	Degrees of freedom
F	Fisher's *F* ratio

M	Mean
SD	Standard deviation
SEM	Standard error of the mean
ANOVA	Analysis of Variance Analysis
p	Probability associated with the occurrence under the null hypothesis
r	Pearson product-moment correlation
t	Computed value of *t* test
η_p^2	Partial eta squared
<	Less than
>	Greater than
=	Equal to

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the assistance and mentorship of individuals to whom I am deeply indebted and grateful. I am so appreciative of the mentorship and feedback from the chair of my dissertation committee, Dr. Mark Klinger, not only during this project but also during my entire tenure as a graduate student. Thank you for taking the time to teach and to mentor me over these past five years. You have struck the perfect balance between challenging me and fostering my ideas, and any research I conduct in the future will indelibly have your mark on it (and will hopefully make you proud). To Dr. Laura Klinger, in addition to your input on this dissertation, thank you for co-mentoring me and insisting that before I research autism, I must know and work with people with autism. By doing so, you gave me (a person who had never studied autism) the opportunity to deeply understand not only the science but also the humanity of autism. You taught me that empathy was not a weakness in a researcher but instead the endless fuel on which scientific inquiry can thrive. To Dr. Rajesh Kana, thank you for providing me the knowledge and amazing opportunities to conduct neuroimaging work in autism. I am so grateful for your mentorship and guidance, and I cannot thank you enough for taking the time to impart to me all that you have about brain function and autism. Thank you for your input into this and many other projects and publications. To Dr. Fran Conners, thank you for your help with my dissertation and for bringing me into your lab for the IDS grant. I learned so much and modeled much of how I conducted this dissertation research after how you conducted the grant. To Dr. Will Hart, thank you for coming onto this

committee for this final stretch and always being open to discuss how my motor resonance ideas may fit with your research.

In addition to the faculty on my committee, I would like to express my deep gratitude to all the fellow graduate students and lab members who assisted me with this project. You are too many to name. However, I would like to individually thank Joanna Mussey for helping me with diagnostic assessments (as well as allowing me to bounce many ideas off of her about the project), and I would like to thank Patrick Powell for being essential in recruiting and running participants.

Thinking of every participant who took the time to participate in this study makes me swell with gratitude. This research would not have been possible if it were not for these amazing people and their families who took time out of their routine to complete the 2.5 hour battery of tasks. After the April 27th tornado that hit Tuscaloosa and many other parts of Alabama, I will never forget coming into the office soon after the tornado to hear messages from the participants and their families making sure I was okay and calling to volunteer for the study. I have been enriched by having known all of you, and I hope that the research you have helped me with makes you proud and is helpful to you. There are not words to express my gratitude.

Finally, I would like to thank my family and friends for their unwavering support. Working on this dissertation meant that I had less time to spend with all of you, but you never showed even the slightest resentment. There is no way I could have completed this without your support. To those who unexpectedly provided me hope during tough times: Jane, who sold us our car two years ago. Thank you for telling me that you refused to live in a world where my dissertation didn't get completed. Thank you to my home church for putting my dissertation on the prayer chain. Thank you to my brother-in-law, Jeff Browne, who helped me try to recover

my dissertation task when it was a casualty of the Blue Screen of Death. Lastly (but most definitely not least), I want to express my deepest gratitude to my best friend and husband, Ryan Browne. You were essential to this project from its inception until its completion, in many roles including (but not limited to) hand actor for the human videos, joystick fabricator, proof-reader, household maintainer, nourishment provider, and eternal optimist. This is as much yours as it is mine.

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INTRODUCTION

Autism Spectrum Disorder (ASD) is a continuum of developmental disorders marked by repetitive behaviors, deficits in social interaction, and deficits in verbal and nonverbal communication (American Psychiatric Association, 2000). All of these behavioral symptoms become apparent in early childhood and typically persist across the lifespan. Motor impairments are only considered "associated symptoms" for ASD and are thus not a required criterion for a DSM-IV diagnosis of autism, Asperger's Syndrome, or PDD-NOS (American Psychiatric Association). However, the prevalence of motor abnormalities in ASD is widely acknowledged. In the first scientific paper on autism, Kanner (1943) highlighted a disturbance in gait and gross motor movement in several members of his case study. Since then, diverse motor impairments such as motor anticipation, clumsiness, impaired postural control, dyspraxia, and impaired gross and fine motor movements have been reported in persons with ASD (for a review see Gidley Larson and Mostofsky [2006]). Additionally, these motor impairments appear to make significant contributions to difficulties in imitation that are commonly seen in individuals with ASD (Green et al., 2002; Vanvuchelen, Roeyers, & De Weerdt, 2007), and these motor impairments have been found both in persons with ASD who have a comorbid intellectual disability and those who have average or above-average IQ (i.e., Green et al., 2009). These results suggest that the observed motor difficulties are associated with ASD symptoms and not just the level of intellectual functioning. Thus, it appears that motor symptoms may be intimately related to the core symptomatology of ASD.

The three most researched motor symptoms in ASD have been motor anticipation, dyspraxia, and postural stability. Each of these different types of motor impairments and possible underlying causes of these motor impairments are discussed in detail below.

Motor Anticipation

Motor anticipation refers to the ability to plan and execute stimulus-driven motor responses. Children with ASD have been shown to have poor motor anticipation compared to matched children with typical development in terms of being slower to move a stylus pen toward a visual target (Rinehart et al., 2006a) and being slower to respond to simple, patterned and un-patterned finger movements (Rinehart et al, 2001). Additionally, persons with ASD have been observed to have overall slower reaction times to stimuli across multiple cognitive studies (i.e., Bogte, Flamma, Van Der Meere. & Van Engeland, 2009; Bowler,1997; Mottron, Burack, Stauder, & Robaey, 1999; Schmitz, Daly, & Declan, 2007; Travers, Klinger, Mussey, & Klinger, 2010). This slower reaction time may be due to poor motor anticipation in persons with ASD. However, this slower reaction time could also be indicative of slower cognitive processing, attention atypicalities, or motor difficulties in this population. Indeed, in addition to motor difficulties, persons with ASD are commonly reported to have slower processing speeds on standardized intelligence measures (Calhoun & Mayes, 2005; Mayes & Calhoun, 2008) and to have delayed orientation of attention to stimuli that appears on a screen (i.e., exogenous orientation of attention) (Greenaway & Plaisted, 2005; Renner, Klinger, & Klinger, 2006; Townsend, Courschesne, & Egaas, 1996). These processing-speed and attentional difficulties may affect the ability of persons with ASD to demonstrate typical motor anticipation. For example, Todd and colleagues (2009) found similar reaction times across a group with ASD and a group with typical development when participants were explicitly instructed where to attend

and then quickly make a motor response toward a target. However, when participants were not explicitly instructed where to attend and exogenous orientation of attention was required, participants with ASD had slower reaction times compared to the control group. Therefore, the way in which individuals with ASD attend to and perceive stimuli that appear in front of them may affect their ability to plan and subsequently execute a quick motor response.

Dyspraxia in ASD

Persons with ASD have also been commonly found to display signs of developmental dyspraxia (Dewey, 1991; Minshew, Goldstein & Siegel, 1997; Mostofsky et al, 2006; Rogers, Bennetto, McEvoy, & Pennington., 1996). Dyspraxia refers to a range of difficulties with motor actions that require higher-level motor planning and sequencing, including speech production (e.g., lack of precision and consistency of movement underlying speech), fine motor control (e.g., difficulties with handwriting), and skilled gesturing (e.g., difficulties with brushing teeth or pantomiming tool use). In terms of verbal dyspraxia, childhood apraxia of speech (American Speech-Language-Hearing Association, 2007) has been hypothesized to contribute to the language delays and impairments that are fundamental to an autism diagnosis (Shriberg, 2010). Nevertheless, recent evidence suggests that verbal children with ASD did not demonstrate the typical features of verbal dyspraxia (Shriberg, Paul, Black, & van Santen, 2011), suggesting that speech-related dyspraxia may not be as common in verbal children with ASD as previously thought.

Even though verbal dyspraxia may not be a fundamental impairment in children with ASD, there is evidence that children with ASD do demonstrate high levels of gestural dyspraxia during limb movements. For example, Dziuk and colleagues (2007) found that children with ASD performed more poorly on gestural praxis exams than children with typical development,

even after accounting for differences in basic motor skill (i.e., overall time to complete repeating limb movements). Therefore, difficulties with skilled gesturing in persons with ASD were present above and beyond more basic motor impairment. Similarly, two additional studies found more praxis impairments in children with ASD compared to children with typical development when asked to imitate a skilled gesture and asked to demonstrate a skilled gesture (Dowell, Mahone, & Mostofsky, 2009; Mostofsky et al., 2006). These results suggest that praxis impairments in skilled gesturing go above and beyond basic impairments in imitation in children with ASD. Furthermore, the degree of gestural dyspraxia has been found to be positively correlated with ASD symptomatology, including repetitive behaviors, restricted interests, social reciprocity impairments, and language impairments in persons with ASD (Dowell et al., 2009; Dziuk et al., 2007). These results suggest that gestural dyspraxia is not only prevalent in children with ASD but is also associated with the core symptom domains of ASD. Similarly, Dewey, Cantell, and Crawford (2007) examined dyspraxia in children with ASD, children with attention deficit/hyperactivity disorder, and children with developmental coordination disorder. Even though basic motor impairments were present in all three of these diagnostic groups, gestural dyspraxia was only impaired in the children with ASD. This result further indicates that dyspraxia may be a type of motor impairment that is prevalent in individuals with ASD and also central to an ASD diagnosis.

Although there is substantial evidence that dyspraxia is a type of motor impairment that is specifically related to ASD symptomatology in childhood, it is unclear whether or not symptoms of dyspraxia persist into adulthood. After an extensive literature search, it appears that all published studies that have examined dyspraxia in ASD have been performed in children. Therefore, it is possible that dyspraxia has not been explored in adults with ASD, or explorations

of dyspraxia in adulthood have gone unpublished due to null findings. Clinical reports provide anecdotal evidence that skilled motor acts such as handwriting or bicycle riding may remain challenging in adolescents and adults with ASD. However, compensatory mechanisms are utilized that allow adolescents and adults with ASD to overcome the limitations of dyspraxia (e.g., taking notes on a laptop rather than writing notes by hand). Future research should examine whether dyspraxia is present in individuals with ASD through adolescence and into adulthood and also whether dyspraxia continues to relate to ASD communication, social, and repetitive behavior symptoms. Taken as a whole, there is strong evidence in the motor literature for gestural dyspraxia in children with ASD, but in adolescents and adults with ASD, it is unclear whether dyspraxia persists.

Postural Control in ASD

Postural control and balance allow human beings to control and maintain symmetry in body movements in order to physically navigate a spatial environment. Successful postural control and balance are thought to require an integration of vestibular (inner ear), somatosensory (foot pressure), and visual input. If one of these inputs is impaired or disrupted, staying upright and completing motor tasks can become much more difficult. Many standardized motor assessments contain at least one measure of balance (e.g., Bruininks-Oseretsky Test of Motor Proficiency, Physical and Neurological Assessment of Subtle Signs, etc.), and studies that have used these assessments have typically found balance impairments in persons with ASD (e.g., Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Green et al., 2002, 2009; Jansiewicz et al., 2006). Additionally, studies that use pressure-sensing foot plates to monitor body sway have found that when children with ASD simply stand, they demonstrate more motor sway with eyes open (Kohen-Raz, Volkmar, & Cohen, 1992) and with eyes closed (Molloy, Dietrich, & Bhattacharya,

2003). Additionally, in a study examining sway in persons ages five to 52, they found more sway in persons with ASD, especially when somatosensory input was disrupted by putting a thick pad on the board (Minshew, Sung, Jones, & Furman, 2004). Interestingly, in non-balance motor tasks such as guiding arm movements through a maze, individuals with ASD have also been shown to have somatosensory (proprioceptive) overreliance, which was found to correlate significantly with the severity of social and imitation impairments (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009). This result suggests that balance and other types of motor function in ASD may be overly dependent on somatosensory cues.

Similarly, a study that examined the length of time that a person can stand on one leg with eyes opened or eyes closed found that persons with Asperger's Syndrome performed similarly to individuals with typical development in the eyes-opened condition but significantly more poorly in the eyes-closed condition (Weimer, Schatz, Lincoln, Ballantyne, & Trauner, 2001). Taken together, these results suggest that persons with ASD may have less steady balance compared to persons with typical development, and they may become even more unbalanced when visual or somatosensory inputs are disrupted. These results may help explain the increased variability in stride length and upper body postural control during gait analyses that have been reported in individuals with ASD (e.g., Rinehart et al., 2006b). Additionally, a recent meta-analysis looked across 51 studies of motor atypicalities in ASD and found evidence for diagnostic differences in movement preparation, upper extremity motor function, and balance (Fournier, Hass, Naik, Lodha, & Caraugh, 2010). The effect sizes derived from this meta-analysis suggested that the largest diagnostic group differences occurred in the gross motor measures of postural control and balance. Therefore, decreased balanced may be a key feature of

ASD that should be further examined in future research that assesses motor atypicalities in this population.

Motor Impairments and ASD Symptomatology

Motor difficulties appear to be one of the earliest and most accurate predictors of a diagnosis of ASD. Using retrospective home videos, research has found that infants later diagnosed with ASD demonstrated motor disturbances in mouth positioning, atypical posturing (Baranek, 1999), and delayed acquisition of motor milestones compared to infants with typical development (Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998). Similarly, Sutera and colleagues (2007) found that delayed motor skills at age two was one of the most distinguishing factors in identifying children who continued to meet criteria for an ASD diagnosis at four years of age, and Iverson and Wozniak (2007) found that infant siblings of children with autism were later in meeting developmental motor milestones and demonstrated evidence of increased postural instability. Therefore, motor symptoms appear to be related to ASD diagnosis and may also relate to the broader autism phenotype.

Motor skills may also be able to predict later symptom severity of individuals with ASD. For example, Gernsbacher, Sauer, Geye, Schweigert, and Goldsmith (2008) retrospectively examined the oral and manual motor abilities of infants and toddlers with ASD compared to infants and toddlers with typical development. They found that children with ASD often fail to meet the age-related motor milestones. Furthermore, the oral and manual motor abilities of infants predicted their later speech fluency in middle childhood and teenage years and also predicted minimally fluent, moderately fluent, and highly fluent speech subgroups within the ASD group during the teenage years (as indicated through parent report and speech pathologist's report). These results suggest that motor impairments are commonly seen early in life in persons

with ASD and are also related to later ASD symptom severity. Interestingly, there is little research examining why motor impairments are related to the repetitive behavior, social, and language symptom domains in ASD. In this dissertation, I hypothesize that an impairment in motor resonance might partly underlie the motor impairments in ASD and might explain the relation between motor ability and the core symptomatology of ASD.

Motor Resonance

Motor resonance is the automatic experience of low-level nerve excitation in efferent motor pathways during the observation of movement in the environment. This low-level motor activation is thought to facilitate future movements by preparing efferent motor pathways to fire. Motor resonance has been shown to be elicited by human movement (Biermann-Ruben et al., 2008), nonhuman movement (Biermann-Ruben et al., Zwaan & Taylor, 2006), and implied movement in sentences (Buccino et al., 2005; Glenberg & Kaschak, 2002; Taylor & Zwaan, 2008; Zwaan & Taylor, 2006). Specifically, when using a rotating dial to indicate the color of a spinning cross on the computer screen, individuals with typical development were faster to turn the dial in the direction of the rotation of the cross (clockwise or counterclockwise) than in the opposite direction. Similarly, when people read sentences that suggest an action (e.g., "Bob unscrewed the lightbulb"), they were faster at turning the dial in the direction of the suggested rotation (e.g., in the counterclockwise direction) (Zwaan & Taylor, 2006). These results demonstrate that motor resonance can occur in response to both human and nonhuman movement in the environment.

Motor resonance appears to facilitate language development, the understanding of other's emotions, and empathic reactivity, all of which have been found to be impaired in persons with ASD. The motor theory of speech perception (Liberman & Mattingly, 1985) suggests that motor

resonance that occurs after seeing others speak underlies speech perception and later speech production. As mentioned previously, early oral and manual motor ability has been found to predict later language outcomes in persons with ASD (Gernsbacher et al., 2008). Thus, an impairment in motor resonance functioning could theoretically lead to communication impairments in persons with ASD.

In terms of social development, motor resonance appears to lead to automatic social mirroring or the *chameleon effect*, in which one automatically and unintentionally imitates another person's prosody, gestures, syntactic structures, and body postures during social engagement (Chartrand & Bargh,1999; Iacoboni, 2007; Niedenthal, Barsalou, Winkielman, Ric, & Krauth-Gruber, 2005). Automatic social mirroring has been shown to lead to increased liking between two individuals (Chartrand & Bargh, 1999). Furthermore, Meltzoff and Moore (1989) demonstrated that automatic social mirroring of tongue protrusion and mouth opening occurs in newborns and most likely provides the newborn with a "like me" framework when watching the actions of others (Meltzoff, 2007). This “like me” framework is thought to set the foundation for understanding the intentions of others (i.e., theory of mind development). These findings suggest that an impairment in motor resonance might also be related to the social and theory-of-mind impairments commonly reported in persons with ASD.

Motor resonance has also been found to be related to the understanding of emotion in others and the experience of empathy. For example, Avenanti, Bueti, Galati, and Aglioti (2005) asked participants with typical development to watch videos of body parts being pricked by a needle and subsequently measured low-level muscle activation in the body parts of the participants that corresponded to the videos. They found that when transcranial magnetic stimulation (TMS) inhibited activation in the primary motor cortex (a motor resonance region),

the participants experienced decreased motor resonance and decreased empathic ratings of the pain experienced by the person in the video. This finding suggests that the motor resonance system may facilitate empathic reactions to another's pain. Similarly, Adolphs, Damasio, Tranel, Cooper, and Damasio (2000) found that persons with damage to the primary and secondary motor cortices were impaired in their ability to identify the type and intensity of emotional expressions. These results suggest that motor resonance may be central to the understanding of the emotions of others.

Neural components of motor resonance. Neurologically, motor resonance is thought to be due to activation in both the primary motor cortex and the mirror neuron system (MNS; Borroni, Montagna, Cerri, & Baldissera, 2008). The MNS is a neural system first discovered in nonhuman primates that consists of neurons that fire not only when a monkey performs an action but also when the monkey observes another performing an action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogasi, 1996). In humans the MNS is thought to be located across the inferior frontal gyrus (IFG) and the inferior parietal lobule (IPL) (with support from areas such as the superior temporal sulcus [STS]) (Iacoboni et al., 1999; Decety, Chaminade, Grèzes, & Meltzoff, 2002). Recent research suggests that controlled imitation and automatic imitation (i.e., motor resonance) may engage separate pathways between the different regions of the MNS. Specifically, Grafton and Hamilton's (2007) and Hamilton's (2008) EP-M Model suggests that controlled imitation engages an emulation pathway that consists of connections between the STS and IPL that code for the goals of the action and subsequent connections between the IPL and IFG that code for action planning. However, automatic imitation engages a mimicry pathway, by which there is a direct connection between the STS and IFG that bypasses the IPL, thus allowing for the automatic translation of a visuomotor perception

into a motor action. Consequently, motor resonance would most likely engage the mimicry pathway, which would allow for visual motion perception in the STS to be directly coded into a motor script in the IFG.

