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UNIVERSITY OF MIAMI

OBJECTIVE MEASUREMENT OF HEAD MOVEMENT IN AUTISM

By

Katherine B. Martin

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OBJECTIVE MEASUREMENT OF HEAD MOVEMENT IN AUTISM

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Objective Measurement of
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Motor functioning and social interactions are dynamically linked in children with Autism Spectrum Disorders (ASD), such that children with more severe social impairments also exhibit more severe motor atypicalities. Deficits in motor functioning, such as head movement atypicalities, may contribute to the perceptual and social impairments that characterize individuals with ASD. To date, deficits in motor movement in children with ASD have been characterized descriptively by human observers; however, automated measurement can provide objective, continuous measurement of head position and head movement. The objective of this study is to quantify differences in pitch, yaw, and roll in children with (n=21) and without ASD (n=33). Children without ASD were classified as low risk (n=21) or high risk dependent on having an older sibling with ASD (n=12) to investigate differences in at-risk children. Children were video recorded while watching a 16-minute video containing different blocks of social and nonsocial stimuli. Three dimensions of rigid head movement—pitch (nodding), yaw (head turns), and roll (lateral head inclinations) were tracked using an automatic person-independent tracker. Compared to low- and high-risk children without ASD, children with ASD inclined their heads (roll) with more variable speeds. As indexed by larger angular displacement of yaw and angular velocity of yaw and roll, children with ASD turned their heads to more variable positions and turned and inclined their heads with more variable speeds than

low-risk children. These group differences were specific to the social condition. By turning their heads with greater positional variability and more variable speeds, children with ASD may be regulating the amount of incoming social stimuli, perhaps in the service of enhancing their perceptual processing.

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CHAPTER 1: INTRODUCTION

Autism Spectrum Disorder (ASD) is a developmental disorder characterized by persistent impairments in social interaction and communication as well as the presence of repetitive and stereotyped behaviors (American Psychiatric Association, 2013). The perceptual and social impairments that characterize individuals with ASD may result from deficits in motor functioning. Previous research has identified deficits in motor development (Provost, Lopez, & Heimerl, 2007) and higher levels of motor stereotypies in children with ASD than children without ASD (Goldman et al., 2009). Atypical movement patterns, such as abnormalities in eye contact and body posture, are used in the evaluation of ASD, but little attention has focused on characterizing these motor differences through automated, objective measurement and none have focused on head movement (American Psychiatric Association, 2013; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Goldman et al., 2009). Given the impairments in social situations, these head movement atypicalities may be particularly prominent when engaging socially. This project examined whether differences in head movement differentiate children with and without ASD, with varying family history of ASD as they watch a video of nonsocial and social stimuli.

General Motor Movement

Motor development and social interaction skills are dynamically linked, as a complete set of functional movements is required to engage in appropriate social interactions. For example, individuals must orient their body and head to engage in direct conversation. Additionally, as a common code for nonverbal communication, typical motor behavior links the perception of other's actions and one's own actions (Wolpert, Doya, & Kawato, 2003). One example of this coordination is joint attention, where children share their mutual interest with others through the use of appropriate gaze, pointing, and showing of objects. Successful social interactions require typical coordination and motor movement initiations (Piek & Dyck, 2004).

Atypical motor movement and stereotypies have been extensively examined in the context of ASD (Bryson et al., 2007; Fournier, Hass, et al., 2010; Goldman et al., 2009; Loh et al., 2007; Ozonoff et al., 2008). ASD has often been associated with atypical gait in toddlers and children (Calhoun, Longworth, & Chester, 2011; Esposito, Venuti, Apicella, & Muratori, 2011), reduced postural stability in children (Chang, Wade, Stoffregen, Hsu, & Pan, 2010; Chen, Tsai, Stoffregen, & Wade, 2011; Fournier, Kimberg, et al., 2010; Memari et al., 2013), and increased repetitive and stereotypic behaviors in children (Goldman et al., 2009; Rodgers, Riby, Janes, Connolly, & McConachie, 2012; Singer, 2009). A recent meta-analysis revealed that motor impairments in movement preparation, upper extremity motor function, and gait were significantly more pronounced in ASD than in individuals without ASD (Fournier, Hass, et al., 2010). In adults, atypical motor stereotypies have been shown to correlate with ASD symptom severity, as adults with ASD with more motor stereotypies also display higher autism symptomatology (Bodfish, Symons, Parker, & Lewis, 2000).

Children with poor motor control may miss critical opportunities to interact with their peers, which may limit their ability to form friendships and maintain social interactions (Bhat, Landa, & Galloway, 2011). Motor delays in ASD, such as the inability to coordinate functional head and arm movements, may contribute to failures in engaging in joint attention by preventing responding to one’s name via head turning, as well as limiting reaching, pointing, and showing objects (Mundy & Newell, 2007). Therefore, basic motor abnormalities, such as head motion atypicalities, in early development may significantly contribute to the motor and the social impairments that characterize individuals with ASD.