Studies have found structural and functional abnormalities in the MNS in persons with ASD (e.g., Dapretto et al., 2006; Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2006; Oberman et al., 2005; Williams et al., 2006), which could explain impairments in theory of mind, imitation, and social reciprocity (for review see Oberman and Ramachandran [2007]). Much of the evidence comes from EEG studies, in which mu-wave attenuation (attenuation in the eight to 13 Hz band) during action and observation of action is thought to be evidence of MNS activity. In these EEG studies, persons with ASD did not exhibit as much mu-wave attenuation compared to typically developing persons during the execution of hand movements (Oberman et al., 2005) or during the observation of hand movements (Bernier, Dawson, Webb, & Murias, 2007). Furthermore, Bernier et al. found that the lack of mu-wave attenuation was correlated with imitation impairments in the ASD group. Structural abnormalities of the MNS have also been found in persons with ASD. For example, in a recent study, increased grey matter thinning in MNS regions in persons with ASD was related to increased problems with social reciprocity and communication (Hadjikhani et al., 2006).

One hypothesis regarding the MNS in persons with ASD is that the impairment may not be localized in the MNS areas (IFG or IPL/STS), but the malfunctioning could be a result of structural or functional underconnectivity between different areas of the MNS or between areas of the MNS and other brain areas (Kana, Wadsworth, & Travers, 2010; Williams et al., 2006). Indeed, the functional connectivity between the posterior brain regions and the frontal lobe have been found to be weaker in persons with ASD (Just, Cherkassky, Keller, & Minshew, 2004;

Kana, Keller, Cherkassky, Minshew, & Just, 2006), which suggests that the connections between the IPL/STS and the IFG may be weaker in this population. Therefore, if motor resonance impairments were to be found in persons with ASD, this may be due to underconnectivity within the MNS.

Motor resonance in persons with ASD. Several studies have examined motor resonance in persons with ASD through paradigms that have assessed physical motor resonance and also emotional contagion. Although earlier studies found impairments in motor resonance in persons with ASD, more recent findings have been mixed. However, of the studies that have examined emotional contagion in young children, all have found impairments. Specifically, Dawson, Meltzoff, Osterling, Rinaldi, and Brown (1998) found that infants by the age of 12 months were less likely to reciprocate the smiling of their caregivers. Similarly, preschoolers with ASD have been shown to be less likely to match the emotion of an experimenter in tasks where the experimenter opens a box and either demonstrates a happy or fearful face (Scambler, Hepburn, Rutherford, Wehner, & Rogers, 2007) or in tasks where the experimenter injures herself (Bacon, Fein, Morris, Waterhouse, and Allen, 1998).

In physical tasks of motor resonance in children and adults with ASD, individuals with ASD have demonstrated less yawn contagion in response to videos of others yawning (Senju et al., 2007) and also in response to people yawning in the room (Helt, Eigsti, Snyder, & Fein, 2010). These results suggest that persons with ASD may not exhibit automatic yawn contagion, which is thought to be a type of motor resonance. Of note is that the study by Helt and colleagues found that those with ASD who had fewer ASD symptoms (the PDD-NOS group) were more susceptible to yawn contagion suggesting that less severe ASD symptoms may be related to increased motor resonance.

Several studies have examined automatic facial responses while passively viewing emotional faces or situations. Most have demonstrated decreased motor resonance in persons with ASD. For example, McIntosh, Reichmann-Decker, Winkielman, and Wilbarger (2006) found that adults with ASD were able to voluntarily mimic pictures of faces as well as participants with typical development. However, when simply shown pictures of faces, adults with ASD did not show rapid automatic face mimicry (measured by electromyography [EMG]), whereas the participants with typical development did. Similarly, Stel, van den Heuvel, and Smeets (2008) found that children and adolescents with ASD were able to imitate a man in a video happily describing his adventures at an amusement park as well as the participants with typical development. However, when passively watching the video, participants with ASD demonstrated decreased spontaneous facial mimicry compared to participants with typical development, even though they spent the same amount of time looking toward the screen. Finally, Beall, Moody, McIntosh, Hepburn, and Reed (2008) found that children with ASD did not show the same degree of rapid automatic face mimicry in response to pictures of emotional faces as children with typical development. However, in this group, they found a significant correlation with age, such that older ASD participants showed more facial motor resonance than younger ASD participants. These results suggest that voluntary imitation may be intact in individuals with ASD. However, automatic imitation based on motor resonance may be decreased in persons with ASD.

Similar passive viewing studies have been conducted using non-facial mimicry. Minio-Paluello, Baron-Cohen, Avenanti, Walsh, and Aglioti (2008) examined motor-evoked potentials in persons with ASD during the observation of another's pain. They found that the participants with ASD exhibited less motor-evoked potentials compared to participants with typical

development, indicating that the persons with ASD lacked an automatic motor representation of the pain they were observing in another. The authors suggested that this lack of a response may be due to difficulties with empathy in ASD, as decreased empathy in ASD has been commonly observed (Baron-Cohen & Wheelwright, 2004; Lombardo, Barnes, Wheelwright, & Baron-Cohen; 2007). The results of this study suggest that non-facial mimicry may also be impaired in persons with ASD while passively viewing social stimuli.

Nevertheless, when persons with ASD are asked to engage their attention to stimuli they are viewing, recent studies have shown that motor resonance may be intact. For example, Magnée, de Gelder, van Engeland, and Kemner (2007) showed pictures of emotional facial expressions which were either paired or not paired with audio of voices to adults with ASD while measuring the degree of facial mimicry through EMG. The participants were asked to engage the stimuli by judging the gender of each picture. The results demonstrated that the ASD group showed intact audiovisual motor resonance and actually showed increased motor resonance in response to the happy and fearful faces compared to the group with typical development. Similarly, in a behavioral motor resonance study, Press, Richardson, and Bird (2010) had participants view pictures of emotional faces and had participants engage the stimuli by making a specified facial action each time they saw a stimulus. Press and colleagues then measured how quickly the participants were able to make the specified facial action when it was either congruent (i.e., lowering eyebrows when the persons in the picture has lowered eyebrows) or incongruent with the expression they were viewing (i.e., lowering eyebrows when the person in the picture has raised eyebrows). The results indicated that both the participants with ASD and participants with typical development demonstrated faster congruent than incongruent facial actions. In an EMG study by Oberman, Winkielman, and Ramachandran (2009), children with

ASD saw pictures of emotional faces and had to classify which emotion was being expressed. During this classification process, the degree of facial mimicry in the participants was measured. The results indicated intact facial mimicry in the participants with ASD. However, this facial mimicry appeared to be temporally delayed, such that it occurred approximately 160 ms later across all of the emotions. Wilbarger, McIntosh, and Winkielman (2009) also showed that when given more time (two seconds) to view affective imagery, participants with ASD demonstrated intact mimicry in facial responses. This result suggests intact but delayed motor resonance in participants with ASD when they are engaging the stimuli.

In a behavioral motor resonance task using non-facial imagery, Bird, Leighton, Press, and Heyes (2007) required participants to do a pre-specified hand action whenever they observed a stimulus (i.e., picture of hand-opening or hand-closing). Both groups showed congruent-incongruent reaction time differences, and there was actually a trend for the ASD group to show even greater motor resonance in response to the hands. Finally, in another study with adults with ASD, Gowen, Stanley, and Miall (2008) required participants to do different arm actions while watching arm actions being performed by another person in front of them. The arm actions were either congruent or incongruent, and the study found that both groups had more variance when the action was incongruent compared to congruent. This result once again suggests intact motor resonance in persons with ASD when they are required to engage the stimuli.

Taken as a whole, these motor resonance studies provide evidence that motor resonance in response to social stimuli may be impaired in persons with ASD when participants are passively viewing stimuli. However, when participants are actively engaging the stimuli either by categorizing or by making physical actions, individuals with ASD demonstrate intact motor resonance. One possible explanation for this effect is that individuals with ASD are not

attending to social information provided in the stimuli to the same degree as participants with typical development during passive viewing. If participants do not attend to the to-be-mimicked information, then it is unlikely that they will demonstrate robust motor resonance effects. However, by requiring individuals with ASD to respond to aspects of the task either by asking them to categorize or make responses in the presence of stimuli, participants must now attend to the information embedded in the stimuli. Additionally, the fact that some studies have found intact but temporal delays in the motor resonance in persons with ASD also may point to attentional mechanisms. Therefore, the following sections review the relevant literature on basic attention, social attention, and working memory in individuals with ASD.

Attention in Persons with ASD

The term *attention* refers to many different aspects of basic cognitive processing, including simple alertness, automatic attentional capture, and even sustained vigilance. Attention research in persons with ASD has found evidence for atypical input or "spotlight" attention, suggesting that there may be impairments in both the timing, focus, and orienting of attentional capture in persons with ASD (for a review see Travers, Klinger, & Klinger, 2011). For example, tasks using exogenous cues (cues that appear on the screen and capture one's attention) have consistently found impairments in persons with ASD across the lifespan (Greenaway & Plaisted, 2005; Renner, Klinger, & Klinger, 2006; Townsend, Courschesne, & Egaas, 1996). Additionally, this type of exogenous attention has been shown to take more time in persons with ASD than in persons with typical development (Townsend et al., 1999; Townsend, Courschesne et al., 1996; Townsend, Harris et al., 1996). Therefore, the degree to which motion or facial expressions capture the attention of persons with ASD may determine whether or not persons with ASD are able to experience motor resonance effects. If exogenous attention is not being pulled as quickly

to the salient to-be-mimicked features of the stimuli in persons with ASD, then this might explain why persons with ASD show delayed motor resonance (Oberman et al., 2009; Wilbarger et al., 2009). However, this effect would likely occur both in response to social and nonsocial stimuli.

There is also evidence that individuals with ASD may demonstrate less attentional capture to social stimuli and more attentional capture to nonsocial stimuli compared to individuals with typical development. For example, Klin, Jones, Schultz, Volkmar, and Cohen (2002) found that adolescents with ASD spent more time examining objects and mouths and less time examining eyes when watching social scenes from a movie. Similarly, when watching caregiver-child interactions, toddlers with ASD spent less time looking at the actions of others and more time looking at background objects than toddlers with typical development or toddlers with developmental delays (Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011).

Additionally, toddlers with ASD were found to attentionally disengage from faces more quickly than toddlers with developmental delay or typical development, suggesting that they did not experience the same "attention capturing" effect of social stimuli compared to other children (Chawarska, Volkmar, & Klin, 2010). Evidence from these attentional anomalies (and from other studies showing social impairments in persons with ASD) has led some researchers to argue that ASD may be primarily a social disorder, such that all three categories of symptoms may be derived from atypicalities in social perception that occur early in life and may have cascading effects across other cognitive domains throughout development (Schultz, 2005; Klin et al., 2002). In terms of motor resonance, increased attentional capture to nonsocial stimuli compared to social stimuli would likely lead to decreased motor resonance in response to social stimuli but possible increased motor resonance in response to nonsocial stimuli (compared to

individuals with typical development). Indeed, Klin, Jones, Schultz, and Volkmar (2003) suggested that children likely enact whatever is capturing their attention, which may lead individuals with ASD to experience motor resonance in response to object motion more than social action. The fact that social stimuli may automatically capture the attention of individuals with typical development more so than that of individuals with ASD may help explain why passive viewing of social stimuli have found motor resonance impairments in persons with ASD. It is theoretically possible that if these passive viewing studies had used nonsocial stimuli, participants with ASD may have attended to the nonsocial stimuli and demonstrated intact or increased motor resonance. Nevertheless, to date, no study has examined motor resonance in persons with ASD in response to nonsocial stimuli. By examining motor resonance in response to both social and nonsocial stimuli, we may better understand whether motor resonance is a global impairment in persons with ASD or a result of atypical attentional capture.

Although the evidence for atypical social attentional capture in persons with ASD is robust, other researchers argue that social attention in persons with ASD cannot explain all of the symptoms of ASD. For example, O'Connor and Kirk (2008) argued that persons with ASD have demonstrated a tendency to engage in enhanced local processing of both nonsocial and social stimuli (i.e., "enhanced perceptual functioning," Mottron, Dawson, Soulières, Hubert, & Burack, 2006; or "weak central coherence", Frith, 1989; Frith & Happé, 1994; Happé & Frith, 2006), which is difficult to explain from a social-deficit perspective. Indeed, studies examining local versus global processing in persons with ASD have consistently demonstrated better local than configural processing in this population (Shah & Frith, 1993; Wang, Mottron, Peng, Berthiaume, & Dawson, 2007), possibly suggesting a narrower spotlight of attention. In terms of motor resonance, a narrowed spotlight of attention during a passive viewing task may cause participants

with ASD to be overly focused on the details of a stimulus to a degree that does not allow the to-be-mimicked information to be perceived and processed. However, by requiring the participant to either categorize or physically respond to the stimuli may broaden the spotlight of attention to allow for the information underlying motor resonance to be perceived and processed.

Working Memory and Motor Resonance

In addition to spotlight attention, it is possible that the ability to experience motor resonance requires that one can control and sustain attention while concurrently acting and holding in mind a percept of the to-be-mimicked information. Therefore, working memory (Baddeley, 2003) may also be involved in motor resonance effects. Working memory has been extensively examined in persons with ASD. Although the results have been inconsistent (see Travers, Klinger, and Klinger [2011] for a review), there is evidence that maintenance working memory (simply keeping information in mind) is intact in individuals with ASD, whereas manipulation working memory (continuously updating and amending information to keep in mind) is more difficult for individuals with ASD, especially after adolescence (Williams, Goldstein, & Minshew, 2006).

The many dual-processing theories in the field of psychology suggest that most tasks can be accomplished through a give-and-take between controlled and automatic processing, and Feldman Barrett, Tugade, and Engle (2004) suggested that individuals with greater working memory capacity may be more likely to approach tasks using controlled rather than automatic processes. Specifically, Feldman Barrett and colleagues argued that if one has greater working memory capacity, one then has more "bandwidth" in order to cognitively engage information in a controlled and effortful way. Conversely, if one has less working memory capacity, then one will find it more difficult to engage the information in a controlled way and will likely respond in

a default automatic fashion. Because motor resonance is thought to occur automatically, it is likely that individuals with less working memory capacity may be more likely to automatically respond to a motor resonance task without conscious control, whereas those with greater working memory capacity may take a more effortful approach to a motor resonance task. Thus, we would expect a negative correlation between working memory performance and motor resonance effects. However, to our knowledge, no prior study has examined working memory in conjunction with a motor resonance task in individuals with typical development or individuals with ASD. Diagnostic group differences in manipulation working memory may help explain past inconsistent results in the ASD motor resonance literature by examining working memory differences within the ASD sample in question. Specifically, individuals with ASD who have poorer manipulation working memory may actually demonstrate more automatic motor resonance, whereas individuals with ASD who have greater manipulation working memory may show similar amounts of motor resonance, but these affects may be temporally delayed (as was seen in Oberman et al. [2009] and Wilbarger et al. [2009]). Therefore, within- and between-group differences in working memory may be able to further explain the nature of the inconsistent motor resonance results.

Motor Resonance: Social and Nonsocial Impairment in ASD?

Differences in attentional orienting (especially in terms of attentional capture by social stimuli) and differences in working memory may help explain the inconsistent results of past research examining motor resonance in persons with ASD. Additionally, the brain areas associated with the orienting of attention overlap greatly with the brain areas suggested to comprise the MNS (i.e., IFG: Corbetta & Shulman, 2002; IPL: Singh-Curry & Husain, 2009). Therefore, attention and motor resonance circuits may be heavily intertwined and interactive.

Past research examining motor resonance and mirror neuron function in persons with ASD has only examined motor resonance in response to social stimuli, and under these conditions, diminished motor resonance in persons with ASD may be caused by decreased social attention. Therefore, these studies may be finding attentional anomalies in persons with ASD and not necessarily evidence of impaired automatic imitation (or motor resonance). Thus, in order for us to best understand the nature of both the social and nonsocial symptoms of ASD, it is important to distinguish whether motor resonance difficulties in persons with ASD are present only in response to social stimuli and intact in response to nonsocial stimuli, or present in response to both social and nonsocial stimuli. Therefore, a study that is able to examine these many facets of ASD symptomatology in relation to motor resonance (in both persons with ASD and persons with typical development) may be able to significantly shed light on these aspects of ASD, while also accounting for social and nonsocial attention atypicalities. Furthermore, being able to examine the links between these constellations of symptoms commonly seen in persons with ASD should help us better conceptualize the multi-faceted nature of this disorder.

To this end, the present study measured motor resonance using a behavioral measure that occurs naturally in response to direct social motion (e.g., hand motion), implied social motion (e.g., sentences that describe hand motion), and nonsocial motion (e.g., object motion), while requiring active engagement of the stimuli. In the present study, if persons with ASD were to exhibit less motor resonance than persons with typical development in response to social stimuli (i.e., hands rotating objects or sentences indicating hands rotating object) but similar motor resonance as persons with typical development to nonsocial stimuli (i.e., objects rotating on their own), this would suggest that motor impairments in ASD are primarily social in nature. However, if persons with ASD showed less motor resonance than persons with typical

development across all conditions (i.e., hand, sentence, and object conditions), this would suggest that the motor impairments in ASD are primarily motor-derived and extend beyond the social domain.

Hypotheses

1) I expect that participants with typical development will show robust evidence of motor resonance in all three conditions. However, in line with the previous motor resonance studies in ASD, I believe that participants with ASD will show decreased behavioral motor resonance in at least the social movement (hand moving) condition. If the participants show reduced motor resonance in the hand video condition and in the sentence condition, this will provide evidence that motor resonance problems in ASD may be limited to social stimuli. If we find reduced motor resonance in just the symbolic action condition (the sentence condition), this may suggest decreased motor resonance in response to symbolic portrayals of action in persons with ASD. However, if we find reduced motor resonance across all three of the conditions, this will provide evidence that motor resonance impairments may have a more global basis in persons with ASD.
2) Additionally, I hypothesize that motor resonance in participants with ASD will be significantly and negatively correlated with social reciprocity impairments, communication impairments, the presence of repetitive behaviors/restricted interests, and general motor impairments. However, I hypothesize that motor resonance across all participants will be significantly and positively related to empathy

METHOD

Design

To test these hypotheses, the study used a 2 X 2 X 3 mixed factorial design. There were two diagnostic groups (ASD vs. TD), two different types of trials (congruent vs. incongruent), and three motion conditions (human rotation, object rotation, and sentences). The types of trials (congruent vs. incongruent) and motion conditions (human rotation, object rotation, and sentences) were within-subject manipulations, whereas the diagnostic group (ASD vs. TD) was a between-subject manipulation. The primary dependent variables were reaction time (RT) and accuracy.

Participants

A total of 54 individuals attempted the study. However, for two participants with typical development, there were technical difficulties that did not allow them to complete the battery of tasks, leaving a total of 52 individuals completing this study. All analyses reported include only these participants who completed the entire battery of tasks.

Participants included 26 adolescents and adults with ASD (age range: 16 years 8 months to 28 years 10 months of age; two females; two left-handed individuals) and 26 participants with typical development (age range: 18 years 2 months to 30 years 10 months; two females; one left-handed individual). All participants were required to have an IQ composite score of at least 80 on the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Every individual in the study met this criterion.

Groups were matched on chronological age, gender, verbal IQ, performance IQ, and full scale IQ on the WASI. Table 1 contains means and standard deviations for the age and intellectual functioning variables that defined the participant groups. Independent sample t-tests revealed that the ASD and typical developing groups were well-matched on age, $t(50) = -0.51$, $p = .61$, WASI verbal IQ scores, $t(50) = -0.22$, $p = .82$, performance IQ scores, $t(50) = 0.55$, $p = .58$, and full scale IQ, $t(50) = 0.38$, $p = .71$.

Table 1

Means and Standard Deviations (SD) of Demographic and ASD Symptomatology Measures in Both the Group with ASD and the Group with Typical Development (TD)

	ASD		**TD**		
	Mean	SD	Mean	SD	*p*-value
Age	21.8	3.2	21.3	3.8	0.61
Verbal IQ	109.1	15.0	108.4	9.1	0.82
Performance IQ	108.2	14.7	110.4	13.0	0.58
FSIQ	109.5	14.0	110.8	10.1	0.71
Self BAPQ Total	3.39	0.48	2.77	0.55	< .001
Parent BAPQ Total (n = 33)	3.54	0.78	2.11	0.45	< .001
EQ	33.5	7.4	43.7	9.7	< .001
SRS Total Raw (n = 21)	74.4	34.0	-	-	-
RBS-R Total Raw (n = 22)	17.6	14.0	-	-	-
ADOS Language	3.3	1.4	-	-	-
ADOS Social Reciprocity	7.0	2.6	-	-	-
ADOS Repetitive Behavior	1.5	1.2	-	-	-

The participants with ASD were recruited from the University of Alabama Autism Spectrum Disorder Research Clinic or through flyers distributed through local service providers. All participants with ASD met the diagnostic standards for autism on the Autism Diagnostic Observation Scale-General (ADOS-G; Lord et al., 2000) or the Autism Diagnostic Interview-Revised [ADI-R; Lord, Rutter, & LeCouteur, 1994] and had received a previous clinical

diagnosis of an ASD. Twenty participants had completed ADOS-G Module 4, and five participants had completed ADOS-G Module 3. All participants met Autism Spectrum criteria on the ADOS-G. Another participant with ASD was unable to complete an ADOS-G Module 3 or 4 due to relocation, but he had a confirmed diagnosis of ASD through the ADI-R and a previous clinical assessment. Because Module 3 and 4 scores should not be combined, means and standard deviations for participants who received an ADOS-G Module 4 (but not an ADOS-G Module 3) are presented in Table 1. Additionally, as can also be seen in Table 1, current ASD symptoms were also assessed using the Social Responsiveness Scale (SRS; Constantino, 2002) and the Repetitive Behavior Scale- Revised (RBS-R; Bodfish, Symons, Parker, & Lewis, 2000; Lam & Aman, 2007). Of the 26 participants with ASD, 21 of their parents returned a completed SRS, and 22 of their parents returned a completed RBS-R. For the ASD group, the average SRS score was 74.4, which was just below the autism cutoff of 75. However, we did have a wide range of SRS scores within the ASD group from 25 to 139, suggesting that our ASD group (who all met diagnostic criteria on the ADOS-G or ADI-R) had a wide-range of social symptom severity. For the RBS-R, the average total score for the ASD group was 17.6 (range: 2 to 52), which a one-way t-test found to be significantly lower than the average total score of individuals ages 21 and older (31.8) in the standardization study (Lam & Aman, 2007), $t(21) = -4.77$, $p < .001$. Therefore, even though all participants met ADOS-G or ADI-R criteria for an ASD diagnosis, the participants with ASD in this study may have had significantly less severe repetitive behavior/restricted interest symptomatology and slightly less severe social symptomatology compared to other ASD samples.

Participants with typical development were recruited through the University of Alabama Psychology 101 Subject Pool and advertisements at the university. Participants with typical

development were screened through self-report history background questionnaire that asked if the participant had ever been diagnosed with Autism, Asperger's Disorder, PDD-NOS, a Learning Disability, Mental Retardation, Cerebral Palsy, or Tourette's/Tic Disorder. No participants with typical development reported the presence of any of these neurological disorders. In terms of medication, one participant with typical development was taking ADHD medication at the time of testing. Medication status in the group with ASD was also assessed. At the time of testing, seven participants with ASD were taking antidepressant medication. Additionally, four participants with ASD were taking a stimulant, and two of those four were also taking an antidepressant.

For both the group with ASD and group with typical development, lifetime autism-like symptoms were assessed using a self-report and parent-report of the Broader Autism Phenotype Questionnaire (BAPQ; Hurley, Losh, Parlier, Reznick, & Piven, 2007). As can be seen in Table 1, participants with typical development indicated significantly lower autism-like symptoms (M = 2.77, SD = 0.55) compared to individuals with ASD (M = 3.39, SD = 0.48) on the overall BAPQ scale, $t(50) = -4.32$, $p < .001$, Cohen's $d = -1.20$. The average self-reported total BAPQ scores for the group with ASD was 3.39, which a one-way t-test found to be significantly greater than the BAPQ self-report cutoff of 3.00 (Hurley et al., 2007), $t(25) = 4.08$, $p < .001$. Therefore, as expected, the ASD group appeared to demonstrate significant autism-like symptoms through self-report. However, it should be noted that five of the 26 individuals with ASD scored below the 3.00 cutoff, thus not meeting the broader autism phenotype cutoff. The average self-reported BAPQ scores for the group with typical development was 2.77, which a one-way t-test found to be significantly less than the broader autism phenotype cutoff of 3.0, $t(25) = -2.17$, $p = .04$.

However, nine participants with typical development were above the 3.00 cutoff, thus displaying some signs of the broader autism phenotype.

In terms of parent-report BAPQ, 20 parents returned a completed BAPQ for the participants with ASD, and 13 parents returned a completed BAPQ for the participants with typical development. As can be seen in Table 1, the group with typical development had significantly lower overall BAPQ scores (M = 2.11, SD = 0.45) compared to the group with ASD (M = 3.54, SD = 0.78), $t(31) = -5.94$, $p < .001$, Cohen's $d = -2.25$. The group with ASD had a total parent-report BAPQ score of 3.54, which a one-way t-test found to be only marginally greater than the 3.30 informant-rating cutoff (Hurley et al., 2007), $t(19) = 1.36$, $p = .19$. From parent report, eight of the 20 individuals with ASD did not meet the BAPQ cutoff. The group with typical development had a total parent-report BAPQ score of 2.11, which a one-way t-test found to be significantly lower than the 3.30 informant-rating cutoff, $t(12) = 9.50$, $p < .001$. All of the participants with typical development were below this cutoff from parent report, suggesting that they did not show evidence of having the broader autism phenotype.

Measures

Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The WASI is an abbreviated IQ measure designed for persons six to 89 years of age that takes approximately 30 minutes to administer. The WASI consists of four subtests: vocabulary, similarities, block design, and matrix reasoning. The WASI renders a verbal IQ (vocabulary and similarities subtests), a performance IQ (matrix reasoning and block design subtests), and a full scale IQ. The WASI has demonstrated good reliability (reliability coefficients for adults range from .84 to .98) and validity (WASI full scale IQ scores are highly correlated [r = .92] with Wechsler Adult Intelligence Scale-III scores).

Autism Diagnostic Observation Schedule – Generic (ADOS-G; Lord et al., 2000). The ADOS-G, Modules 3 or 4, (35-40 minutes to administer) are semi-structured play assessments of communication, social interaction and imaginative or symbolic play administered to adolescents and adults who are believed to have ASD. The ADOS-G were administered to all but one individual with ASD to both confirm an ASD diagnosis and to measure current autism symptomatology (i.e., social skills, communication, and repetitive behaviors). Good criterion validity has been demonstrated, with 24 out of 25 clinically diagnosed children with autism also meeting criteria for autism on the Autism Diagnostic Interview-Revised.

The Social Responsiveness Scale (SRS; Constantino, 2002). The SRS is a 65-item parent report measure that examines current (past six months) ASD symptoms across the ASD spectrum. Each item on the scale asks about an aspect of observed reciprocal social behavior and is rated on a scale from "0" (never true) to "3" (almost always true). Higher scores on the SRS indicate greater severity of social impairment. The test has been validated for clinical populations age four to 18 years. The test-retest reliability after three months for the SRS was very good, with a correlation of .88. After 27 months, the test-retest reliability for the SRS was still good with a correlation of .83. Furthermore, Constantino et al. (2003) found that the composite score of the SRS correlated highly (a coefficient of between .65 and .77) with the composite score of the Autism Diagnostic Interview- Revised. Because most participants were older than 18 and the SRS was normed for children from 4 to 18 years of age, raw scores rather than t-scores are reported.

Broader Autism Phenotype Questionnaire (BAPQ; Hurley et al., 2007). The BAPQ is a 36-item questionnaire developed in a typically developing population that assesses the domains associated with broader (i.e., subclinical) ASD-like symptoms: aloof personality

(social), pragmatic language difficulties (communication), and rigid personality (repetitive behaviors). To date, research has used the BAPQ to primarily assess autism-like symptoms in parents of individuals with ASD (e.g., Wilson, Freeman, Brock, Burton, & Palermo, 2010). However, the present study used parent- and self-report of the BAPQ to assess autism-like symptoms in all participants. Therefore, both self-report and caregiver-report versions were administered to all participants (participants with ASD and participants with typical development) in order to assess current levels of ASD and ASD-like symptomatology.

The BAPQ has been shown to have good inter-item and inter-scale consistency, as well as strong sensitivity (being able to differentiate parents of persons with ASD who have broader autism features compared to parents of persons with typical development who do not have broader autism features) (Hurley et al., 2007). However, in the present study, correlational analyses between self- and parent-report BAPQ indicated that the total raw scores were significantly correlated across both diagnostic groups, $r(32) = +.39$, $p = .03$ but not separately in each diagnostic group (TD, $r[12] = -.14$, $p = .65$; ASD, $r[19] = +.27$, $p = .25$). I also conducted an intraclass correlation coefficient (ICC), which is similar to a Pearson's *r* correlation but centers the scale on a pooled mean and standard deviation (rather than on each scale's own mean and standard deviation) (Koch, 1982). This reliability analysis across all participants indicated that the self-report BAPQ and the parent-report BAPQ had a significant ICC of .30, $p = .03$. However, good interrater reliability is typically considered when obtaining an ICC of .75 or above (Portney & Watkins, 2000), which means that in the present study, I did not find good interrater reliability between the self reports and the parent reports of autism-like symptoms on the BAPQ.

Empathy Quotient (EQ; Baron-Cohen & Wheelwright, 2004). The EQ is a 60 item, self-report questionnaire that measures empathy (how easily an individual can pick up on another's feelings and to what extent that individual is affected by another's feelings). The EQ has previously used in both ASD and typically developing populations. The EQ demonstrated good criterion validity, with a Cronbach's alpha of 0.92, and a test-retest reliability or $r = +.97$ ($p < .001$).

Repetitive Behavior Scale – Revised (RBS-R; Bodfish et al., 2000; Lam & Aman, 2007). The RBS-R is a 43-item caregiver questionnaire (10 minutes to administer) that assesses the presence and severity of repetitive behaviors in the previous month. The RBS-R has been found to be a reliable measure of multiple types of repetitive behaviors and restricted interests for individuals ages 3 to 48 years old (Lam & Aman, 2007). Caregivers of participants with ASD completed the RBS-R. Internal consistency for all of the subscales was high (Crohnbach's alphas of 0.78 to 0.91, $M = 0.83$).

Balance Board Motor Task. In this task, participants stood on a Nintendo ® Wii balance board that collected data via Bluetooth connectivity on a nearby laptop. Prior to the motor tasks, the balance board was calibrated for each participant (by having them hop on and off the board), and the laptop was able to record the participant's center of balance (left versus right foot) and stability over time with a data point for every 2.5 ms. Participants were asked to complete six tasks for 45 seconds each or until they lost balance: 1) stand on two feet with eyes open, 2) stand on two feet with eyes closed, 3) stand on right foot with eyes open, 4) stand on left foot with eyes open, 5) stand on right foot with eyes closed, and 6) stand on left foot with eyes closed. In addition to balance data collected by the Wii board, the duration of each motor task was recorded by the experimenter. The Wii balance board has been found to be a reliable and

valid tool to measure balance in research and clinical settings (Clark, Bryant, Pua, McCrory, Bennell, & Hunt, 2010).

Working Memory Computer Task. The working memory task was programmed to assess working memory via computer administration using forward digit span, backward digit span, and sequencing digit span. The participant began each trial with a mouse click on a laptop, and then the participant heard numbers spoken one-at-a-time at one-second intervals (i.e., 1-4-6). A box then appeared on the computer screen, and participants typed the numbers they heard into the box. In the forward span section, participants typed the numbers into the box in the same order they heard the numbers. In the backward span section, the participants typed the numbers into the box in the reverse order they heard the numbers, and in the sequencing span section, the participants typed the numbers into the box from the lowest to the highest number they had heard. Each of the three sections began with a practice trial. Each section was structured so that it began with shorter (3-digit) number strings and incrementally increased to longer (8-digit number strings). Operation span (i.e., the length of digit span where at least one of the two trials was correct) was recorded for each type of digit span.

Sentence Questionnaire. A paper and pencil sentence questionnaire was administered to participants prior to the motor resonance computer game in order to determine the direction associations (left or right) participants had with certain actions (e.g., unscrewing a light bulb). For each of the 24 rotation actions that were presented in the sentence condition of the motor resonance task, participants indicated whether the action required them to rotate the object to the left or to the right. Additionally, participants were instructed to estimate approximately how often they did each action per month. This measure assessed the familiarity that the participant had with the action and the way the participant might perform the action.

Demographic Form. A self-report demographic form was completed by participants. Demographic data, including participant's sex, race, diagnoses, and family income were collected to obtain information about sample characteristics. The date of birth of the participant was collected in order to calculate appropriate standard scores on the WASI.

Apparatus

Behavioral motor resonance data were collected on a *Windows*-based laptop computer. The laptop computer was connected to a modified joystick connected via a USB port and connected to a 15-inch external monitor via 15-pin video connector. The external monitor faced the participant with the rotation joystick directly in front of the participant. The laptop was behind the monitor and facing away from the participant. The joystick was structurally modified to only allow 30° rotations either to the left or to the right, and the joystick automatically sprung back to the center position after being twisted. A ball was placed on top of the joystick in order to simulate rotating a round object to the left or right. Participants were instructed to place their dominant hand on top of the ball to twist the joystick to the left or right.

Procedure

All participants were run individually in the presence of two experimenters. First, participants were given an informed assent form or consent form (depending on age) with a brief overview of the experiment. If they were under 19 years of age, their parent was given the consent form. Participants completed the tasks in a fixed order: 1) Demographic form, 2) Sentence questionnaire, 3) Computer motor resonance task, 4) EQ, 5) ADOS-G (if participant with ASD did not have a Module 3 or Module 4 on file) 6) Working memory task, 7) WASI, 8) BAPQ, and 9) Wii balance board game. After completion of these tasks, questionnaires (SRS,

RBS-R, & BAPQ) completed by the participant's parent were retrieved and/or mailed to the parent with a self-addressed, stamped envelope for return of the completed measures.

Motor resonance task. In the motor resonance task, participants completed the task on a laptop computer connected to a rotation joystick and an external monitor. The external monitor faced the participant, with the joystick box directly in front of the participant. All participants were instructed to use their dominant hand to twist the rotation knob, while resting their elbow on the table. Participants were informed that they would see blue and yellow squares or words, and their job was to twist the knob to indicate if the square/word is yellow or blue. Participants were told to turn the rotation dial one way if the square/word is blue and the other way if the square/word is yellow. The turn direction of the rotation dial turn was counterbalanced across participants (e.g., half of the participants turned the rotation dial left for blue and right for yellow, and the other half turned the rotation dial right for blue and left for yellow).

Before the official task, the participants completed 26 sentence direction trials, where they read a sentence and twisted the joystick in the same direction as the action of the sentence (to measure the participant's associations with whether the action in the sentence requires a clockwise or counterclockwise rotation). Following the sentence direction trials, the participants completed 12 practice trials, where they practiced indicating whether a word or square that appeared on a blank screen was blue or yellow. From this point, participants completed both sentence and video motor resonance trials. However, in order to counterbalance the order of the stimuli, one half of the participants completed the video blocks before the sentence blocks, whereas the other half of the participants completed the sentence blocks before the video blocks. The video blocks of trials began with four practice trials (two human motion and two object motion trials), in which the participants practiced indicating the color of the square during the

videos. After the practice, participants were presented with five blocks of 32 video trials each (160 trials total). Each block consisted of randomly presented trials from the two video conditions (human motion and object motion). Each trial in the human and object trial consisted of a three-second video of a rotating hand (human condition) or an object (nonhuman condition) (See Table 2 for a list of the human videos and object videos). After approximately 1000 milliseconds of the video, a blue or yellow square appeared near the center of the screen, and the participant responded to the color of the square via the rotation joystick. As soon as the participant answered, a blank screen appeared for 500 ms, and then the next video started.

Table 2

List of Human Videos and Object Videos

Human Videos	Object Videos
Spinning a pompom	The *Wheel of Fortune* wheel spinning
Using a screwdriver	A sprinkler gear spinning
Spinning a twister wheel	An electric mixer spinning
Opening/closing a peanut butter jar	A lawn pinwheel spinning
Opening/closing a coke bottle	A roulette wheel spinning
Turning on/off a bath faucet	A car tire spinning
Opening/closing a car gas tank	A physic's torus spinning
Fast forwarding/rewinding an ipod	A waterwheel spinning
Manually recharging a lantern battery	A windmill on a hill spinning
Stirring with a whisk	A close-up of a different windmill spinning
Stirring with a wooden spoon	A bike wheel spinning
Screwing in/taking out a light bulb	A mechanical gear turning

The sentence blocks of trials began with four practice trials that were then followed by five blocks of 16 trials each (80 sentence trials in all). In each of these trials, participants were instructed to read visually presented sentences written in black lettering. Each sentence was displayed for four seconds in the middle of the screen. After the four seconds, one of the words in the sentence turned yellow or blue, and the participant responded to the color via the rotation

joystick. Each sentence contained action phrases that implied either a clockwise or counterclockwise rotation (See Table 3 for a list of the sentence stimuli). To encourage the semantic processing of the sentences, participants were told to pay close attention to the content of the sentences, as they would be asked to complete a short memory test at the end of the sentence blocks of trials. The memory test consisted of nine items, in which a sentence was presented, and the participant had to indicate via the rotation joystick whether they had seen that sentence in the previous block of trials (e.g., turn the dial right if you previously saw it, and turn the dial left if you did not previously see it). Six of the nine sentences had been seen previously, whereas the other three sentences were novel and had not been seen during the task.

Table 3

List of Clockwise and Counterclockwise Sentences in Sentence Condition

Clockwise Sentences	Counterclockwise Sentences
Susan turned right at the intersection.	Mark turned left at the intersection.
Dennis turned on the lamp.	Vincent dimmed the lights.
Emilia tightened the top of the water bottle.	Troy twisted open the water bottle.
George cranked up the radio volume.	Eric turned down the radio volume.
Jane turned the ignition to start the car.	Peter turned off the car engine.
Jenny screwed in the light bulb.	Isabella unscrewed the light bulb.
Jerry turned the deadbolt to unlock the door.	Carla turned the deadbolt to lock the door.
Chloe twisted closed the mayo jar.	Liza twisted open the pickle jar.
Allen spun the bottle to the right.	Rhonda spun the bottle to the left.
Sara turned the faucet to shut off the water.	Kara turned the faucet to get water.
Larry screwed together the pieces of wood.	Dave unscrewed the screw from the wall.
Gregory turned the padlock to the right	Annette turned the padlock to the left.

Across the entire motor resonance task, there were both congruent and incongruent trials. Incongruent trials were trials where the participant had to rotate the joystick in the opposite direction of the rotation in the videos or the sentences in order to correctly identify the color of

the square or word. Congruent trials were trials where the participant had to rotate the joystick in the same direction as the rotation in the videos or sentences. Reaction time was measured as the time (in ms) it took for the participant to rotate the joystick 30° in the correct direction in response to the color of the word or square. Accuracy was measured as whether or not the participant turned the dial the full 30° in the correct direction. At the end of the session, participants were debriefed about the study, answering any questions they may have. Then participants received $20 in appreciation of their participation.

RESULTS

To address the present dissertation's hypotheses, results included analyses presented in the following order: Diagnostic group differences in motor resonance, diagnostic group differences in postural stability, relation between motor functioning and demographic information, relation between motor functioning and working memory, relation between motor functioning and empathy, and relation between motor functioning and ASD symptom severity.