Head Movement

Examining head motion in children may be particularly relevant for social functioning. Typical head motion serves as a form of nonverbal communication. For example, a simple nod can indicate agreement; whereas, a head shake can indicate disagreement. In addition, head motion is an important index of social interaction, as head nods and turns serve to influence turn-taking between social partners (Hammal, Cohn, Messinger, Mattson, & Mahoor, 2013). Facial expressions embedded within head movements and particular gaze patterns may differentiate between emotional states and serve as a form of nonverbal communication (Cohn et al., 2004). For example, smiling while gazing towards an individual often indexes happiness or shared enjoyment, while smiling while gazing away from an individual often indexes shame or embarrassment. Lastly, head motion may index an important regulation strategy. When exposed to an aversive stimuli, turning away often marks a child's need to self-regulate (Mundy & Newell, 2007). In summary, head motion provides valuable information to interact and communicate with others.

While research has focused on repetitive behaviors in ASD, an in depth exploration into head movement disturbances in ASD compared to no ASD groups has been limited and mostly conducted in relation to trunk posture. Goldman et al. (2009) found that head/trunk movements (head tilting, shaking, nodding; body rocking) differentiated children with low-functioning ASD (LFA), high-functioning ASD (HFA), developmental language disorder (DLD), and non-autistic-low-IQ groups (NALIQ). LFA children had the highest frequency of head/trunk movements, and ASD groups as a whole were most likely to exhibit rhythmical head/trunk movements (tilting the head from side-to-side; bending) (Goldman et al., 2009). Within a postural sway task, children with ASD moved their heads with greater positional variability than children without ASD (Chang et al., 2010). In another study of postural sway, children with ASD also produced greater side-to-side sway and greater front-to-back sway than children without ASD (Fournier, Kimberg, et al., 2010). However, little is known about the position and movement of the head in the context of ASD.

Observing children's behavior suggests ASD children have non-normative head motion. Descriptively, children with ASD have been documented to exhibit atypical head movement as they stare at their fingers or objects closely from a "strange angle" (Goldman et al., 2009), repetitively peer at objects "from the side" (Kim & Lord, 2010), and examine objects from "odd angles or peripheral vision" (Ozonoff et al., 2010). This staring at a strange angle stereotypy has garnered little attention, even though this stereotypy is viewed as highly suggestive of ASD from a clinical standpoint (Freeman, Ritvo, Guthrie, Schroth, & Ball, 1978; Goldman et al., 2009; Zwaigenbaum et al., 2005). Goldman et al. (2009) found that this stereotypy is rare, but seemingly specific to children with ASD. This rare staring from an angle stereotypy may be an adaptive strategy that provides a basis for perception and communication (Hellendoorn et al., 2014; Mottron et al., 2007). By engaging in head movement stereotypies, individuals with ASD may be regulating incoming visual and social information that is atypically processed in ASD (Mottron et al., 2007).

Detecting group differences in head movement would benefit from automated measurement. To date, deficits in motor movement in ASD have been characterized descriptively by human observers. In addition to observations by clinicians, some analyses rely on parental reports, which are prone to discrepancies and biases (Fournier, Hass, et al., 2010; Mooney, Gray, & Tonge, 2006). Coding schemes of motor movement and stereotypies are often designed for a specific study at hand with little to no independent validation (Goldman et al., 2009; Ozonoff et al., 2008). With project-specific coding, findings of motor impairments in ASD have been varied and inconsistent. Few studies have utilized automatic measures to study motor movement differences (Chang et al., 2010; Esposito et al., 2011), and even fewer studies have focused on head motion as a variable of interest (Hammal, Bailie, et al., 2013; Hammal, Cohn, & George, 2014; Hammal, Cohn, et al., 2013). In fact, within automated measurement analyses, head motion is often considered a “nuisance” variable and is controlled for as noise, rather than being a variable of interest. Given this gap in the literature, it is not surprising that studies have not utilized automated measurement to study head movement in children with ASD. However, documenting differences in head movement using automated, objective measurement may help us better understand social deficits in ASD.

In this study, we used a continuous, objective measurement system to quantify head movement differences in children with and without ASD. Additionally, we examined individuals with varying family history of ASD because high-risk siblings (i.e., children with an older sibling with ASD) have a greater likelihood of demonstrating subclinical ASD deficits, including initiating joint attention (Cassel et al., 2007; Rozga et al., 2011) and behavior problems (Gangi, Ibañez, & Messinger, 2014; Georgiades et al., 2013; Messinger et al., 2013). We hypothesized that children with ASD would exhibit greater head positions and movements than high- and low-risk non ASD groups (HR-NoASD, LR-NoASD, respectively). We also expected that children with ASD would exhibit differences from low-risk children in head positions and movements only during social stimuli, but would not differ from low-risk children during nonsocial stimuli. Lastly, we hypothesized that children with the greatest head positions and movements would exhibit higher levels of ASD symptomatology.