Motor Resonance Results

Judgment responses (i.e., rotations of the joystick to answer blue or yellow to the stimuli) were recorded for each type of stimulus presented during the motor resonance task with mean reaction time and accuracy calculated for incongruent and congruent trials in the human, object, and sentence conditions. Initial analyses examined participants' performance on the sentence memory test and participants' associations with the directions presented in the sentences.

Sentence memory test. In order to encourage semantic processing of each sentence during the sentence portion of the motor resonance task, participants were given a nine-item, forced choice memory test after the last sentence block. In this memory test, participants with typical development demonstrated an average of 79% accuracy (*SD* = 17%), and participants with ASD demonstrated an average of 82% accuracy (*SD* = 19%). There were no significant between-group differences in performance on the memory test, $t(50) = -0.52$, $p = .61$, Cohen's $d = -0.17$, which suggests that both groups processed the sentences similarly during the motor resonance block. Additionally, to examine if performance on the memory test was at above chance levels, I calculated the number of hits for each participant (i.e., percent of time a

participant indicated previously seeing a sentence that had indeed been previously presented) versus the number of false alarms (i.e., percent of time that a participant indicated previously seeing a sentence that actually had not been previously presented). The group with typical development had an average of 49% hits (*SD* = 16%) and 3% false alarms (*SD* = 5%). A within-subject t-test suggested that the group with typical development had significantly more hits than false alarms, $t(25) = 13.70$, $p < .001$. Similarly, the group with ASD had an average of 53% hits (*SD* = 13%) and 5% false alarms (*SD* = 9%). A within-subject t-test suggested that the group with ASD also had significantly more hits than false alarms, $t(25) = 13.26$, $p < .001$. Therefore, both groups' memory test performance was found to be greater than chance.

Sentence direction analyses. In the sentence direction block of trials, participants indicated whether they associated the action in the sentence with either a clockwise or counterclockwise rotation by rotating the joystick. Across all participants, there was agreement with the preconceived directions of 87% of all sentences (TD: 90%; ASD: 85%). The most commonly disagreed upon sentence directions included sentences dealing with deadbolt locking/unlocking (4%), turning on/off the faucet (3%), and turning on a lamp (1%). I wanted to base congruency on the participant's personal associations with the direction of the sentence. Therefore, for the remainder of the analyses, the participants' associations with the direction of the sentence (and not the experimenter's preconceived direction) determined whether the stimulus was considered congruent of incongruent.

Accuracy motor resonance. Initial statistical analyses examined accuracy for the motor resonance task using a 2 (ASD or TD) X 2 (incongruent or congruent) X 3 (human, object, or sentence condition) mixed factors ANOVA. The types of trials (congruent and incongruent) and the three types of conditions (human, object, and sentence) were within-subject variables,

whereas the diagnostic group (ASD vs. TD) was a between-subject variable. Please see Table 4 for the means and standard deviations for each of these conditions.

Table 4

Mean (Standard Deviation) Accuracy Motor Resonance

	TD			**ASD**		
	Congruent	Incongruent	Accuracy Motor Resonance	Congruent	Incongruent	Accuracy Motor Resonance
Human Videos	96.3%(4.2)	94.5%(4.1)	+1.9%	95.8%(4.2)	95.8%(5.0)	+0.0%
Object Videos	93.5%(3.9)	94.4%(4.0)	-0.8%	94.6%(3.4)	94.6%(3.4)	+0.0%
Sentences	97.2%(2.9)	97.1%(2.8)	+0.1%	95.6%(5.6)	93.1%(9.5)	+2.5%
Overall	95.7%	95.3%	+0.4%	95.3%	94.5%	+0.8%

The ANOVA did not find a significant main effect for diagnosis, $F(1,50) = 0.57$, $p = .45$, $\eta_p^2 = .011$, suggesting that the groups did not perform differently in accuracy across the task. However, I did find a marginally significant main effect for congruency, $F(1,50) = 3.54$, $p = .07$, $\eta_p^2 = .066$. An examination of the means suggested that there was a trend for participants to perform more accurately on the congruent trials than the incongruent trials across conditions. I also found a significant main effect for condition, $F(2,49) = 4.93$, $p = .01$, $\eta_p^2 = .168$. *Post hoc* pairwise comparisons (Sidak adjusted for multiple comparisons) suggested that participants were significantly more accurate when responding to the human trials compared to the object trials, $p = .02$, but there were no differences in accuracy between the human trials and the sentence trials, $p = .99$, or between the object trials and the sentence trials, $p = .19$.

I did not find a significant interaction between diagnosis and congruency, $F(1,50) = 0.51$, $p = .48$, $\eta_p^2 = .010$. Similarly, I did not find a significant interaction between either congruency

and condition, $F(2,49) = 1.89$, $p = .16$, $\eta_p^2 = .072$, or between diagnosis and condition, $F(2,49) = 2.24$, $p = .12$, $\eta_p^2 = .084$. However, there was a significant three-way interaction among diagnosis, congruency, and condition, $F(2,49) = 3.09$, $p < .05$, $\eta_p^2 = .112$. An examination of the means suggested that this three-way interaction was driven by individuals with ASD showing accuracy motor resonance effects in the sentence condition but not in the other conditions, and individuals with typical development showing accuracy motor resonance effects in the human condition but not in the other conditions.

Single-sample t-tests examined whether the motor resonance accuracy (the difference between the accuracy during congruent trials and the accuracy during incongruent trials) was greater than chance (zero) in each of the diagnostic groups. For the human videos, the group with typical development had an average motor resonance accuracy effect of +1.9% (*SD* = 3.8%), which was significantly greater than zero, $t(25) = 2.52$, $p = .02$, Cohen's $d = 0.50$, and the group with ASD had an average motor resonance accuracy effect of zero (*SD* = 3.8%), which was not significantly greater than zero, $t(25) < 0.01$, $p > 0.99$, Cohen's $d < 0.01$. For the object videos, the group with typical development had an average motor resonance accuracy effect of -0.8% (*SD* = 4.1%), which was not significantly greater than zero, $t(25) = -1.06$, $p = .30$, Cohen's $d = -0.20$, and the group with ASD had an average motor resonance accuracy effect of zero (*SD* = 3.0%), $t(25) < 0.01$, $p > .99$, Cohen's $d < 0.01$. In the sentence condition, the group with typical development demonstrated an average motor resonance accuracy effect of +0.1% (*SD* = 3.8%), which was not found to be greater than zero, $t(25) = 0.18$, $p = .86$, Cohen's $d = 0.03$, and the group with ASD demonstrated an average motor resonance accuracy effect of +2.5% (*SD* = 7.0%), which was only found to be marginally greater than zero, $t(25) = 1.79$, $p = .09$, Cohen's $d = 0.36$ (small effect size). These results suggest that even though I found an overall congruency

motor resonance accuracy effect, the only effect that was greater than chance was that by the group with typical development in the human condition.

Reaction time motor resonance. Reaction time was used as the main dependent variable for the motor resonance task, and only reaction times of correct trials were used. Additionally, a paired-samples t-test indicated that trials after incorrect responses were on average 147 ms slower than trials after correct responses, which was a significant difference, $t(51) = 2.03$, $p < .05$. It appeared that after making a mistake participants became overly cautious and slowed their responses. Therefore, I also omitted trials that followed an incorrect response. Prior to the reaction time analyses, reaction times in response to human videos, object videos, and sentences were examined individually to ascertain that they met the assumptions of normality and homogeneity of variance. The reaction times in response to the human and object videos were normally distributed. However, the reaction times in response to the sentence stimuli were positively skewed. To normalize this sentence reaction time data, I used a reciprocal transformation that computed the reciprocal reaction time for each trial (1/reaction time), aggregated it, and then converted the reaction times back into harmonic means (1/reciprocal reaction time). After this reciprocal transformation, the sentence reaction time data met the assumptions of normality.

Even though the data were normally distributed there were still outliers present in the data. To control for the outliers, reaction times that were outside of two standard deviations of each participant's average reaction time during each block (in the human, object, and sentence conditions) were eliminated. In all, 5% of trials were eliminated (6% of human trials, 5% of object trials, and 3% of sentence trials). After the data were trimmed, the reaction times were

aggregated by block, and analyses examined congruency effects across the different types of stimuli.

To analyze possible reaction time motor resonance, a 2 (ASD vs. TD) X 2 (incongruent vs. congruent) X 3 (human vs. object vs. sentence) X 5 (blocks) mixed factorial ANOVA was conducted. The types of trials (congruent and incongruent), the three types of conditions (human, object, and sentence), and blocks were within-subject variables, whereas the diagnostic group (ASD vs. TD) was a between-subject variable. I examined the main effects of diagnosis and type of trial and any interaction between diagnosis and type of trial. The means and standard errors for these analyses are presented in Table 5.

Table 5

Mean (Standard Error of the Mean) Reaction Time Motor Resonance

	TD			**ASD**		
	Congruent	Incongruent	RT Motor Resonance	Congruent	Incongruent	RT Motor Resonance
Human Videos	648(12)	657(14)	+10 ms	695(12)	716(14)	+20 ms
Object Videos	628(14)	632(13)	+4 ms	680(14)	679(13)	-1 ms
Sentences	798(44)	802(46)	+5 ms	785(44)	801(46)	+15 ms
Overall	691(20)	697(21)	+6 ms	720(20)	732(21)	+12 ms

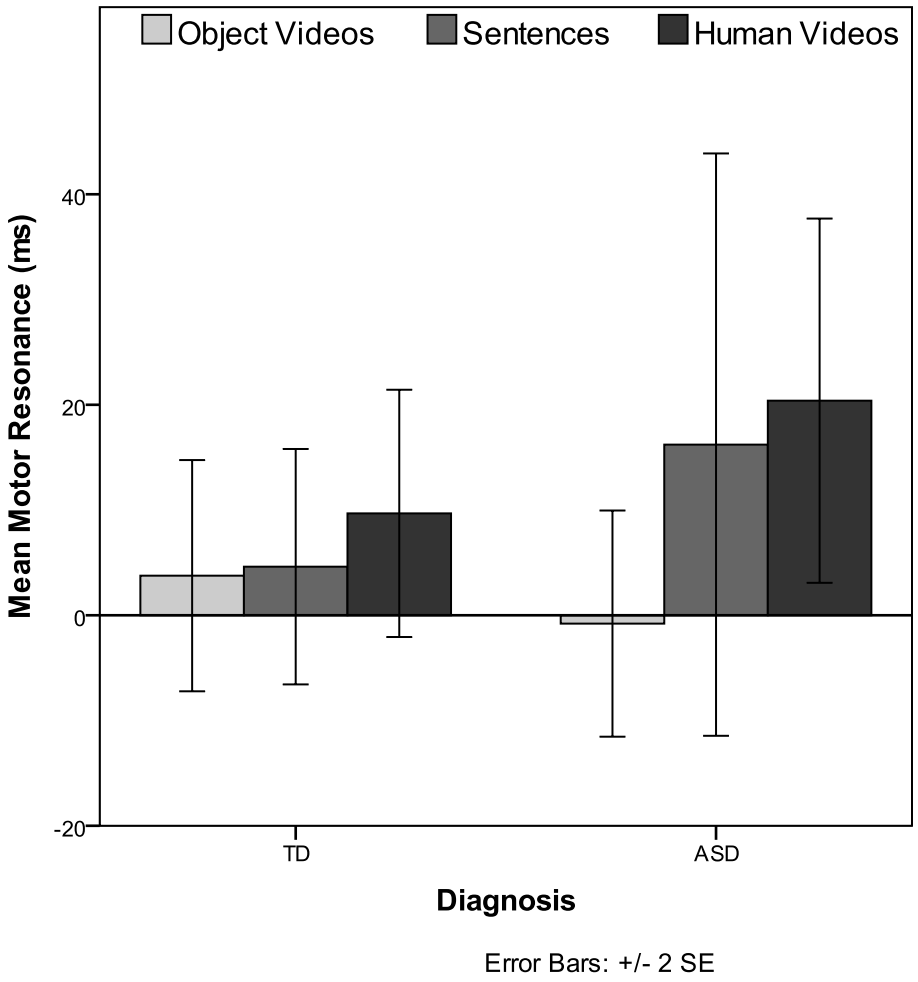
I did not find a significant main effect for diagnosis, $F(1,50) = 1.24$, $p = .27$, $\eta_p^2 = .024$, suggesting that both groups had similar reaction times across the task. However, the ANOVA indicated a significant main effect for congruency, $F(1,50) = 6.56$, $p = .01$, $\eta_p^2 = .116$. An examination of the means suggested that participants had an average reaction time of 706 ms (*SEM* = 14) to congruent trials and 715 ms (*SEM* = 15) to incongruent trials, suggesting that overall participants were faster to respond to congruent trials than to incongruent trials. I also found a main effect for condition, $F(2,49) = 56.19$, $p < .001$, $\eta_p^2 = .696$. *Post hoc* pairwise

comparisons (Sidak adjusted for multiple comparisons) suggested that participants were significantly faster at responding to object trials compared to human trials, $p < .001$, and participants were significantly faster at both object trials and human trials compared to sentence trials (object RT < sentence RT, $p = .001$; human RT < sentence RT, $p < .001$).

There was also a significant main effect for block, $F(4,47) = 5.35$, $p = .001$, $\eta_p^2 = .313$. An examination of the means suggested that participants got faster over the course of the first three blocks but then plateaued. There was not a significant interaction between diagnosis and congruency, $F(1,50) = 0.71$, $p = .40$, $\eta_p^2 = .014$, nor a significant three-way interaction among diagnosis, congruency, and condition, $F(2,49) = 0.73$, $p = .49$, $\eta_p^2 = .029$. Therefore, contrary to my hypotheses, both groups showed similar congruency motor resonance effects across all three conditions (See Figure 1). All other effects were non-significant.

Figure 1

Overall Reaction Time Motor Resonance as a Function of Condition



Follow-up single-sample t-tests were conducted to determine if motor resonance was occurring in each of the conditions for each of the groups. A significantly greater mean reaction time or lower mean accuracy in response to incongruent trials compared to congruent trials was considered as evidence of reaction time motor resonance. Therefore, I calculated a measure of motor resonance by subtracting the mean congruent reaction time for that condition from the mean incongruent reaction time for each condition, and then I used t-tests to determine if these scores were greater than zero.

For the human videos, the group with typical development had an average motor resonance reaction time effect of +10 ms (*SD* = 30 ms), which was not significantly greater than zero, $t(25) = 1.65$, $p = .11$, Cohen's $d = 0.33$ (although a small effect size). For the human videos, the group with ASD had an average motor resonance reaction time effect of 20 ms (*SD* = 44 ms), which was significantly greater than zero, $t(25) = 2.36$, $p = .03$, Cohen's $d = 0.45$. This result suggests that the group with ASD showed significant reaction time motor resonance in response to the human videos, whereas the group with typical development only did so marginally.

For the object videos, the group with typical development had an average reaction time motor resonance effect of 4 ms (*SD* = 28 ms), which was not significantly greater than zero, $t(25) = 0.69$, $p = .50$, Cohen's $d = 0.14$. For the object videos, the group with ASD had an average reaction time motor resonance effect of zero (*SD* = 27 ms), $t(25) = -0.15$, $p = .88$, Cohen's $d < 0.01$. Therefore, neither group appeared to show significant reaction time motor resonance in response to the object videos.

In the sentence condition, the group with typical development demonstrated an average reaction time motor resonance effect of +5 ms (*SD* = 29 ms), which was not found to be greater than zero, $t(25) = 0.83$, $p = .42$, Cohen's $d = 0.17$. The group with ASD demonstrated an average reaction time motor resonance effect of +15 ms (*SD* = 70 ms), which was also not significantly greater than zero, $t(25) = 1.11$, $p = .28$, Cohen's $d = 0.21$.

These results suggest that even though I found an overall congruency motor resonance reaction time effect, the only individual effect that was greater than chance was that of the group with ASD in the human condition. The group with typical development in the human condition showed non-significant reaction time motor resonance effects that were in the hypothesized

direction (small effect size). This non-significant effect could be due to low power in this study to detect a small effect or due to the fact that the group with typical development showed significant accuracy motor resonance effects in this condition, which might have suppressed motor resonance seen in the reaction time data (e.g., participants with typical development may have rotated the joystick in the direction of the motion rather than delaying their response and rotating the joystick in the opposite direction). In the object condition, neither group demonstrated significant reaction time motor resonance effects, and the very small effect sizes (Cohen's $d < 0.15$) suggests that the object condition failed to elicit consistent motor resonance across both groups of participants. In the sentence condition, both groups had non-significant reaction time motor resonance effects that were in the hypothesized direction but very small effect sizes. These results suggest that the majority of the reaction time motor resonance effects were elicited in the human condition and not as robustly in the sentence and object conditions.

Balance Board Motor Measure Results

The Wii balance board was used to get an overall measure of each participant's motor ability in terms of balance. The dependent variables for this measure included the length of time the participant was able to hold each pose, each participant's distance from center of balance in each pose, and also the variability in balance over time.

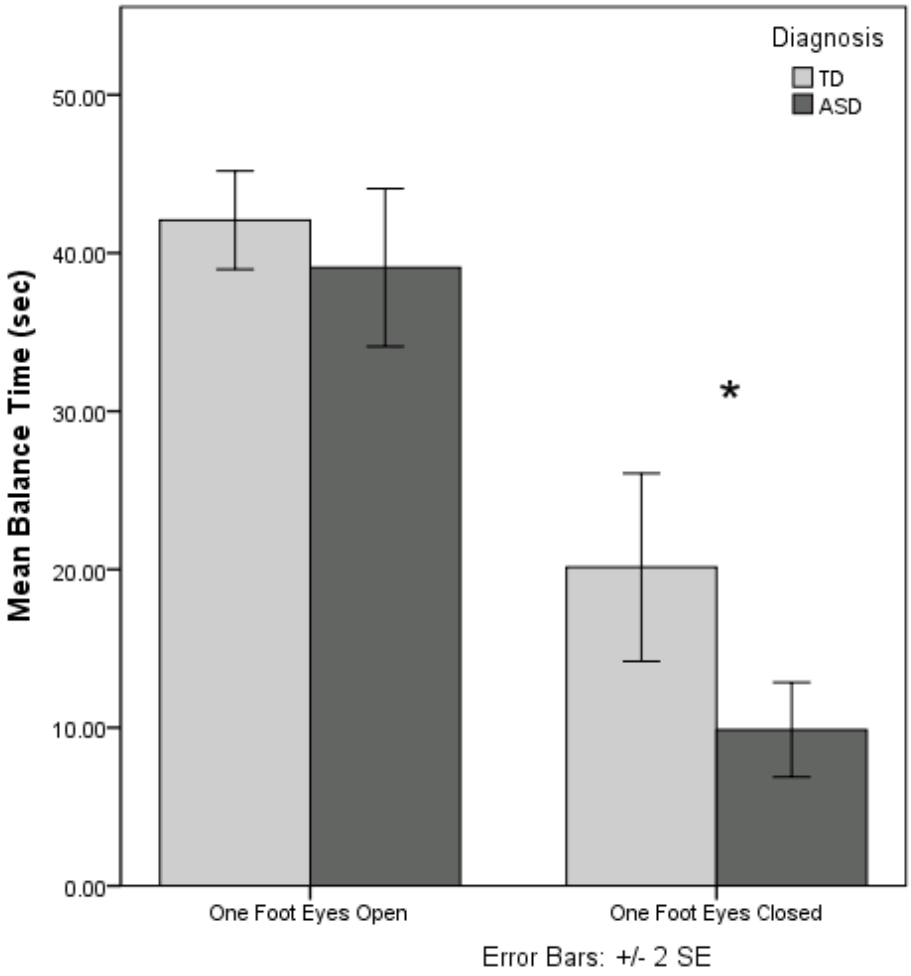
Balance board time results. Analyses that assessed possible group differences in the length of time participants were able to hold each pose were conducted. When participants were asked to stand on both feet with eyes open and with eyes closed, all participants in both groups were able to sustain the full 45 seconds. Therefore, there were no group differences in length of time holding the posture when participants were standing on both feet.

When participants were asked to stand on one foot with their eyes open (left and right foot times combined), participants with typical development held the pose for an average of 42.08 seconds (*SD* = 7.90 seconds), and participants with ASD held the pose for an average of 39.08 seconds (*SD* = 12.71 seconds). An independent-samples t-test indicated that this was not a significant group difference, $t(50) = 1.02$, $p = .31$, Cohen's $d = 0.28$. However, it should be noted that ceiling effects likely affected these results. Specifically, twenty-one of the 26 individuals with typical development and 21 of the 26 individuals with ASD were able to stand on their right foot with eyes open the full 45 seconds. Similarly, 22 of the 26 individuals with typical development and 21 of the 26 individuals with ASD were able to stand on their left foot with eyes open for the full 45 seconds. Because of these ceiling effects, the lack of a diagnostic difference in standing times with eyes open should be interpreted cautiously.

When asked to stand on one foot with their eyes closed (right- and left-foot times combined), participants with typical development held the pose for an average of 20.13 seconds (*SD* = 15.14 seconds), and participants with ASD held the pose for an average of 9.87 seconds (*SD* = 7.62 seconds). An independent-samples t-test indicated that this was a significant group difference, $t(50) = 3.09$, $p = .003$, Cohen's $d = 0.86$. These results indicate that individuals with ASD may have more difficulty when standing on one leg with eyes closed compared to individuals with typical development.

Figure 2

Diagnostic Differences in Length of Time Standing on One Foot



Note. There were no significant differences between right and left foot. Therefore, left and right foot times were averaged to create one collapsed time variable for eyes opened and for eyes closed. *$p < .05$.

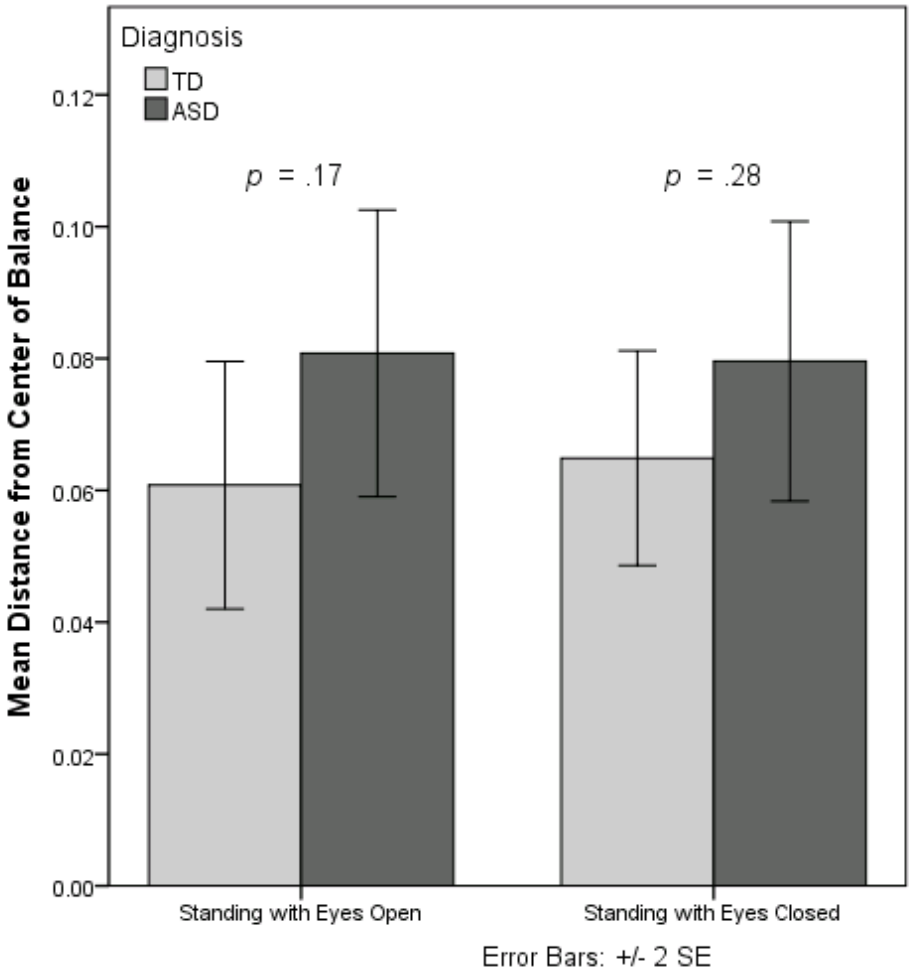
Distance from center of balance results. I also conducted analyses that assessed possible group differences in the balance between the left and right foot while participants held each pose standing on both feet. To do so, I subtracted the balance scores of the right foot from the balance scores of the left foot at each time point, and I divided this difference by the sum of

the left and right foot in order to create a proportion that takes into account overall pressure (weight) on the balance board. To specifically measure balance, I calculated the mean of the absolute value of this proportion over time to come up with a measure of the distance away from center of balance.

When asked to stand on both feet with eyes open, participants with typical development had an average distance from center of balance of 0.061 (*SD* = 0.048), and participants with ASD had an average distance from center of balance of 0.081 (*SD* = .055). An independent-samples t-test indicated that there was not a significant group difference in distance from center of balance, $t(50) = -1.39$, $p = .17$, Cohen's $d = 0.39$, while standing on two feet with both eyes open. When asked to stand on both feet with eyes closed, participants with typical development had an average distance from center of balance of 0.065 (*SD* = 0.042), and participants with ASD had an average distance from center of balance of 0.080 (*SD* = 0.054). An independent-samples t-test indicated that there was not a significant group difference in distance from center of balance, $t(50) = -1.10$, $p = .28$, Cohen's $d = 0.31$, while standing on both feet with eyes closed. Therefore, even though the ASD group showed a trend for being less centered during both standing conditions, these differences were not statistically significant.

Figure 3

Mean Distance from Center of Balance during Standing



Postural stability results. In order to measure possible diagnostic group differences in postural stability during the standing poses, I examined variability in the center of balance of each participant over time. In doing so, I developed two measures of postural stability: 1) postural drift over time and 2) postural waiver (changes in pressure not accounted for by systematic drift over time). Postural drift was measured by conducting a linear regression that examined the center of balance as a function of time (one center of balance score every 2.5 ms), and then I took the absolute value of the beta for each participant to create a quantitative measure

of this drift. In contrast, postural waiver was computed as the standard deviation of the residuals from this regression equation. In other words, postural waiver was the variability in center of balance that was not accounted for by systematic drift over time.

When standing on both feet with eyes open, participants with typical development had an average drift score of 1.09 *E*-5 (*SD* = 9.19 *E*-6), and participants with ASD had an average drift score of 1.04 *E*-5 (*SD* = 7.83 *E*-6). An independent-samples t-test indicated that there was not a significant group difference in drift, $t(50) = 0.22$, $p = .83$, Cohen's $d = 0.18$, while standing on two feet with both eyes open. In terms of postural waiver, it was noted that there was an extreme outlier in the group with ASD whose waiver score was ten times that of the group mean. Therefore, this participant was excluded for the independent-samples t-test (and all following correlations). Without this outlier, participants with typical development had an average waiver score of .010 (*SD* = .006), and participants with ASD had an average waiver score of .012 (*SD* = .006). Without this participant, an independent-samples t-test indicated that there was not a significant group difference in waiver, $t(49) = -0.46$, $p = .64$, Cohen's $d = -0.18$, while standing on two feet with both eyes open. (An analysis conducted with the extreme outlier also rendered non-significant results [$p = .27$]). Therefore, there did not appear to be any diagnostic group differences in drift or waiver during standing with eyes open.

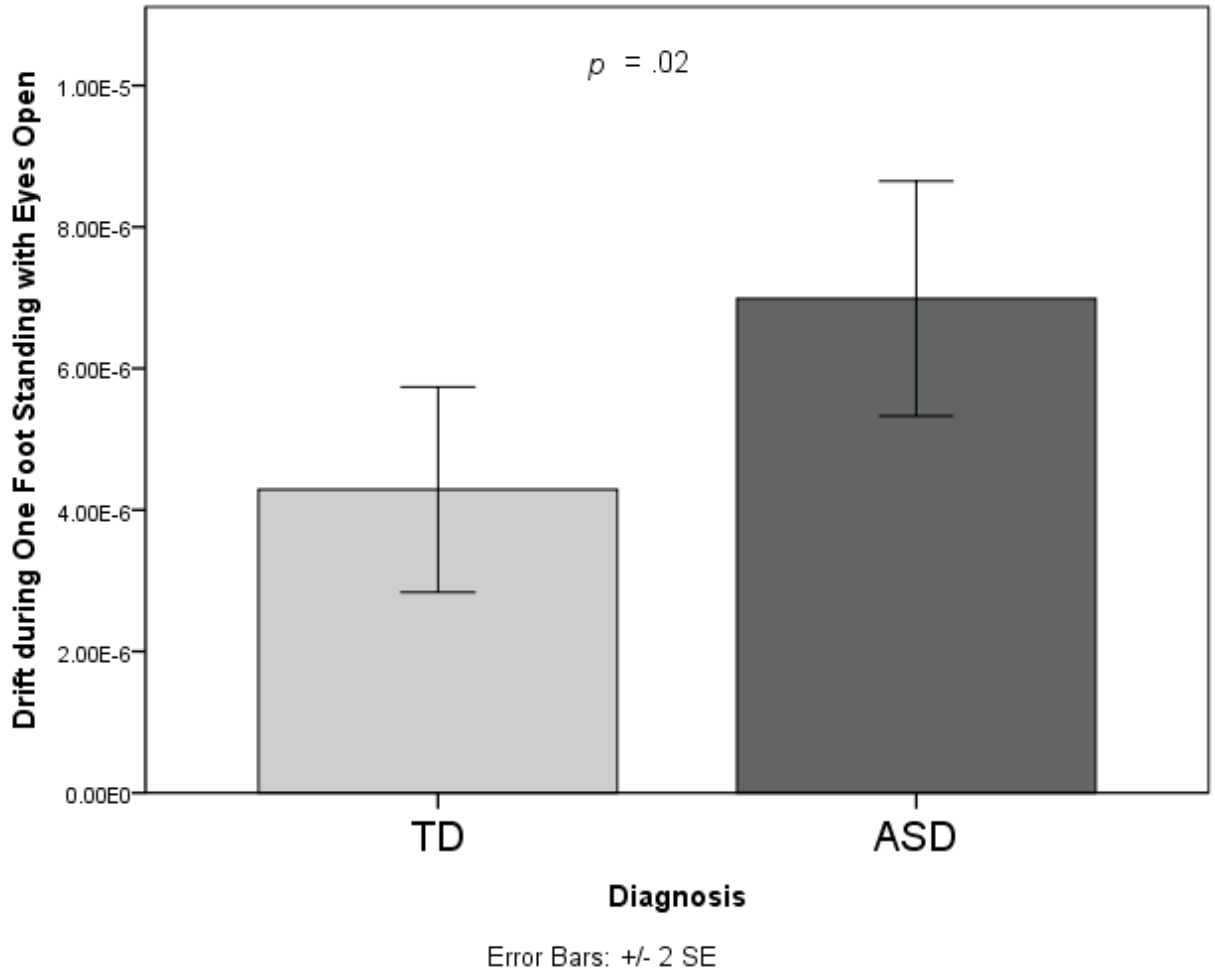
When standing on both feet with eyes closed, participants with typical development had an average drift score of 8.80 *E*-6 (*SD* = 1.08 *E*-5), and participants with ASD had an average drift score of 8.53 *E*-6 (*SD* = 6.42 *E*-6). An independent-samples t-test indicated that there was not a significant group difference in drift, $t(50) = 0.11$, $p = .91$, Cohen's $d = 0.03$, while standing on two feet with eyes closed. In terms of postural waiver, the same outlier that was observed in the standing with eyes open analyses was also excluded in the eyes closed analyses. Without this

outlier, participants with typical development had an average waiver score of .011 (*SD* = .005), and participants with ASD had an average waiver score of .012 (*SD* = .005). An independent-samples t-test indicated that there was not a significant group difference in waiver, $t(49) = -0.82$, $p = .41$, Cohen's $d = -0.20$, while standing on two feet with eyes closed. (An analysis conducted with the extreme outlier also rendered non-significant results [$p = .29$]). Therefore, there were tendencies across both standing conditions for there to be less postural stability in the group with ASD. However, none of these trends were significant and all had very small effect sizes.

When asked to stand on one foot, all participants were required to place their foot on the center line. Therefore, only postural drift and waiver (and not distance from center of balance) during one-foot balance poses were analyzed. Similar to the analyses done on balance times, postural drift and waiver for the right and left foot were averaged together. Additionally, because a person who falls off early may end up actually exhibiting less drift and waiver compared to a person who lasts the entire 45 seconds, I selected out only the participants who completed the full 45 seconds in both poses. In terms of postural drift while asked to stand on one foot with eyes open, participants with typical development who lasted the full 45 seconds (n = 20) had an average drift score of 4.29 *E*-6 (*SD* = 3.24 *E*-6), and participants with ASD who lasted the full 45 seconds (n = 20) had an average drift score of 6.99 *E*-6 (*SD* = 3.71 *E*-6). An independent-samples t-test indicated that the group with ASD demonstrated significantly more postural drift than the group with typical development with eyes open on one foot, $t(38) = -2.45$, $p = .02$, Cohen's $d = -0\ .78$.

Figure 4

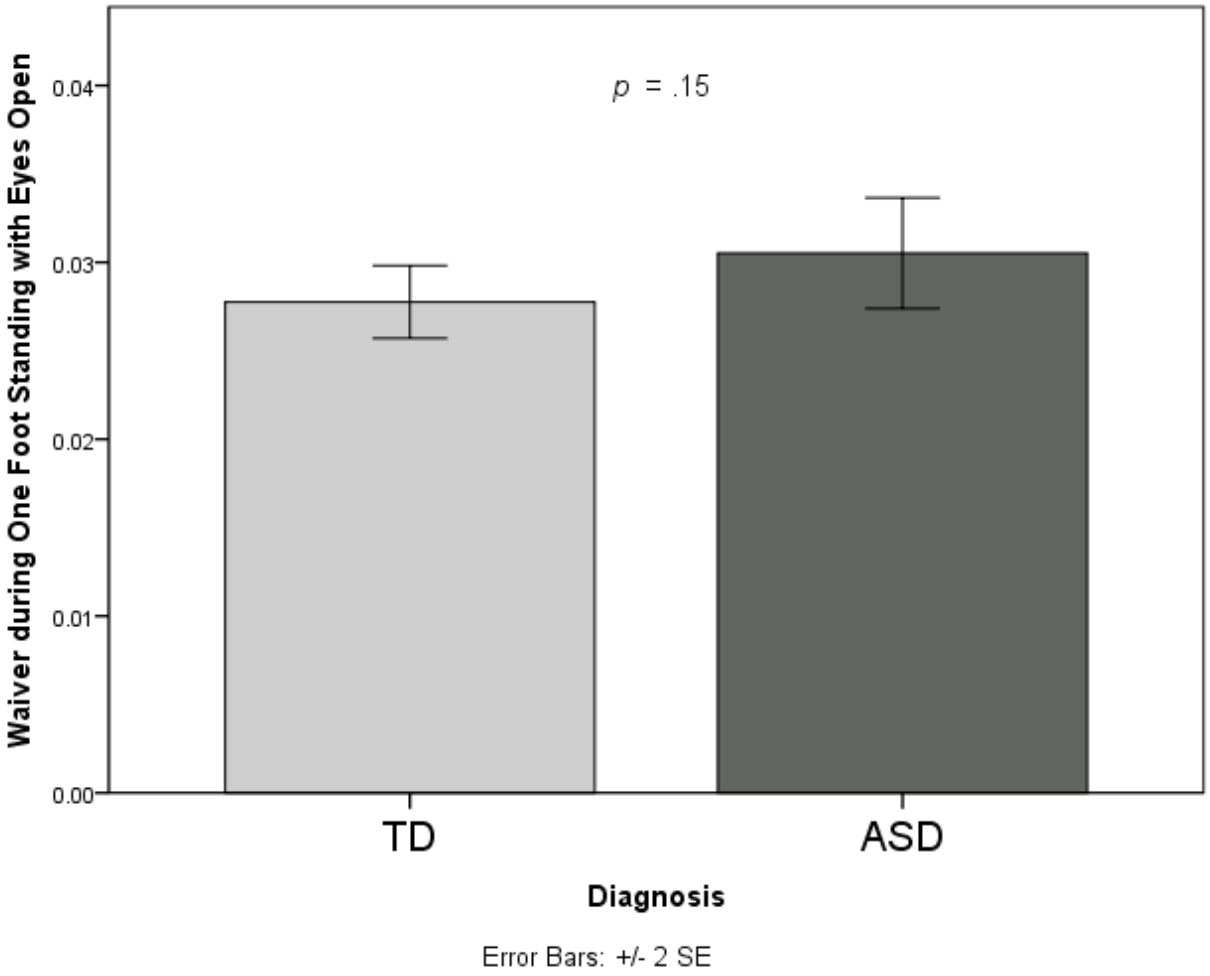
Average Drift during One Foot Standing with Eyes Open



In terms of postural waiver while asked to stand on one foot with eyes open, participants with typical development had an average waiver score of .028 (*SD* = .005), and participants with ASD had an average waiver score of .031 (*SD* = .007). An independent-samples t-test indicated that there was not a significant group difference in waiver with eyes open on the right foot, *t*(38) = -1.48, *p* = .15, Cohen's *d* = -0.49. Therefore, the group with ASD demonstrated significantly more postural drift and non-significantly more postural waiver during standing one the right foot with eyes open (medium effect size).

Figure 5

Average Waiver during One Foot Standing with Eyes Open



In analyzing waiver during one-foot standing with eyes closed, too few people made it the entire 45 seconds (i.e. five individuals in the group with typical development and one individual in the group with ASD). Therefore, there was not enough power to assess postural drift or waiver in this condition.

Balance Board Motor Performance and Motor Resonance

In order to examine if motor resonance was related to general motor performance in the sample, I correlated overall reaction time motor resonance with the average length of time the

participants was able to stand on one foot, with the distance from center of balance during standing, with postural drift during standing, and with postural waiver during standing on the balance board (eyes opened and eyes closed combined). To come up with a measure of overall motor resonance, I averaged the reaction time motor resonance of the human, object, and sentence conditions to create an overall motor resonance variable. I found that the balance times, distance from center of balance, and postural drift motor performance variables were not significantly correlated with overall motor resonance (length of time on one foot, $r[51] = -.08$, $p = .58$; distance from center of balance, $r[51] = -.06$, $p = .68$; postural drift, $r[51] = -.20$, $p = .48$). However within the ASD group (not including the extreme motor resonance outlier or the extreme waiver outlier), I found a significant negative correlation between waiver during standing with eyes open and overall motor resonance, $r(23) = -.41$, $p < .05$. However, after examining the scatterplot, I noticed another (not as extreme) outlier. Without this additional outlier, the relation between waiver during standing with eyes open and overall motor resonance no longer held, $r(22) = -.16$, $p = .46$. Additionally, this relation was not found within the group with typical development $r(25) = .07$, $p = .73$. This finding suggests that postural waiver and motor resonance did not appear to be related in either the group with ASD or the group with typical development.