CHAPTER 2: METHOD

Participants

Fifty-four participants were 2.5-6.5-year-old children (mean=4.72 years, SD=1.14 years, range=2.25 years) with and without ASD, with varying family history of ASD. Children were grouped by outcome according to a confirmed diagnosis by a licensed psychologist of ASD or no ASD. The non-ASD group was further divided by whether they had an older sibling with ASD (high vs. low-risk status). Therefore, we studied three independent groups: children with ASD (n=21, 17 male, ASD), children at high risk for ASD (n=12, 8 male, HR-NoASD), and low-risk children (n=21, 14 male, LR-NoASD). Children were excluded from the study if they had a gestational age below 37 weeks or major birth complications.

Clinical diagnosis of ASD or no ASD was determined at study entry. The Autism Diagnostic Observation Schedule (Lord et al., 2000) and Autism Diagnostic Interview-Revised (Lord, Rutter, & Le Couteur, 1994) were used to inform the DSM-IV-based best estimate diagnosis from a licensed psychologist unfamiliar with a child's previous diagnosis. To obtain an index of ASD symptomatology, severity scores for social affect (SA) and restricted, repetitive behaviors (RRB) were calculated from raw scores of the ADOS (Hus, Gotham, & Lord, 2014). Groups were comparable on chronological age, $F(2,49)=2.90, p>.05$, mental age, $F(2,46)=.04, p>.05$, and gender, Fisher's exact test $p=.58$ (Table 1).

Mental Age

To assess children's mental age, children received either the Wechsler Preschool and Primary Scale of Intelligence (n=40; WPPSI-III, Wechsler, 2002) or the Mullen

Scales of Early Learning (n=7; Mullen, Mullen, 1995). To obtain a mental age from the WPPSI-III, we summed the mental ages from the 7 subtests that contribute to the IQ composite on the WPPSI-III (block design, information, matrix reasoning, vocabulary, picture concepts, word reasoning, and coding) and divided by the number of subtests. To obtain a mental age from the Mullen, we summed the mental ages from the 5 subtests (gross motor, visual reception, fine motor, receptive language, and expressive language) and divided by the number of subtests. Of 54 children, 3 children (2 ASD and 1 Low-Risk-No ASD) did not have a valid WPPSI or Mullen to include in analyses.

To assess the importance of mental age and chronological age in head movement analyses, we examined correlations of mental age and chronological age with head movement parameters. No associations of chronological age with head movement parameters and only yaw angular displacement was marginally associated with mental age, r=-.300, p=.044. Independent samples t-tests revealed no differences in head movement parameters by gender (ps>.13). Because of minimal associations with head movement parameters, mental age, chronological age, and gender were not used as covariates.

Procedure

Children were seated directly in front of the monitor while watching a video. The 16-minute video was composed of a six blocks of stimuli (Figure 1). Each block varied in length and content (i.e., social or non-social). Block 1 was a two-minute joint attention stimulus presentation of an actual boy pointing in a virtual environment to a side television of an animated character (SpongeBob), which was designed to elicit looks from the boy to the television. Block 2 was a two-minute presentation of a screensaver and served as the only non-social condition. Block 3 was a two-minute joint attention stimulus presentation of an animated boy pointing in a virtual environment to a side television of an animated character (SpongeBob), which was designed to elicit looks from the boy to the television. Block 4 was an eight-minute presentation of an emotion eliciting story of a birthday party told by a woman. Block 5 is a short one-minute Wonder Pets cartoon clip, and block 6 was a short one-minute Mickey Mouse cartoon clip. The order of the blocks was consistent across all participants.

Head Tracking

While children watched the video, a camera recorded a frontal view of the child. The video was analyzed using a person-independent tracker (http://zface.org/, Zface, Jeni, Cohn, & Kanade, 2015) For each video frame, the tracker outputs three degrees of rigid head movement—pitch (vertical movement; nodding), yaw (horizontal movement; head turns), and roll (lateral head inclinations toward the shoulder) (Figure 2).

Data Cleaning

Only frames that were correctly tracked by the automatic tracker and were free of visual errors were included in analyses. Failures were detected via automated and manual methods. An automated failure message occurred on 17.4% of the frames, which is comparable with previous work in this area (Hammal, Bailie, et al., 2013). Several conditions contributed to tracking failure, including self-occlusion (hands in the face), extreme head movement, and children out of frame when out of the chair. To assess the quality of the tracking and to remove tracking noise, a primary coder manually reviewed the tracking visualization results overlaid on the video (see Figure 2). Twenty percent of the videos were manually inspected by a second trained coder (kappa=.94). Visual inspection of the data revealed approximately 1% of the tracked frames contained errors, and these frames with errors were excluded from analyses.