Motor Functioning and Participant Characteristics

Motor resonance and participant characteristics. I correlated overall motor resonance with demographic variables, such as age and full scale IQ (FSIQ), and I found that overall motor resonance was not significantly correlated with age, $r(51) = .10$, $p = .46$. However, overall motor resonance appeared to be correlated with FSIQ, $r(51) = -.29$, $p = .04$, such that individuals wither lower FSIQ scores demonstrated more motor resonance. In examining a scatterplot, I

discovered that this correlation was likely affected by an extreme motor resonance outlier in the group with ASD. I removed this outlier, and the relation between FSIQ and overall motor resonance no longer held, $r(50) = -.06$, $p = .67$. Therefore, it is unlikely that there was truly a negative relation between FSIQ and overall motor resonance in this study.

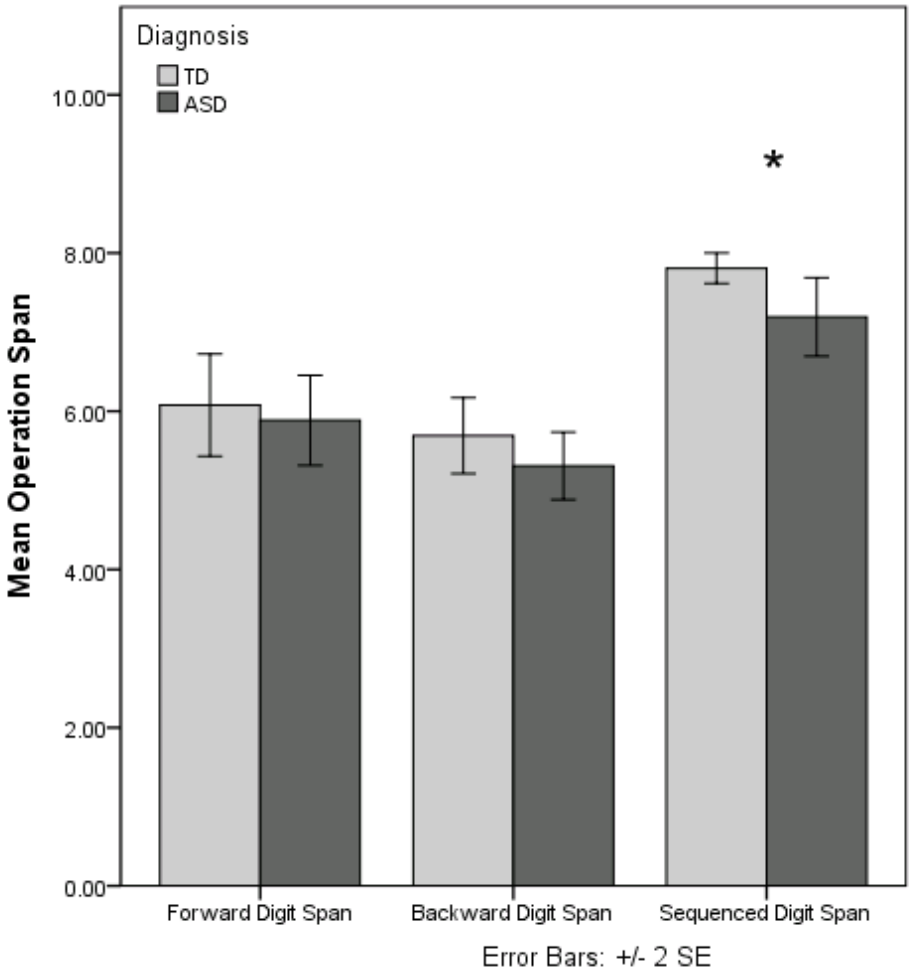
Balance board performance and participant characteristics. I correlated measures of general motor balance and stability with age and FSIQ, and I found that none of these variables were significantly correlated (n = 52, all *r*'s greater than -.20 and less than +.10).

Motor Functioning and Working Memory

Group differences in working memory. Results from the digit span working memory task suggested that on forward digit span, participants with typical development had similar operation spans ($M = 6.08$, $SD = 1.65$) to participants with ASD ($M = 5.88$, $SD = 1.45$), $t(50) = 0.45$, $p = .66$, Cohen's $d = 0.13$. On backward digit span, participants with typical development ($M = 5.69$, $SD = 1.22$) also had similar operation spans compared to participants with ASD ($M = 5.31$, $SD = 1.09$), $t(50) = 1.20$, $p = .24$, Cohen's $d = 0.33$. However, this was a small effect size, suggesting that with more participants and power, this has the potential to become a significant effect. Additionally, a significant group difference in operation span arose in the sequenced digit span portion of the task, with the participants with typical development showing greater operation spans ($M = 7.81$, $SD = 0.49$) than the participants with ASD ($M = 7.19$, $SD = 1.27$), $t(50) = 2.33$, $p = .03$, Cohen's $d = 0.64$. This result suggests that the online sequencing of verbal information may not be as helpful for the participants with ASD in memory retention as it may be for the individuals with typical development.

Figure 6

Operation Span during Working Memory Task



Note. * $p < .05$.

Motor resonance and working memory. To examine if working memory was related to the degree of overall motor resonance, I correlated overall motor resonance with the accuracy scores on the forward digit span, backward digit span, and sequenced digit span tasks. I did not find any significant correlations between working memory and overall motor resonance across any of the three types of working memory (forward digit span, $r[51] = +.21$, $p = .14$; backward digit span, $r[51] = +.04$, $p = .77$; sequenced digit span, $r[51] = -.16$, $p = .26$). Therefore, neither

maintenance nor manipulation working memory appeared to be related to the overall motor resonance expressed by participants.

Motor Functioning and Empathy

Group differences in empathy. On the self-report Empathy Quotient (EQ), participants with typical development had significantly higher empathy (M = 43.69, SD = 9.72) than the participants with ASD (M = 33.54, SD = 7.40), $t(50) = 4.24$, $p < .001$, Cohen's d = 1.18. This suggests that individuals with typical development were more empathic than individuals with ASD, replicating previous work demonstrating less empathy in individuals with ASD (Baron-Cohen & Wheelwright, 2004; Lombardo et al., 2007).

Motor resonance and empathy. Because self-reported empathy was previously found to be associated with motor resonance in a group with ASD (Minio-Paluello et al., 2008), I hypothesized that empathy on the EQ would significantly correlate with motor resonance (particularly social motor resonance) in the present study. In this analysis, I used the overall reaction time motor resonance variable, and I additionally created a social motor resonance variable by averaging the reaction time motor resonance of the human video and sentence conditions. I then correlated these variables with scores on the EQ. Contrary to my hypotheses, empathy scores did not appear to be significantly correlated with either overall motor resonance, $r(51) = +.04$, $p = .80$, or social motor resonance, $r(51) = +.07$, $p = .65$. Even when separating the diagnostic groups, empathy scores were not found to be significantly correlated with overall motor resonance or social motor resonance (TD overall motor resonance, $r[25] = -.05$, $p = .82$; TD social motor resonance, $r[25] = +.09$, $p = .67$; ASD overall motor resonance, $r[25] = +.25$, $p = .22$; ASD social motor resonance: $r[25] = +.26$, $p = .21$). Therefore, motor resonance did not appear to be related to empathy in this study.

Balance board performance and empathy. I conducted exploratory analyses to investigate if empathy might be related to any of the balance board motor performance variables. I found that empathy was significantly correlated with the amount of postural waiver during standing with eyes open in both groups, $r(50) = -.38$, $p = .006$ (ASD, $r[24] = -.49$, $p = .01$; TD, $r[25] = -.35$, $p = .08$). As can be seen in Figure 7, both groups expressed this negative relation between empathy and motor waiver, but the group with typical development did so with only marginal significance. Similarly, I found postural drift during eyes closed standing to be related to empathy in the ASD group, $r(25) = -.53$, $p = .006$, but not in the group with typical development, $r(25) = -.16$, $p = .44$. This result suggests that participants with ASD with decreased empathy tended to waiver more during standing with eyes open and drift more during standing with eyes closed. Participants with typical development demonstrated a similar but less robust relation between empathy and postural waiver.

Figure 7

Scatterplot of Correlation between Empathy (EQ) and Mean Postural Waiver during Standing with Eyes Open

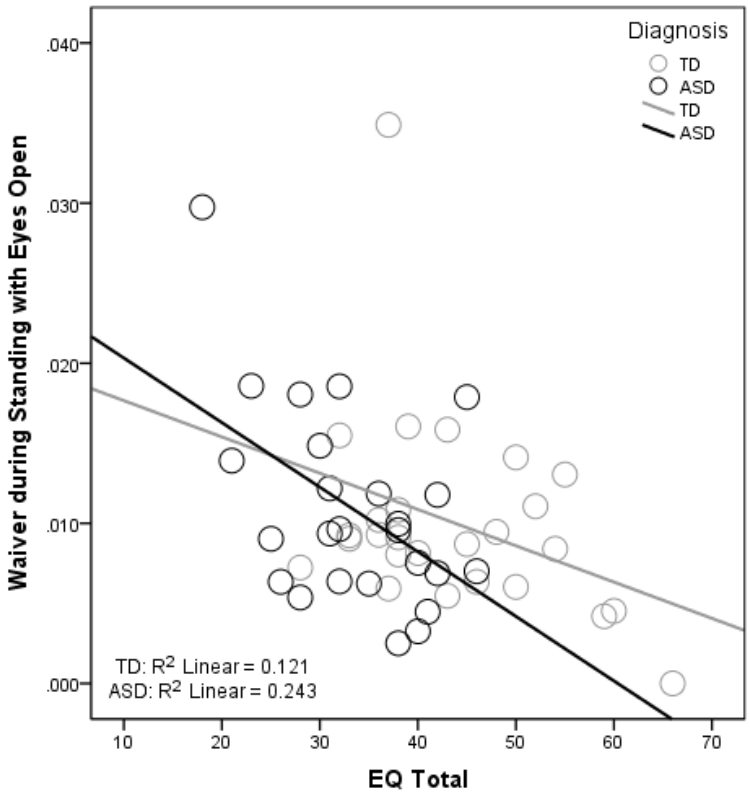
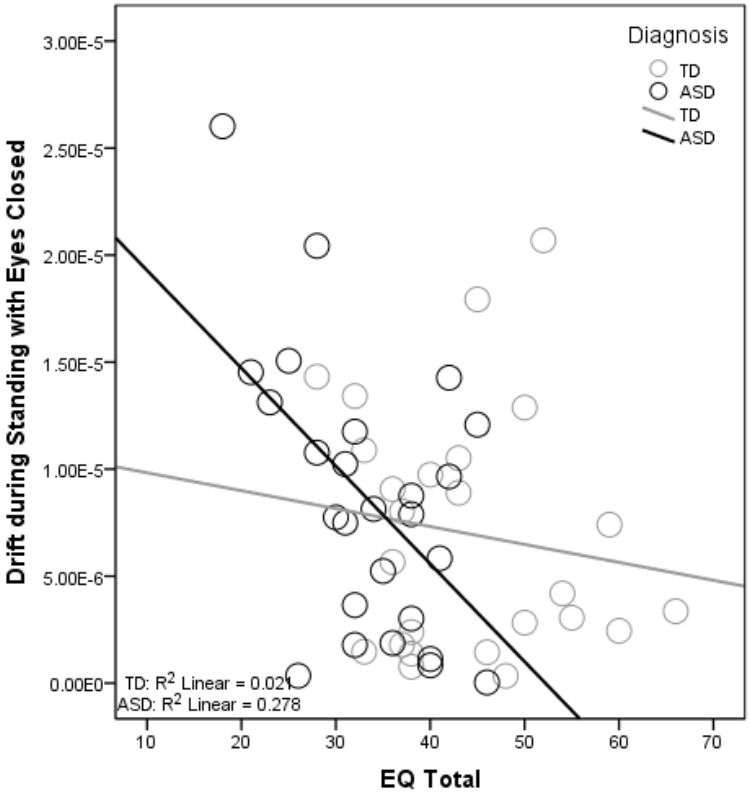


Figure 8

Scatterplot of Correlation between Empathy (EQ) and Mean Postural Drift during Standing with Eyes Closed



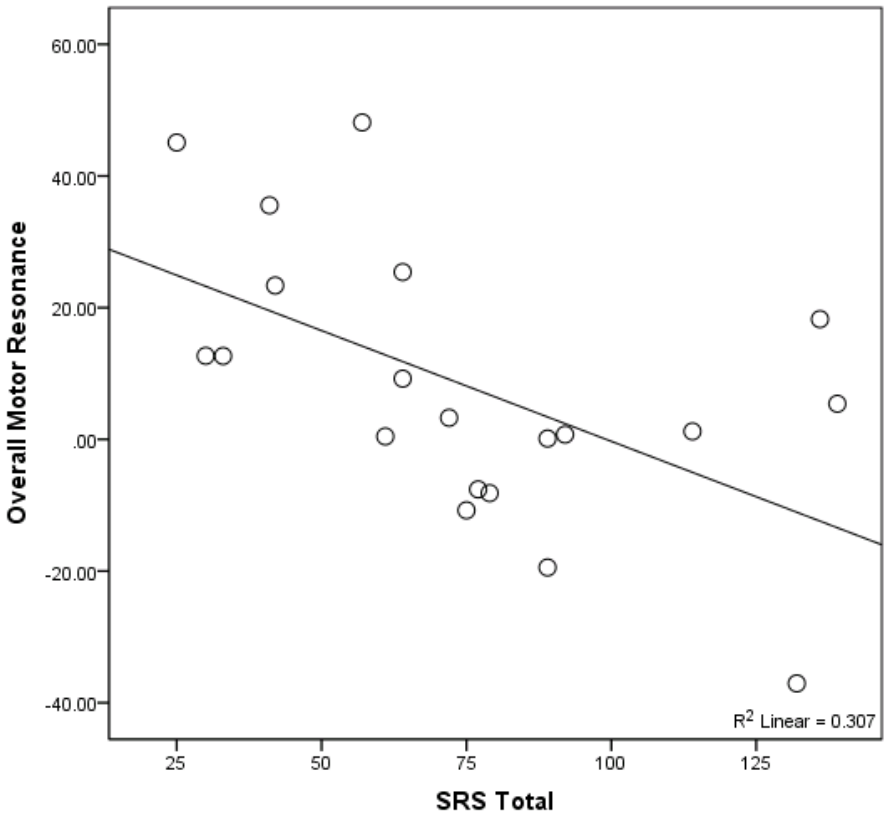
Motor Functioning and ASD Symptomatology

Motor resonance and autism symptom severity. In order to examine if the degree of motor resonance elicited in the task was related to ASD symptom severity, I correlated overall motor resonance with SRS total raw scores, RBS-R total raw scores, and parent-report BAPQ scores in the ASD group. I found that RBS-R and parent-report BAPQ scores had medium-sized correlations with overall motor resonance (BAPQ, $r[19]=-.24$, $p = .32$; RBS-R, $r[21]=-.23$, $p = .31$), but these correlations were not statistically significant. In contrast, the SRS total raw score was negatively and significantly correlated with overall motor resonance, $r(20) = -.45$, $p = .04$. Therefore, those who appeared to have more severe autism symptomatology (as measured by the

SRS) were more likely to have decreased motor resonance. Therefore, even though I did not find diagnostic group difference in the degree of overall motor resonance, more severe ASD symptoms within the ASD group appear to be related to decreased motor resonance.

Figure 9

Scatterplot of Correlation between SRS and Overall Motor Resonance in Group with ASD



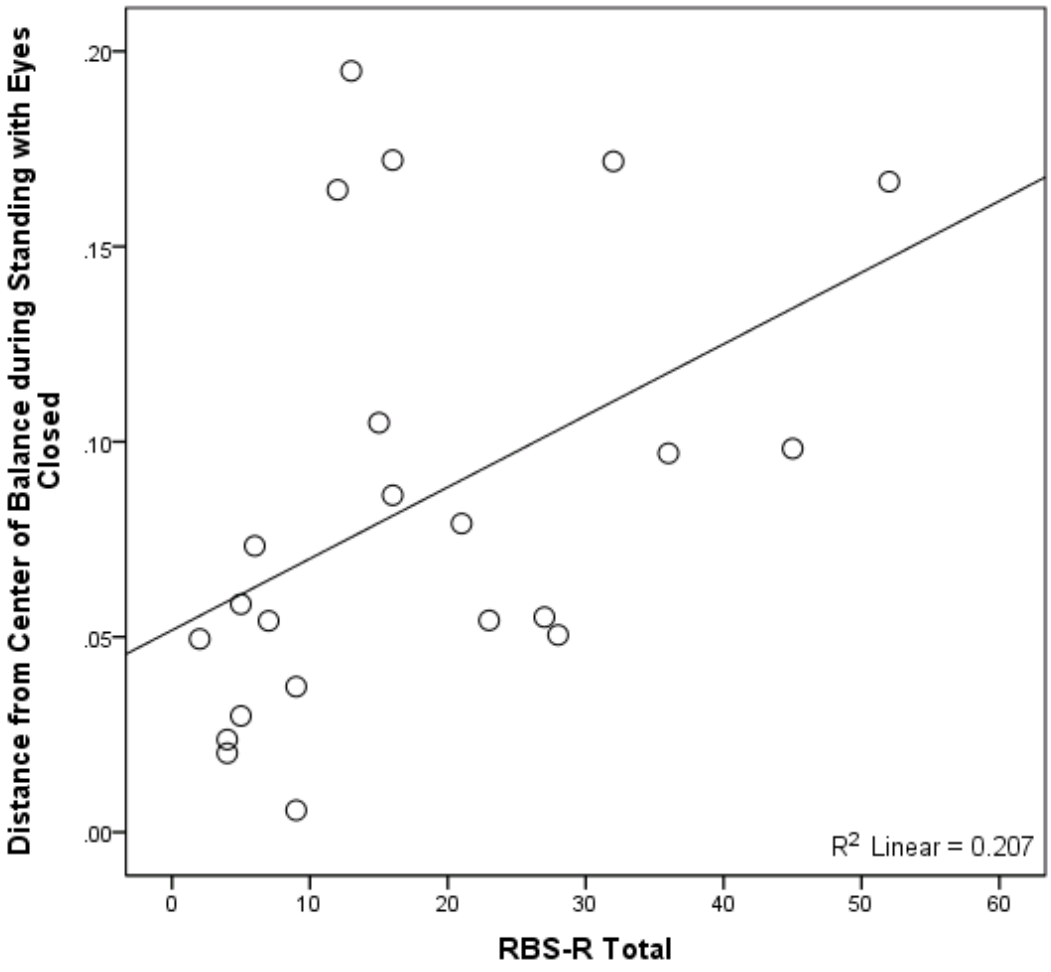
Balance board motor performance and autism symptom severity. Because motor symptoms are commonly present in persons with ASD (e.g., Gidley Larson & Mostofsky, 2006), I wanted to examine if motor balance and stability within the ASD group were related to ASD social, language, and repetitive behavior symptom severity. To do so, I used the SRS, parent-report BAPQ, and RBS-R total raw scores as indicators of ASD symptom severity. For the motor measures, I chose to examine time standing on one foot, distance from center of balance, postural drift, and postural waiver during standing with eyes open and eyes closed.

I found that two of the three symptom severity measures had medium-sized correlations with the average amount of time a person with ASD was able to stand on one foot (eyes opened and eyes closed combined) (parent-report BAPQ, $r[19] = +.38$, $p = .10$; $p = .40$; SRS, $r[21] = +.30$, $p = .19$; but not RBS-R, $r[21] = +.19$). However, none of these correlations were statistically significant. Therefore, overall ability to stand on one foot did not appear to be robustly correlated with ASD symptom severity within the ASD group.

In terms of center of balance, the RBS-R was significantly correlated with distance from center of balance during standing with eyes closed, $r(21) = +.46$, $p = .03$ (See Figure 10). Similarly, the RBS-R demonstrated a medium-sized correlation with distance from center of balance with eyes open, but this correlation was not statistically significant, $r(21) = +.32$, $p = .15$. Therefore, more severe repetitive behavior/restricted interest symptoms were robustly associated with a more off-center center of balance during standing with eyes closed but only marginally so with eyes open. Similarly, the SRS was marginally correlated with distance from center of balance during eyes closed, $r(20) = +.39$, $p = .08$ (nearing a large effect), but not with eyes open, $r(20) = +.26$, $p = .26$. Therefore, there was a trend for greater social symptom severity to be related to a more off-center center of balance, but this relation did not reach significance.