Preliminary analyses of the proportion of frames successfully tracked revealed no group differences, F(52)=.213, *p*=.81. A repeated measures ANOVA indicated that the number of excluded framed varied over time (main effect of block, F(3.637, 49)=5.99, $p<.001$, partial $\eta^2=.11$, and tended to be greater in the high-risk group (a nonsignificant interaction of block by group F(7.275,49)=1.82, *p*=.08, partial $\eta^2=.07$ (Figure 3).

Data Reduction

Head movement was quantified with respect to pitch, yaw, and roll. For each of these measurements, we calculated angular displacement, velocity, and acceleration in radians for each frame of video within an epoch. An epoch was constituted of consecutive successfully tracked frames within stimulus blocks (mean epoch length= 329.11 frames, at 29.971 frames per second).

These measurements provided different aspects of head movement. Angular displacement quantifies head position in radians for pitch, yaw, and roll. Angular velocity quantifies speed of head movement and is the first derivative of displacement. Angular velocity was calculated by subtracting the previous displacement value from the current displacement value for consecutive frames within an epoch. Angular acceleration measures velocity changes in head movement for pitch, yaw, and roll and is the second derivative of displacement. Angular acceleration was calculated by subtracting the previous velocity value from the current velocity value for consecutive frames within an epoch.

Variable Transformations

The movement parameters were aggregated in three ways to capture overall direction, overall non-directional, and variability of the head angular displacement, angular velocity, angular and acceleration.

Means. Pitch, yaw, and roll can take on both positive and negative values. Means of pitch, yaw, and roll displacement, velocity and acceleration within epoch were used to capture overall directional values. A positive value for pitch indexed a nod down from neutral, while a negative value for pitch indexed a nod up from neutral. A positive value for yaw indexed a head turn to the right from neutral, while a negative value for yaw indexed a head turn to the left from neutral. A positive value of roll indexed a lateral inclination toward the left shoulder, while a negative value of roll indexed a lateral inclination toward the right shoulder.

(1) Mean of values = $\frac{x_1+x_2+\cdots+x_n}{n}$

where $x_1 \ldots x_n$ are values of pitch, yaw, or roll for consecutive frames in an epoch.

Mean of Absolute Values. Absolute values of the mean pitch, yaw, and roll were used to calculate overall (non-directional) mean values of pitch, yaw, and roll with respect to displacement, velocity, and acceleration.

(2) Mean of absolute values = $\frac{|x_1|+|x_2|+\cdots+|x_n|}{n}$

where $x_1 \ldots x_n$ are the absolute values of pitch, yaw, or roll for consecutive frames.

Root Mean Square. The root mean square (RMS) was calculated to measure the magnitude of variation of the displacement, velocity, and acceleration values for pitch, yaw, and roll. The RMS was computed as the square root of the mean of the squared values. To account for missing data and for varying lengths of epochs, the RMS value for each epoch was weighted by its epoch duration and averaged across all epochs to obtain a normalized RMS value (nRMS) for displacement, velocity, and acceleration for pitch, yaw, and roll. For means of final variables and transformations, see Table 5.

$$(3)\ nRMS_x = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots + x_n^2\right)}$$

where $x^2{}_1 \ldots x^2{}_n$ are the squared differences between the value of a frame and the mean value of frames within an epoch of pitch, yaw, or roll

Analytic Approach

To prepare for hypothesis testing to examine group differences (Aim 1), we examined how pitch, yaw, and roll were associated, by examining their intercorrelations. Overall, we expected pitch, yaw, and roll to be moderately intercorrelated for all children ($.20 < r\text{s} < .80$). To test group differences, the intercorrelations for pitch, yaw, and roll were examined by group and further examined with Fisher r-to-z test. We hypothesized a higher intercorrelation in the ASD-group of pitch, yaw, and roll than in the high-risk or low-risk non-ASD groups, reflecting more integrated but less discrete patterns of head movement in children with ASD.

The mean, mean of absolute values, and nRMS (Tables 2-4, respectively) were tested separately. Significance was tested using alpha=0.05.

Means. Overall, interrcorrelations were detected for means of displacement and velocity but not acceleration (Table 2). Group differences were detected for velocity and acceleration, but not displacement. One outlier was detected for means of velocity and acceleration, driving these differences in intercorrelations between groups. Consequently, there did not appear to be evidence for different intercorrelations between groups, *p*s>.33. Due to low intercorrelation coefficients overall, three repeated measures analysis of variance (rANOVAs) were examined separately for pitch, yaw, and roll for displacement, velocity, and acceleration.

Means of Absolute Values. Intercorrelations were detected for means of absolute values of velocity and acceleration, but not displacement (Table 3). Intercorrelations did not differ by group for displacement, velocity, and acceleration, *p*s>.21. Because intercorrelations for displacement were nonsignificant, three rANOVAs were examined separately for pitch, yaw, and roll. The intercorrelations for velocity and acceleration were strong (*r*s>.86); composite variables were formed by taking the average of pitch, yaw, and roll for each block of each subject to avoid multicollinearity in testing group differences in velocity and acceleration(Tabachnick & Fidell).

nRMS. Pitch, yaw, and roll were intercorrelated for the root mean square of displacement, velocity, and acceleration (Table 4). Intercorrelations did not differ by group for displacement, velocity, and acceleration, *p*s>.86. Since the intercorrelations for displacement and velocity were moderate (.20<*r*s<.90), separate multivariate analysis of variances (MANOVAs) were conducted to test for group differences in displacement and velocity. The intercorrelations of for acceleration were strong (*r*>.90); a composite variable was formed by taking the average of pitch, yaw, and roll for each block of each subject to avoid multicollinearity in testing group differences in acceleration (Tabachnick & Fidell).

CHAPTER 3: RESULTS

Aim 1. Objectively quantify differences in pitch, yaw, and roll by group.

Since motor stereotypies in children with ASD have been clinically described as head nods, body rocking, and staring at odd angles, we expected that children with ASD would exhibit differences in displacement, velocity, and acceleration for pitch, yaw, and roll than children without ASD (both low- and high-risk). We expected these findings for directional mean values, nondirectional overall mean values (means of absolute values), and nRMS values of pitch, yaw, and roll.

Between group differences were only found for nRMS for roll velocity. Children with ASD had greater levels of roll velocities than children without ASD (both low- and high-risk), F(2, 47) = 4.11, *p*=.023, η_p^2=.15 (Figure 4). All groups varied their pitch, yaw, and roll velocity depending on stimulus, *p*s<.05. No significant between group findings were detected when examining the means or means of the absolute values in any direction (i.e., pitch, yaw, and roll) or any head movement parameter (e.g., displacement, velocity, and acceleration), *p*s>.05. There was a main effect of stimulus block for yaw displacement for the means of absolute values, p=.008 and for the composites of velocity and acceleration, *p*s<.05, such that children showed different overall yaw displacements and overall velocities and accelerations depending on the stimulus presentation

Aim 2. Planned Contrast: Objectively quantify differences in pitch, yaw, and roll between LR-NoASD and ASD groups

An a priori follow-up contrast was planned to examine whether there was a between subjects effect between ASD and Low-Risk-No ASD children for pitch, yaw, and roll with respect to displacement, velocity, and acceleration. Between-group differences of LR-NoASD and ASD were only found for nRMS for yaw displacement and yaw and roll velocity.

Children with ASD had greater yaw angular displacement than low-risk children without ASD, F(1,37)=3.21, *p*=.044, η_p^2=.11 (Figure 6). Children with ASD had greater yaw velocity, F(1, 37)=4.00, *p*=.050, η_p^2=.10 (Figure 7) and roll velocity, F(1, 37) = 7.35, *p*=.010, η_p^2=.17 (Figure 8), than low-risk children. rANOVA on the composite variable of acceleration revealed no between group effect. All children exhibited varying degrees of pitch and yaw displacements and pitch and roll velocities depending on stimulus presentation, *p*s<.05. There was no interaction of stimulus block by group for displacement, velocity, or the composite of acceleration.

No significant between group findings were detected when examining the means or means of the absolute values in any direction (i.e., pitch, yaw, and roll) or any head movement parameter (e.g., displacement, velocity, and acceleration), ps>.05. Nevertheless, rANOVA on the means revealed an interaction of stimulus block by group for velocity of pitch, F(2.693, 102.327)=3.21, *p*=.031, η_p^2=.08 (Figure 5), driven by children with ASD exhibiting greater pitch velocities than low-risk children in Block 5 (cartoon clip). There was a main effect of stimulus block of roll for velocity, p=.015.

Aim 3. Planned Contrasts: Examine whether pitch, yaw, and roll displacement, velocity, and acceleration differ by stimulus type

Block 2 versus Block 4.

Children with ASD have been documented to exhibit preferential attention to nonsocial stimuli than social stimuli. Stimulus block was a repeated measure and a within-subjects effect of block was used to examine whether pitch, yaw, and roll variables change with respect to stimulus type for all children. We hypothesized a significant interaction of stimulus block by group. Compared to LR-NoASD children, we expected children with ASD would differ significantly in block 4 (social stimuli) on measures of pitch, yaw, and roll, but would differ less in block 2 (nonsocial stimuli) on measures of pitch, yaw, and roll. Because the two blocks differed in lengths (Block 4 was longer than Block 2), Block 4 was trimmed to be the same length as Block 2 (3595 frames).