Figure 10

Scatterplot of Correlation between RBS-R and Mean Center of Balance during Standing with Eyes Closed in Group with ASD



In terms of postural stability, I did not find any significant correlations between postural drift and any of the ASD symptom severity measures. However, I did find that postural waiver during standing with eyes open was significantly correlated with all three autism symptom severity measures (SRS, $r[19] = +.54$, $p = .01$; RBS-R, $r[20] = +.50$, $p = .02$; parent BAPQ, $r[18] = +.52$, $p = .02$) (See Figures 11-13). In terms of waiver during standing with eyes closed, I found that waiver had medium-sized correlations with all three symptom severity measures.

However, none of these correlations reached statistical significance (SRS, $r[20] = +.33$, $p = .14$; RBS-R, $r[21] = +.34$, $p = .12$; parent BAPQ, $r[19] = +.35$, $p = .13$). These results suggest that those with more severe autism symptoms also tended to waiver more during standing. However, this relation was particularly pronounced when participants had eyes open and diminished when participants had eyes closed.

Figure 11

Scatterplot of Correlation between SRS and Mean Waiver during Standing with Eyes Open in Group with ASD

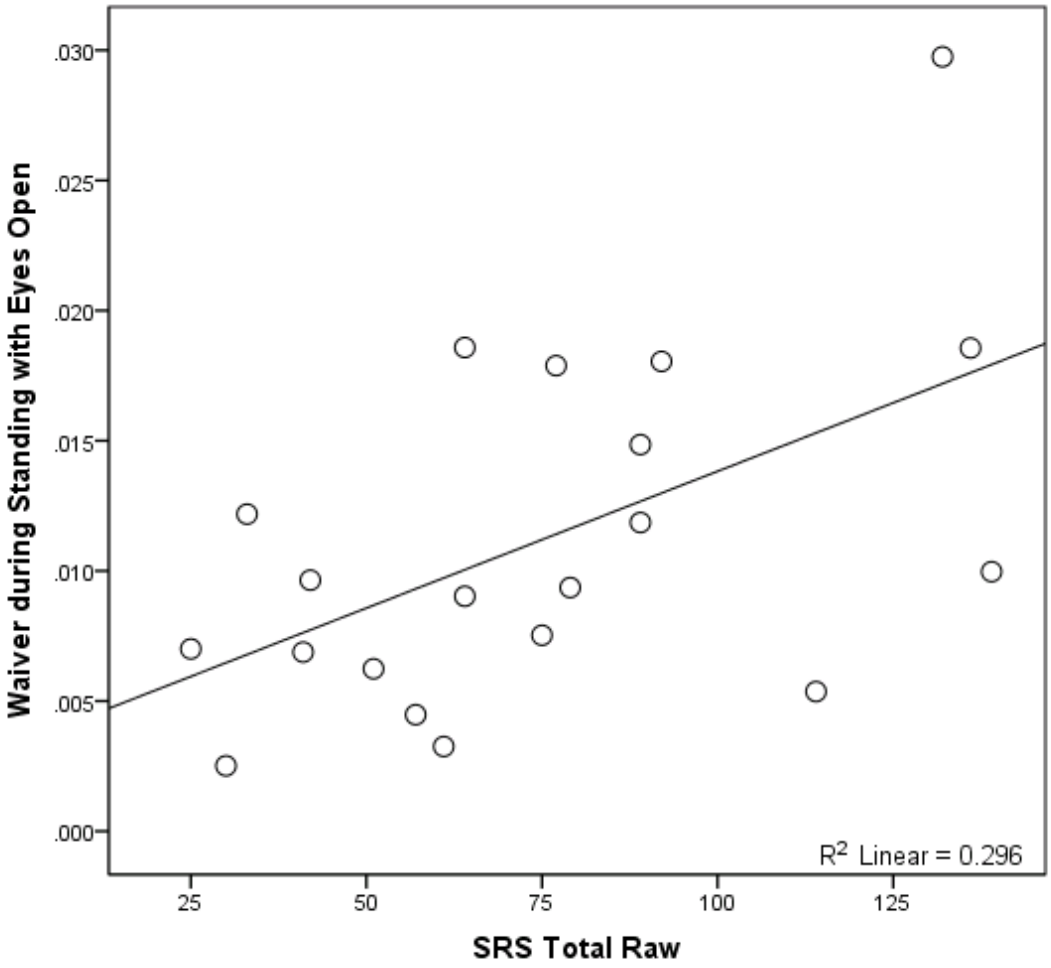


Figure 12

Scatterplot of Correlation between RBS-R and Mean Waiver during Standing with Eyes Open in Group with ASD

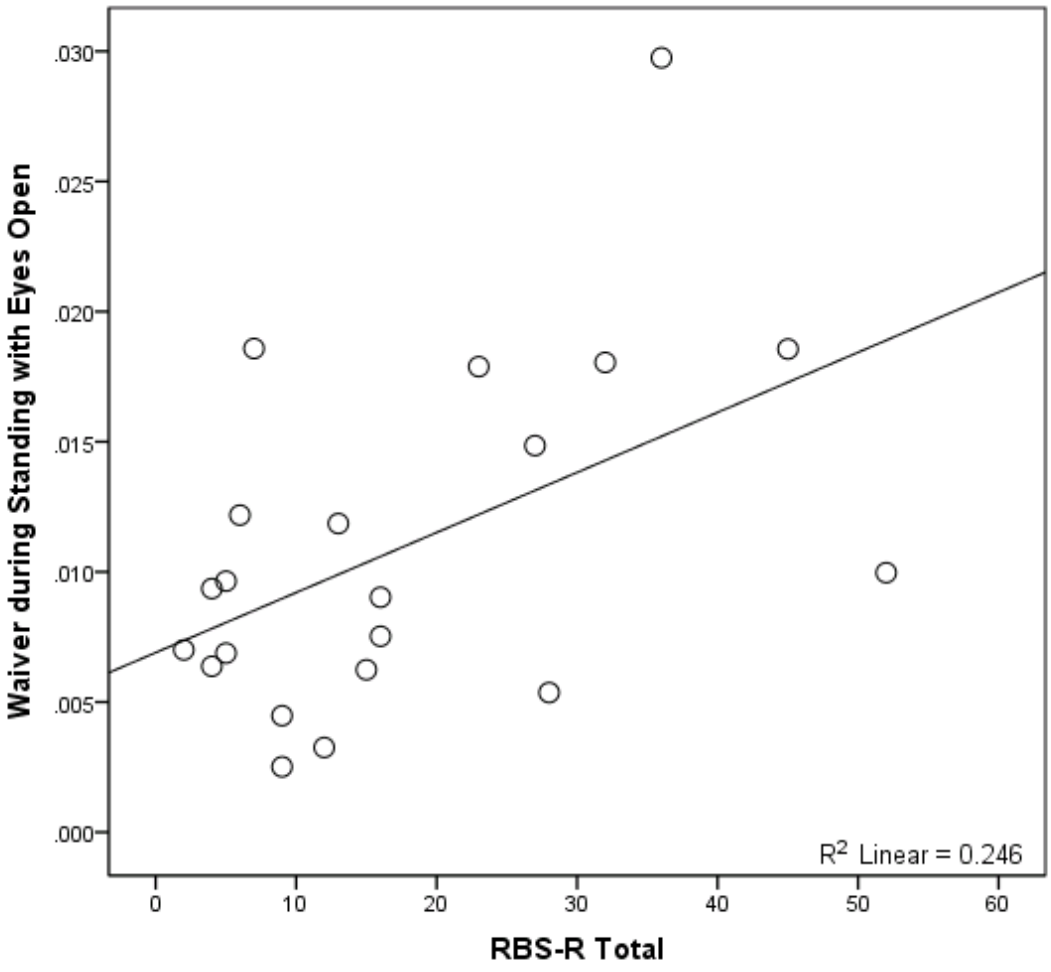
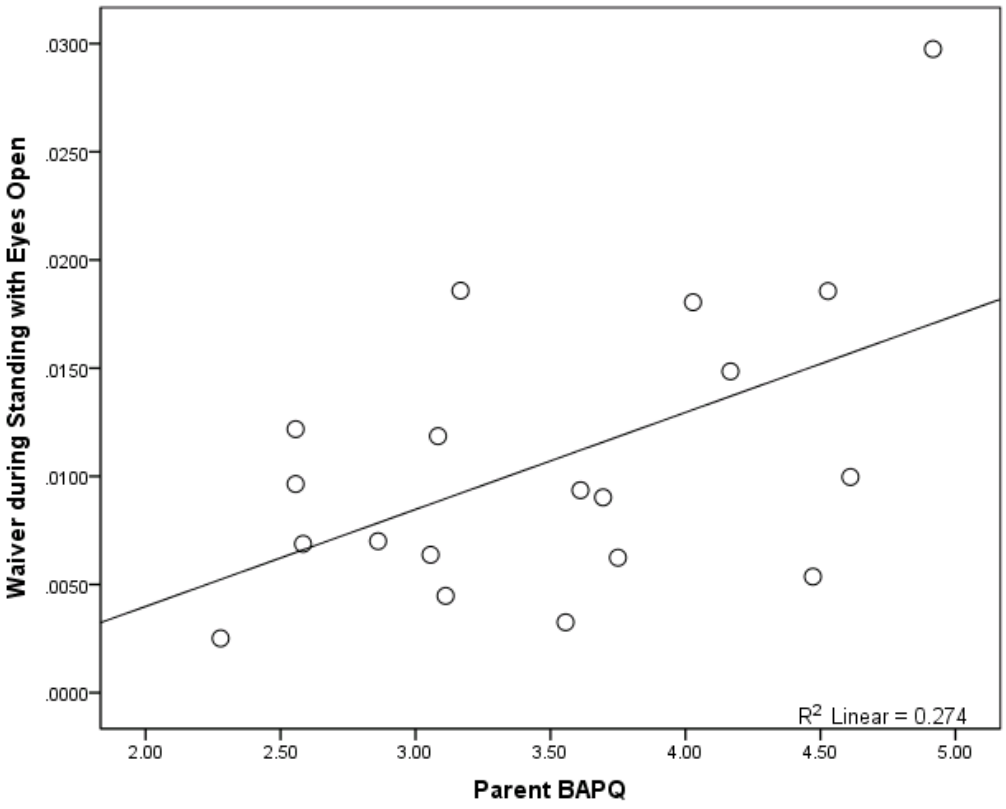


Figure 13

Scatterplot of Correlation between Parent-Report BAPQ and Mean Waiver during Standing with Eyes Open in Group with ASD



DISCUSSION

Motor resonance is motor activation that occurs in the body when one observes movement or reads sentences about movement (Zwaan & Taylor, 2006). Prior research suggests that motor resonance may be fundamental to the development of language (Liberman & Mattingly, 1985), empathy (Avenanti et al., 2005), and social reciprocity (Meltzoff, 2007), and these three cognitive domains have all been found to be impaired or atypical in persons with ASD. Therefore, in the present dissertation, I set out to examine motor resonance in adolescents and adults with ASD in response to human motion, object motion, and sentences that imply motion. Then, I examined possible relations between motor resonance and different aspects of ASD symptomatology (e.g., social, repetitive behavior, communication, motor, and empathy symptoms). The main results of this study can be summarized into the following three categories: 1) Diagnostic group similarities in motor resonance, 2) Significant relation between motor resonance and ASD symptom severity (but not empathy or working memory), and 3) Diagnostic group differences in postural stability and balance. Each of these three categories of results will be discussed in more detail below.

Motor Resonance in Persons with ASD

By using different types of stimuli to elicit motor resonance, the present study was able to examine how human versus nonhuman motion may differentially produce motor resonance in persons with ASD compared to persons with typical development. Specifically, across the human movement conditions, we hypothesized that individuals with ASD would show decreased motor resonance compared to individuals with typical development. However, in response to the

object movement, we hypothesized that individuals with ASD may actually show similar or increased amounts of motor resonance due to a tendency to attend to nonsocial information more than social information (Chawarska et al., 2010; Shic et al., 2011).

Accuracy motor resonance. Because motor resonance is thought to speed up responses to congruent stimuli and slow down responses to incongruent stimuli, our primary measure of motor resonance was the reaction time difference between responses to congruent and incongruent stimuli. However, we also examined possible accuracy motor resonance effects (e.g., being more inaccurate on incongruent trials than on congruent trials) that may have accompanied reaction time motor resonance effects. In terms of accuracy, we found a significant three-way interaction among diagnosis, stimulus type, and congruency. This three-way interaction appeared to be driven by individuals with ASD showing accuracy motor resonance in response to sentences (but not in response to human or object videos), and individuals with typical development showing accuracy motor resonance in response to human videos (but not in response to sentences or object videos). These results suggest that motor resonance may have differentially affected the accuracy of participants with ASD and participants with typical development in the social conditions. However, both groups were extremely accurate across all conditions, and ceiling effects may have been present. These ceiling effects may have limited the expression of motor resonance through accuracy, and these ceiling effects may be the reason that previous studies have not used accuracy as the primary measure of motor resonance. Nevertheless, the fact that the accuracy motor resonance effects were in the correct direction coupled with the reaction time motor resonance results suggest that congruency in the videos affected the responses of the participants.

Reaction time motor resonance. Reaction time motor resonance in the present study was examined as a function of diagnosis, stimulus type, congruency, and block. Collapsing across all stimulus types and both groups, we found a significant motor resonance effect, suggesting that overall participants were slower to respond to incongruent stimuli compared to congruent stimuli. Contrary to our hypotheses, we also found that motor resonance in individuals with ASD was similar to that of individuals with typical development with more robust motor resonance in response to social stimuli compared to nonsocial stimuli. However, group-level motor resonance for each of the separate stimulus types was relatively weak across both diagnostic groups. In the human video condition, the ASD group's motor resonance was significantly greater than chance (small-to-medium effect size), but the typically developing group's motor resonance was only marginally greater than chance (small effect size). In the object video condition, neither group demonstrated greater-than-chance motor resonance with both groups showing very small motor resonance effect sizes. In the sentence condition, both groups showed small effects sizes that trended towards having greater-than-chance motor resonance, but neither of these groups showed statistically significant effects. Therefore, the motor resonance effects of the present study were robust only when combined together and not when examined separately.

In order to make sure that the present motor resonance task was able to detect motor resonance effects that were similar in size to prior studies, I compared the effect sizes of the present study to past studies. For example, in the study by Biermann-Ruben and colleagues (2008), the Cohen's *d* in the biological stimuli condition was 0.34. This small effect size was similar to the effect size of the group with typical development in the human video condition of the present study (Cohen's $d = 0.33$) but slightly less than that of the group with ASD (Cohen's *d*

= 0.45). Therefore, the present motor resonance task was able to elicit small-sized motor resonance effects during the human video condition, and these effects were similar in size to that of at least one prior study.

In terms of sentences that imply human motion, the Cohen's *d* for the sentence stimuli in the study by Zwaan and Taylor (2006, experiment 2) was 0.31. This effect size was substantially larger than that of the participants with typical development in the present study (Cohen's *d* = 0.17) and of that of the participants with ASD (Cohen's *d* = 0.21). The stimuli in Zwaan and Taylor's study differed from that of the present study in that the sentence stimuli were auditorily presented (rather than visually presented). Therefore, the visual presentation of the stimuli in the present study may have decreased the sentence motor resonance effects, and subsequently, the motor resonance computer task of the present study may have elicited smaller sentence-based motor resonance effects. Extensive piloting of the motor resonance task prior to this study attempted to determine the best methods to decrease noise in the reaction time data and increase power to find motor resonance effects. However, perhaps further methodology changes should occur in order to enhance the robustness and power of the motor resonance effects in this task (i.e., auditorily presenting the sentences, or creating a response window to standardize reaction times and use accuracy as the primary motor resonance dependent variable).

In terms of object motion, the Cohen's *d* for the nonhuman stimuli in the study by Zwaan and Taylor (2006, experiment 1) was 0.19, and in the nonbiological portion of the study of Biermann-Ruben et al. (2008), it was 0.15. Both of these effect sizes were similar to the effect size of motor resonance in the present study from the object videos in the group with typical development (Cohen's *d* = 0.14) but much greater than the effect size of motor resonance in the group with ASD (Cohen's *d* < 0.01). This result suggests that the effect sizes elicited by the

object videos of the present motor resonance task were quite small (< 0.3) but similar to that of prior studies with persons with typical development. With such small effect sizes, it is interesting to consider if object motion can reliably induce motor resonance. In fact, some researchers have suggested that activation of the Mirror Neuron System (MNS) only occurs in response to human motion (Urgesi, Moro, Candid, & Aglioti, 2006) and thus may not be activated by nonhuman motion. Similarly, Saygin, Wilson, Hagler, Bates, and Sereno (2004) found that the inferior frontal gyrus aspect of the MNS was shown to activate during the observation of upright point-light walkers but not during the observation of scrambled biological motion. These results suggest that if object-motion motor resonance reliably exists, it may rely on different neural substrates from that of human-motion motor resonance. Alternatively, it is possible that the effect of object-motion motor resonance on the MNS is so small, that it has not been detected in neuroimaging studies that typically have fewer participants (and thus less power). Future research will be needed to validate if motor resonance in response to object motion does reliably exist and whether is activates similar neural pathways compared to motor resonance in response to human motion.

Even though the present study did not appear to elicit reliable object-motion motor resonance, it is interesting to note that this lack of object-motion motor resonance occurred across both diagnostic groups. To our knowledge, no prior study has examined motor resonance effects in persons with ASD in response to nonhuman stimuli. However, this is an important line of investigation considering that individuals with ASD may be more likely to attend to inanimate objects in the environment compared to animate objects (Chawarska et al., 2010; Shic et al., 2011). In the present study, both groups demonstrated more motor resonance in response to the human videos than in response to the object videos, and there were no diagnostic differences in

this effect. Therefore, even though young children with ASD may attend more to inanimate objects than to animate objects, this social attention does not appear to modulate motor resonance in adolescents and adults with ASD.

With all types of motor resonance combined, the present study did not find evidence for less motor resonance in the ASD group (e.g., no interaction between diagnosis and congruency). This result suggests that participants with ASD demonstrated relatively intact motor resonance. As reviewed in the introduction, the evidence for a motor resonance impairment in persons with ASD has been inconsistent with studies that require participants to actively respond to the stimuli finding intact motor resonance (e.g., Bird et al., 2007; Gowen et al., 2008; Magnée et al., 2007; Oberman et al., 2009; Press et al., 2010), and studies that require participants to passively view stimuli finding impaired motor resonance (e.g., Beall et al., 2008; Helt et al., 2010; McIntosh et al., 2006; Minio-Paluello et al., 2008; Stel et al., 2008). The present task required participants to make a joystick response to each stimulus, and our results are consistent with past studies that have required participants to make a motor response (e.g., Bird et al., 2007; Gowen et al., 2008; Press et al., 2010). Additionally, the findings of Oberman and colleagues (2009) and of Wilbarger and colleagues (2009) suggested that motor resonance in persons with ASD was present but possibly delayed. The present study accounted for this possibility by encouraging each participant to respond as quickly as possible but allowing them to respond to the stimuli within their own time frame. Therefore, each motor resonance effect was a within-subject variable, allowing delayed motor resonance to still be exhibited in persons with ASD. These results suggest that motor resonance may be fundamentally intact in individuals with ASD. However, the pattern of results of past research suggests that individuals with ASD may need more directive instruction and time to engage the stimuli that induce motor resonance.