Planned follow-up contrasts on nRMS findings revealed an interaction between stimulus block and group for yaw in displacement, $F(1,40)=9.95$, $p<.01$, $\eta_p^2=.20$, with a significant between subjects effect of group, $F(1,40)=8.14$, $p<.01$, $\eta_p^2=.17$ (Figure 9). Children with ASD had greater variability in their head position of yaw in Block 4 (social block) than LR-NoASD children and did not differ in head position in Block 2 (nonsocial block) than LR-NoASD children. There was also an interaction between stimulus block and group for velocity of yaw, $F(1,40)=8.35$, $p<.01$, $\eta_p^2=.17$, with a significant between subjects effect of status, $F(1,40)=4.90$, $p=.033$, $\eta_p^2=.11$ (Figure 10) and velocity of roll $F(1,40)=4.27$, $p=.045$, $\eta_p^2=.10$, with a significant between subjects effect of status, $F(1,40)=4.69$, $p=.036$, $\eta_p^2=.11$ (Figure 11). Children with ASD had greater variability in their speed of head movement of yaw and roll in Block 4 (social block) than LR-NoASD children and did not differ in their speed of head movement of yaw and roll in Block 2 (nonsocial block) than LR-NoASD children.

Block 1 versus Block 3.

Children with ASD were expected to show more typical motor control when viewing the animated boy than the actual boy stimuli. We hypothesized that children with

ASD might show more typical measures of pitch, yaw, and roll than children without ASD when viewing the animated boy (block 3) than the actual boy (block 1). MANOVA on displacement and velocity revealed no interaction of stimulus block by group, no main effect of stimulus, and no between subjects effect of group for pitch, yaw, and roll, *p*s>.05. rANOVA on the composite acceleration revealed no interaction of stimulus block by group, no main effect of stimulus, and no between subjects effect of group, *p*s>.05

Aim 4. Test for associations between pitch, yaw, and roll and ASD severity scores.

To examine the relationship between head coordination/control and ASD symptomatology, we correlated nRMS displacement, velocity, and acceleration for pitch, yaw, and roll with social affect and repetitive behavior symptom severity scores from the ADOS. The analysis was first carried out for all children and then repeated within each group. Since motor control and social interactions are intricately linked, we expected significant positive correlations between pitch, yaw, and roll with social affect and repetitive behavior symptom severity scores in the entire sample (ASD, High-Risk-No ASD, and Low-Risk-No ASD), and in analyses including only children with ASD.

Over all groups, children with greater variability in displacement in yaw showed higher levels of repetitive behaviors (*r*=.35, *p*<.01) and social affect deficits (*r*=.28, *p*<.05) (Table 5, Figures 12 & 13). Unexpectedly, within the ASD group, children with less variability in velocity and acceleration in pitch, yaw, and roll showed greater levels of repetitive behaviors (*r*s>-.40, *p*<.05. Children with ASD with greater variability in displacement in pitch showed higher levels of social affect deficits (Table 6). For significant correlations of nRMS, correlations were plotted and two subjects were identified as possible outliers through their studentized residuals (*r'i* >+2.0).

Consequently, there was no evidence that velocity and acceleration in pitch, yaw, and roll was correlated with repetitive behaviors when the outliers were removed.

CHAPTER 4: DISCUSSION

This study is the first to use objective measurements to quantify head movement differences in children with and without ASD. As such, these analyses are exploratory, and the most robust findings (nRMS) are emphasized here. Using automated, objective measurement, we documented differences in head position and head movement between children with and without ASD, shedding light on head movement atypicalities in ASD previously noted by clinicians.

Consistent with previous work on head movement (Chang et al., 2010; Chen et al., 2011; Hammal, Cohn, et al., 2013), nRMS (a measure of the magnitude of variation around the mean within an epoch) yielded the strongest and most consistent results. Previous work has focused on nRMS values of head position during postural sway tasks, in order to capture group differences of the magnitude of variation. In our sample, children with ASD moved their heads on a lateral incline (roll) with greater variability in speed than children without ASD (low- and high-risk).

Findings were strongest in the planned contrast (Aim 2) when the high-risk group without ASD was excluded. Children with ASD held their heads in turned positions (yaw) with greater variability than children without ASD. Children with ASD also turned their heads (yaw) and inclined their heads (roll) with greater variability in speed than children without ASD. These findings are similar to results of a postural sway task. In the postural sway task, children with ASD moved their heads with greater positional variability in both the anterior-posterior (front-to-back) and medial-lateral (side-to-side) axes than did children without ASD (Chang et al., 2010; Fournier, Kimberg, et al., 2010).

Together, these findings suggest that children with ASD hold and move their heads with greater variability than children without ASD.

We expected to find evidence of a left-bias laterality for children with ASD (Cohen, Gardner, Karmel, & Kim, 2014), but not for children without ASD, but mean results did not support this hypothesis. We also examined the absolute values of pitch, yaw, and roll to capture overall (non-directional) mean displacement, velocity, and acceleration. We expected to find evidence for overall mean differences between groups, but children with ASD did not show greater mean levels of displacement, velocity, nor acceleration than children without ASD.

Automated measurement characterized and quantified the clinical descriptions of strange angle stereotypies in ASD. Clinical descriptions suggest that some children with ASD repetitively peer at objects from strange angles and from the side—termed "strange angle stereotypy"(Goldman et al., 2009). In our sample, automated measurement revealed that children with ASD exhibited the strange angle stereotypy in the x-axis, as they had greater variability in yaw displacement than children without ASD. In addition, automated measurement revealed that children with ASD moved their heads with more variables speeds from left to right (yaw) and on an incline (roll) than children without ASD. Automated measurement allowed us to objectively characterize and quantify head movement atypicalities in children with ASD that had previously been described qualitatively.

Automated measurement also allowed us to quantify differences in head movement by stimulus sociality. Children with ASD have specific social impairments, and we explored whether head positions and movements differed with respect to stimulus sociality. Follow-up a priori contrasts of children with and without ASD examined head position and movement differences between social and nonsocial stimuli. Children with ASD did not differ from children without ASD in their yaw displacement or in their yaw and roll velocity during the nonsocial stimulus. However, children with ASD had greater yaw displacement and yaw and roll velocity during the social stimulus than children without ASD. Children with ASD have more variable head position and head movements than children without ASD during social blocks, but children with ASD have similar patterns of head position and movements to children without ASD during the nonsocial blocks.

More displacement and velocity in children with ASD may reflect an adaptive strategy that regulates the amount of visual and social information processed. Children with ASD may be using head position and movement as a way to modulate their sensory experience (Dunn, 1997). Previous research using eye-tracking has found that children with ASD look less at social stimuli than nonsocial stimuli (Chawarska, Macari, & Shic, 2013; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011), suggesting children with ASD shift their gaze to regulate overstimulating social information. Children with ASD may adopt more extreme head positions and more variables speeds than children without ASD during the social stimulus than during the nonsocial stimulus to regulate the amount of incoming social information. One theory that might account for greater head position and movement in children with ASD is the weak coherence model. Previous literature has suggested that children with ASD have weak coherence (Happé & Frith, 2006; L. Mottron, Dawson, Soulières, Hubert, & Burack, 2006), which results in heightened detail perception and reduced global processing. This reduction in global processing may account for the deficits in social interaction that characterize individuals with ASD, since viewing faces and engaging with social partners requires both local level processing and global level processing (Happé & Frith, 2006). In an effort to reduce the amount of information during a social situation, children with ASD may turn their heads as a strategy to decrease the amount of incoming visual information and maximize their ability to process the information. Thus, sensory modulation may account for the head movement differences seen in the current study, marking a child’s need to self-regulate (Mundy & Newell, 2007).

Associations of Pitch, Yaw, and Roll with ASD Symptomatology

In addition to group differences, we expected to find that higher displacement, velocity, and acceleration would be associated with higher ASD symptomatology in both the social affect and repetitive behavior domains. With the entire sample, we found that greater variability in head turns (yaw displacement) was associated with higher ASD symptomatology in both the social affect and repetitive behavior domains. Within the ASD group, we expected to find that children with ASD who had greater head position and movement would shower higher levels of restricted and repetitive symptomatology. Instead, within the ASD group, greater variability in pitch, yaw, and roll of velocity and acceleration was associated with lower ASD symptomatology in the repetitive behavior domains, which was the opposite direction than expected. However, these results should be interpreted with caution because of two outliers in the ASD group.

Limitations and Future Directions

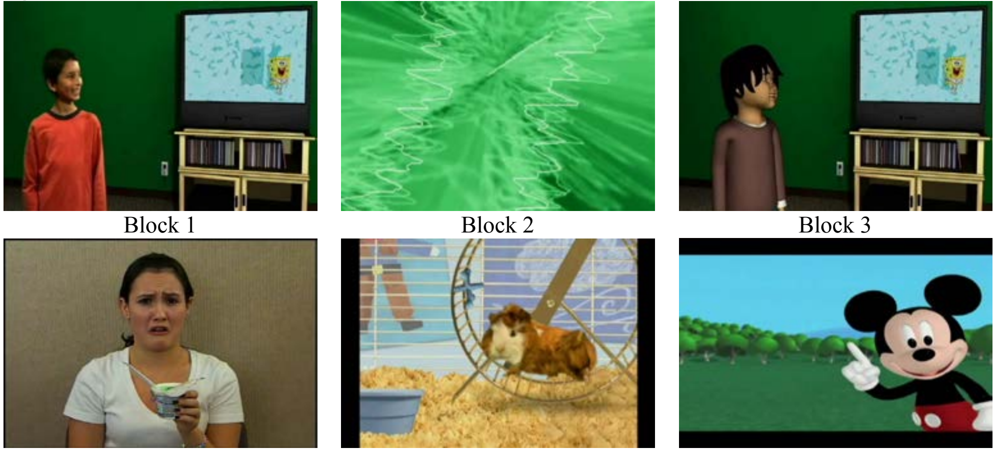
Head position and movement were examined with a small sample, highlighting the need for a larger sample. The high-risk group without ASD was particularly small in this study (n=12), and there may have not been enough power to detect differences between low-risk and ASD groups. High-risk children without ASD are particularly important, as they are by definition a heterogeneous group, with varying levels of ASD symptoms. Future researchers should examine whether high-risk children without a diagnosis hold and move their heads in an atypical manner that might suggest subclinical movement deficits. Larger group sample sizes would allow for more reliable testing of associations between head movement parameters and severity score domains, and would not be prone to the outlier effects that occurred in this study. Of particular interest is whether these head movement differences in ASD are characterizing the same construct of RRB as clinical ratings of RRB used in diagnostic evaluations.