By requiring participants to engage and respond to the stimuli in some way, researchers are essentially affecting how individuals orient attention during motor resonance tasks. Therefore, it may be that attention orientation is determining whether persons with ASD demonstrate motor resonance effects. Prior attention research has found that persons with ASD show atypical attentional capture to exogenous cues (Greenaway & Plaisted, 2005; Renner, Klinger, & Klinger, 2006; Townsend, Courschesne, & Egaas, 1996) and less attention to social cues compared to nonsocial cues in the environment (Chawarska et al., 2010; Shic et al., 2011). Therefore, studies that have not required participants to attend to and respond to the stimuli may be confounded by the stimuli not exogenously capturing the attention of the participants with ASD to the same degree that it captures the attention of the participants with typical development. Moreover, most neuroimaging studies that have found impaired functioning of the Mirror Neuron System (MNS) in persons with ASD have only required passive viewing of stimuli (e.g., Bernier et al., 2007; Oberman et al., 2005), and studies that require engagement with the stimuli could theoretically demonstrate typical MNS function in persons with ASD. Therefore, successful attentional orienting towards the social stimuli may be a prerequisite for successful MNS activation, and future research should examine MNS function when participants are required to attend to and engage the stimuli. This type of research would be able to directly test whether decreased MNS activation in persons with ASD is a fundamental impairment in ASD or is simply due to diagnostic differences in attentional capture.

By instructing participants to engage and respond to each stimulus in a motor resonance task, researchers are also essentially instructing participants to use more controlled attentional mechanisms during the task. In contrast to exogenous attention orientation, a number of different controlled attention tasks have demonstrated similar performance of persons with ASD

and persons with typical development. These controlled attention tasks include Stroop tasks (Eskes, Bryson & McCormick, 1990; Ozonoff & Jensen, 1999; Russell, Jarrold, & Hood, 1999) and Stop-Signal tasks (Ozonoff & Strayer, 1997). Indeed, the present motor resonance task could be described as a "Motor Stroop task," in that it measured response competition or facilitation between the viewed motion and the to-be-performed action. The fact that participants with ASD demonstrated an intact motor Stroop effect in the present study further suggested that controlled attention in persons with ASD may be intact and fits nicely with the past findings of intact Stroop task performance in persons with ASD.

In all, the present study's results cannot directly speak to whether attention orientation is responsible for the inconsistency of prior findings regarding motor resonance in persons with ASD. Nevertheless, the present results found that when participants were instructed to engage and respond to each stimulus, persons with ASD did show intact motor resonance. Clinically, these results suggest that it is possible for individuals with ASD to automatically imitate and possibly show social mirroring when communicating with others, but in order to automatically imitate in these social situations, persons with ASD may need to first explicitly attend to and respond to the other person in some way. Automatic social mirroring has been found to increase likeability of a person (Chartrand & Bargh, 1999), which means that social mirroring might be a great social tool for individuals with ASD. Perhaps role playing certain situations with a therapist where social mirroring might be particularly important (i.e., job interviews) and being aware of the mechanisms of social mirroring may allow this type of mirroring to spontaneously occur in persons with ASD in the outside social world. By drawing attention to features that are typically socially mirrored (i.e., body posture, syntax, and facial expressions), persons with ASD may be more likely to attend to these features in live social interactions, which may result in

increased social mirroring. This proposal would need to be directly tested in a clinical study. However, it is an interesting and important avenue for future research.

Relation of motor resonance to empathy and working memory. In addition to motor resonance, the present study examined empathy and working memory in individuals with ASD compared to individuals with typical development, and we examined whether these domains were related to the degree of motor resonance. Because of past research in these areas, we hypothesized that individuals with ASD would show decreased empathy and working memory capacity, and we hypothesized that decreased performance in these domains would be related to decreased motor resonance in individuals with ASD. In line with these predictions and similar to past research (e.g., Baron-Cohen & Wheelwright, 2004; Lombardo et al., 2007), the group with ASD demonstrated lower empathy levels than the group with typical development. However, empathy did not significantly correlate with either overall motor resonance or social motor resonance across both groups or in each group individually. This result is in direct contrast with the study of Minio-Paluello and colleagues (2008), who found that the motor evoked potentials of the ASD group while watching videos of others in pain were significantly correlated with self-rated empathy. Perhaps the more emotional nature of the stimuli in the Minio-Paluello study led to empathy being related to motor resonance, whereas the lack of emotion demonstrated in the present study's stimuli decreased the relation between motor resonance and empathy. Future research should examine how emotional valence of stimuli modulates both empathy and motor resonance in persons with ASD. It is possible that persons with typical development may experience even more motor resonance when the stimuli are emotional, whereas individuals with ASD (who show decreased empathy), may not have facilitated motor resonance as a result of the emotional valence of the stimuli. Future research

should manipulate the degree to which the participant can relate to the person performing the action in the stimuli in order to examine possible diagnostic group differences in motor resonance as a function of empathy.

We also wanted to investigate possible diagnostic group differences in both maintenance and manipulation working memory. The present study found that both groups performed similarly in forward digit span, suggesting intact maintenance working memory in individuals with ASD. However, the group with ASD demonstrated a trend for being less accurate in the backward digit span, and a significant group difference in sequenced digit span, suggesting diagnostic differences in manipulation working memory. These results are similar to prior studies that suggest that maintenance working memory is intact in adolescents and adults with ASD, whereas manipulation working memory is more difficult for adolescents and adults with ASD (Williams, Goldstein, & Minshew, 2006). Specifically, this result suggests that the online sequencing of verbal information may not be as helpful for the participants with ASD in memory retention as it may be for the individuals with typical development. Contrary to our hypotheses, motor resonance was not correlated with working memory. Therefore, it appears that diagnostic group differences in the ability to actively manipulate information in the mind did not influence the amount of motor resonance exhibited by participants in the present study.

Relation of Motor Resonance to ASD Symptomatology

Although we did not find diagnostic differences in motor resonance, we still wanted to test the relation between ASD symptom severity and motor resonance within the ASD group. Helt and colleagues (2010) found that individuals with less severe ASD symptoms were more likely to show increased yawn contagion, suggesting that less severe ASD symptoms may be related to increased motor resonance. To examine this possibility, we correlated overall motor

resonance with autism symptom measures including the SRS, RBS-R, and parent-report BAPQ. We found medium-sized but non-significant negative correlations between overall motor resonance and the RBS-R and the parent-report BAPQ. However, we found a large-sized and significant negative correlation between overall motor resonance and the SRS total raw score, suggesting that individuals with more severe ASD symptoms may demonstrate decreased motor resonance. Compared to the RBS-R and the parent BAPQ, the SRS primarily examines social impairments in persons with ASD. Therefore, it may be that the social symptoms of ASD are more related to the presence of motor resonance than the repetitive behavior or communication symptoms of ASD. This result coincides nicely with the findings of Helt and colleagues and extends these findings to suggest that it may be primarily the social symptoms of ASD underlying this relation.

There are several possible interpretations for why social symptoms in ASD and overall motor resonance are inversely related. First, there may be a subgroup within ASD who have motor resonance impairments, and this group is then more likely to have social reciprocity impairments. Hypothetically, if participants with ASD were selected only from this subgroup, this could lead to a study finding diagnostic group differences in motor resonance. Future research examining motor resonance should carefully monitor the symptom severity within the ASD group in order to be able to best interpret the underpinnings of a diagnostic difference. Secondly, it is possible that if you have had more social reciprocity symptoms in the last six months (as measured by the SRS), then you might be less likely to attend to the stimuli in the motor resonance task, thus affecting your motor resonance results. This possibility could be investigated using eye-tracking technology in future studies. Finally, attention orienting may be a third variable that is related to both social symptoms in ASD and motor resonance effects, such

that poor exogenous attention orienting may cause more severe social symptoms and less motor resonance. One limitation of the present study was that it did not have an exogenous attention task to measure the attention orienting of the participants and this relation to motor resonance. Future research in motor resonance would likely benefit from having such a task. In doing so, that study would be able to examine if attention orienting is related to both social symptoms in ASD and motor resonance.

In terms of clinical implications for this relation between ASD social symptom severity and motor resonance, it would be interesting to see if the intervention of explicitly teaching individuals with ASD to attend to other people (as outlined above) may be able to both increase the presence of motor resonance and improve social symptoms in persons with ASD. Indeed, interventions such as Pivotal Response Therapy (Koegel, Koegel, & McNerney, 2001), the Early Start Denver Model (Dawson et al., 2010), and TEACCH (Ozonoff & Cathcart, 1998) are interventions that encourage individuals with ASD to shift attention to socially salient information. One limitation of the present study was that we were not able to chronicle the intervention history of each participant. However, future research done in motor resonance would likely benefit from doing so.

Diagnostic Differences in Postural Control and Stability

The present study also investigated possible diagnostic differences in motor balance and stability by having participants stand in different postures with either eyes open or eyes closed on a Wii balance board. The dependent variables for this measure included the length of time the participant was able to hold each pose, each participant's center of balance, and each participant's variability in balance over time. Indeed, difficulties with postural control appear to be common in individuals with ASD and perhaps a defining feature of ASD (Fournier et al.,

2010; Minshew et al., 2004). Past studies of postural control in persons with ASD have examined time holding the posture or sway, but never the two in combination. Therefore, a strength of the present study was that it was able to examine these multiple indicators of postural control within the same participants.

Balance standing time. In the present study, both groups were able to stand on both feet with eyes open and eyes closed for the full time of 45 seconds. When standing on one foot with eyes open, there was a non-significant trend for individuals with typical development to be able to stand longer on both the right foot and the left foot. However, this analysis was likely affected by ceiling effects. Nevertheless, diagnostic group differences emerged when standing on one foot with eyes closed. Specifically, persons with ASD lost balance significantly faster than individuals with typical development when eyes were closed, and this occurred both for right-foot standing and left-foot standing. This result parallels that of Weimer and colleagues (2001), who found that persons with Asperger's Syndrome compared to persons with typical development were able to stand for significantly less time on one foot with eyes closed, but were able to stand for approximately the same amount of time on one foot with eyes open. Indeed, closing eyes impaired the standing performance of both groups, but it especially impaired the standing performance of the individuals with ASD. This result suggests that occluding visual input while balancing on one foot may especially impact balance in persons with ASD. We correlated the overall length of standing score with symptom severity measures. From this analysis, we did not find any significant correlations between duration of one-leg standing and symptom severity.

Distance from center of balance. During standing with two feet, we found trends with small effect sizes for the group with ASD to have less-centered balance. However, these trends

were not statistically significant. Infants who are later diagnosed with ASD have been found to have more postural asymmetry compared to infants with developmental delay and infants with typical development during lying (Esposito, Venuti, Maestro, & Muratori, 2009; Teitelbaum et al., 1998) and walking (Esposito, Venuti, Apicella, & Muratori, 2011). However, an extensive literature review did not find any study that had directly examined postural asymmetry in standing or walking in adolescents and adults with ASD. The present study may not have had sufficient power to detect these small differences in postural asymmetry in adults with ASD. However, future studies should exam whether postural asymmetry persists across the lifespan.

Additionally, we found that the distance from center of balance in the eyes closed standing condition was significantly and positively correlated with the degree of repetitive behavior symptoms in the ASD group (measured via the RBS-R). Therefore, those with more severe repetitive behavior symptoms may also have more postural asymmetry during standing with eyes closed. Interestingly, the cerebellum may be particularly involved in postural symmetry and balance (Morton & Bastian, 2004), and structural cerebellar abnormalities are one of the most consistent findings in post-mortem (Bailey et al., 1998; Kates et al., 2004; Kemper & Bauman, 2002; Pierce & Courchesne, 2001; Ritvo et al., 1986; Williams et al., 1980) and MRI-based studies of persons with autism (Akshoomoff et al., 2004; Webb et al., 2009; Scott et al., 2009; Hodge et al., 2010). Additionally, Pierce and Courchesne (2001) found that hypoplasia of the cerebellar vermis (lobules VI and VII) in children with ASD was correlated with their rate of stereotyped motor movements. Therefore, it is possible that repetitive behaviors and postural asymmetry in persons with ASD may have common neural substrates. Future research should further examine the relation among cerebellar structural atypicalities, repetitive behaviors, and postural asymmetry in adolescents and adults with ASD.

Postural drift and waiver during two-leg standing. During standing with eyes open and with eyes closed, participants with ASD showed a trend for more postural drift and more waiver in all conditions. However, each of these trends were non-significant and had very small effect sizes (i.e., all Cohen's $d < 0.21$). Therefore, there was not evidence in this study of participants with ASD exhibiting more postural drift or waiver during standing on two feet. These results differ from prior research that has found significantly more sway in children with ASD with eyes open (Kohen-Raz et al., 1992) and with eyes closed (Molloy et al., 2003). Perhaps the older participants in the present study caused our results to differ from that of past studies who examined postural sway in children. Future research with a larger sample and larger age groups should examine age-related and diagnostic changes in postural control.

Despite no diagnostic group differences, waiver during standing with eyes open was significantly correlated with all measures of autism symptom severity (i.e., the SRS, RBS-R, and parent-report BAPQ) in the group with ASD. Similarly, waiver during standing with eyes closed was marginally correlated with measures of autism symptom severity (with medium effect sizes). Once again, waiver during standing may rely heavily on the cerebellum, specifically the vermis of the cerebellum. For example, individuals with benign tumors in the cerebellar vermis tend to demonstrate more sway during standing, especially with eyes closed. Therefore, cerebellar atypicalities commonly reported in individuals with ASD may relate to autism symptom severity and postural control in this population. Future research should examine this possibility more in depth, including an examination of the integrity of white matter tracts that allow the cerebellum of individuals with ASD to communicate with other areas of the cortex.

In an exploratory analysis, we also found that waiver during eyes open and eyes closed standing was significantly and negatively correlated with empathy in the group with ASD. Once

again, waiver is likely mediated by structure and function of the cerebellum, and functional activation of the cerebellum has been implicated in the experience of empathy. Specifically, cerebellum activation has been associated with empathy for pain (Jackson, Meltzoff, & Decety, 2005; Lamm, Batson, & Decety, 2007; Moriguchi et al., 2007; Singer et al., 2004), and a previous neuroimaging study found that EQ scores were significantly correlated with functional activation during the emotional interpretation of a stick figure's body posture (Kana & Travers, 2011). Therefore, empathy and waiver may both rely on the function of the cerebellum. However, future research will need to specifically correlate cerebellum structure and function with both empathy and motor waiver in persons with ASD to examine if this relation truly exists.

Postural drift and waiver during one-leg standing. When examining postural drift and waiver during one-leg standing with eyes opened, we only examined drift and waiver in individuals who lasted the full 45 seconds in the pose and only during the eyes open condition. We found that individuals with ASD demonstrated significantly more drift (large effect size) and marginally more waiver (medium effect size) compared to individuals with typical development during one-leg standing with eyes open.

Overall, waiver and center of balance analyses indicated a trend for more waiver and less centered balance in persons with ASD, but this trend was not significant across any of the conditions. It is possible that the Wii balance board is not sensitive enough of a tool to detect diagnostic group differences. Alternatively, the power in this study may be a bit low to detect fine-tuned differences in waiver and center of balance. Therefore, future research should examine waiver and balance with the Wii balance board in a larger sample of individuals with ASD.

Motor balance and motor resonance. Both overall motor resonance and motor waiver with eyes closed were related to ASD symptom severity as measured by the SRS. However, we did not find any significant correlations between any of our measures of postural control and overall motor resonance. It is possible that different measures of general motor functioning (e.g., a measure of manual motor control) may have been more related to motor resonance than motor balance. However, it is reassuring that diagnostic group exhibitions of motor resonance did not appear to depend on general motor ability. Future research should examine different aspects of motor ability and relate it to motor resonance in better to understand the role of motor ability in automatic imitation.

In all, it appears that persons with ASD had decreased postural stability compared to persons with typical development, but this decreased postural stability only reached statistical significance under certain conditions (i.e., decreased balance time on one-leg standing with eyes closed and increased postural drift during one-leg standing with eyes open). In spite of the lack of significant diagnostic differences, the measures of postural stability (especially waiver during standing with eyes open) were highly correlated with measures of ASD symptom severity. Additionally, waiver during standing with eyes open was related to empathy and overall motor resonance in the group with ASD. The postural instability seen in the group with ASD is symptomatic of cerebellar atypicalities, which have been commonly reported in persons with ASD in the past. It is possible that the relation among waiver, symptom severity, and empathy are due to common cerebellar underpinnings. However, future research will be needed to substantiate these correlational results.

In terms of clinical applications of the postural stability results in the present study, it is likely that persons with ASD may exhibit slightly less postural stability than persons with typical

development in adolescence and adulthood. Postural stability is extremely fundamental and serves as the basis for many motor tasks. In adolescents and adults with ASSD, a slight decrease in postural stability compared to typically developing peers may not be a highly noticeable impediment. However, if persons with ASD lose postural stability as they enter later adulthood (as occurs in persons with typical development), postural instability may become more of a difficulty for this group. Very little is known about aging and ASD. However, the present results combined with prior studies of postural control in persons with ASD suggest that postural instability may make persons with ASD more of a "fall risk" later in life. Additionally, postural instability could profoundly affect an individual's ability to walk or ride a bicycle without falling. Additionally, this inability to engage in motor tasks with other individuals (e.g., riding bicycles with the other children in the neighborhood) may be socially isolating and have profound social impacts on an individual. Finally, cerebellar atypicalities may underlie postural instability in persons with ASD. The common presence of cerebellar atypicalities in persons with ASD may explain why motor symptoms are commonly observed in this population. However, future research will be needed to directly examine the relation among the cerebellum, postural stability, and ASD symptomatology.

Summary and Implications

The findings of the present study suggest that motor resonance, a form of automatic imitation, is intact in adolescents and adults with ASD. However, the present task differed from previous studies that found impaired motor resonance in persons with ASD in that it required participants to engage and attend to the stimuli. Therefore, when persons with ASD are instructed to attend to the stimuli, they may be more likely to exhibit automatic motor resonance compared to passive viewing.

Additionally, the results suggest that both individuals with ASD and individuals with typical development exhibited more motor resonance in response to human movement compared to object movement, in spite of previous reports that young children with ASD attend to nonsocial stimuli more than social stimuli. We additionally found that individuals with more severe ASD social symptoms (as measured by the SRS) were more likely to show decreased motor resonance. This result suggests that a sample with more severe ASD social symptoms may be more likely to demonstrate impaired motor resonance compared to a group with typical development.

In terms of general motor function, the present findings suggest that persons with ASD may have decreased postural stability compared to persons with typical development, but this decreased postural stability only reached statistical significance under certain conditions. Postural stability was found to relate to ASD symptom severity and also to empathy in the group with ASD. Future research should further examine the role and neurological basis of postural instability in persons with ASD and find ways for individuals with ASD to possibly improve their balance.

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APPENDICES

Appendix A

Institutional Review Board Approval

February 21, 2011

Office for Research

Institutional Review Board for the Protection of Human Subjects

Brittany Travers
Department of Psychology
College of Arts & Sciences
The University of Alabama

THE UNIVERSITY OF ALABAMA RESEARCH

Re: IRB # 09-OR-129-R2 "Motor Resonance in Persons with Autism Spectrum Disorders"

Dear Ms. Travers:

The University of Alabama Institutional Review Board has granted approval for your renewal application.

Your renewal application has been given expedited approval according to 45 CFR part 46. You have also been granted the requested waiver of informed consent for the psychology 101 participants. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your application will expire on February 17, 2012. If your research will continue beyond this date, complete the relevant portions of Continuing Review and Closure From. If you wish to modify the application, complete the Modification of an Approved Protocol Form. When the study closes, complete the appropriate portions of FORM: Continuing Review and Closure.

Please provide psychology 101 participants with a copy of the attached participant information sheet. Please use reproductions of the IRB approved informed consent forms to obtain consent from your participants.

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.

Sincerely,

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