While use of automated measurement marks a remarkable jump forward in objectively quantifying head movement behavior, there are some limitations associated with the tracker to note. The automated tracker tracked the video recordings of children watching a video on a monitor, but many of these children moved around and some children left their seats. Because of child movement and the inability of the automated tracker to track extreme movement (like a child leaving his/her seat), there were missing data (~17%). While missing data did not vary by group, missing values resulted in examining the data with respect to a child's epoch rather than examining the entire session as a whole. Means, means of absolute values, and nRMS values were all examined with respect to an epoch and then averaged across epochs to obtain a single overall value for a given subject. Future work should harness the power of the repeated nature of the measurement and examine the dynamics of head movement.

Despite the limitation in sample size and possible outliers, the results are a promising advancement in characterizing head position and movement objectively. Using automated measurement, we objectively quantified differences in head position and head movement between children with and without ASD, finding that children with ASD had greater variability in yaw displacement and greater variability in yaw and roll velocity, and that these differences were most pronounced during social stimulus presentation. Using this automated measurement system, researchers may be able to better quantify head movement behaviors in children with varying levels of ASD behaviors and further examine relationships with ASD outcome and symptomology.

FIGURES

Figure 1. Stimuli presentation by block



Block 1 Block 2 Block 3

Block 4 Block 5 Block 6

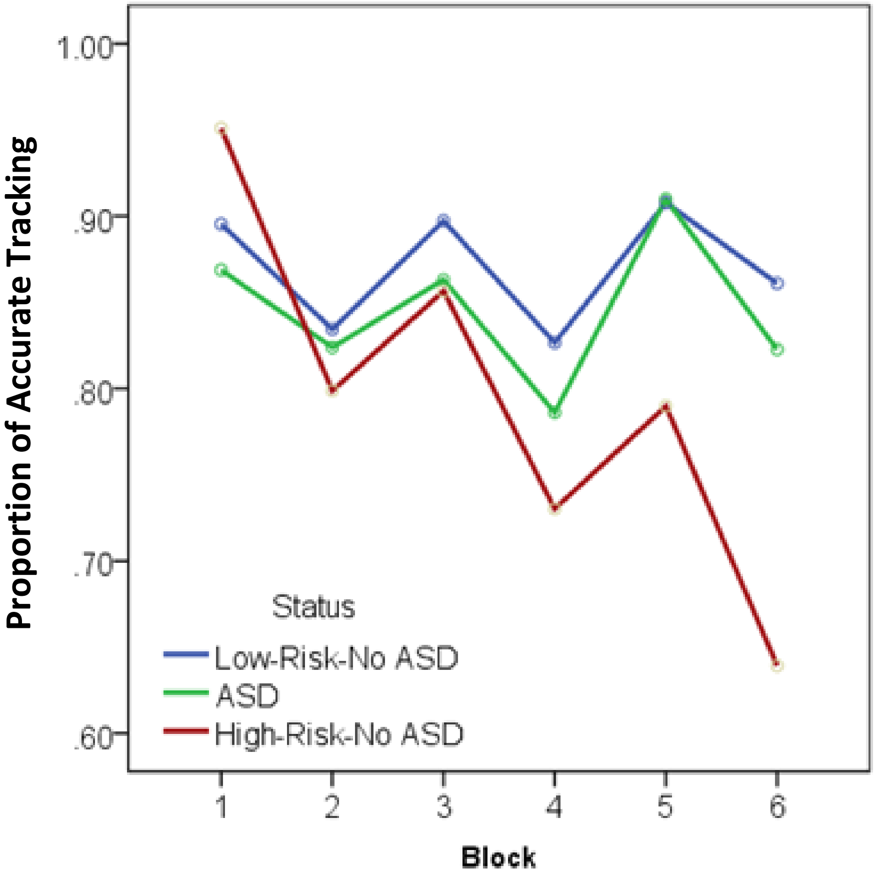
Note. Block 1, 3, 4, 5, 6 are social stimuli. Block 2 is nonsocial stimuli.

Figure 2. Head orientation

Pitch **Yaw** **Roll**

Note. Pitch (green), yaw (blue), roll (red)

Figure 3. Proportion of accurate tracking by group



Note. A repeated measures ANOVA indicated a main effect of block and a nonsignificant interaction of block by ASD status. One High-Risk-No ASD child who was not tracked for block 5 and block 6. Removing the child from analyses results in an interaction effect of p>.15.

Figure 4. *Children with ASD have greater roll angular velocity than children without ASD (low- and high-risk).*

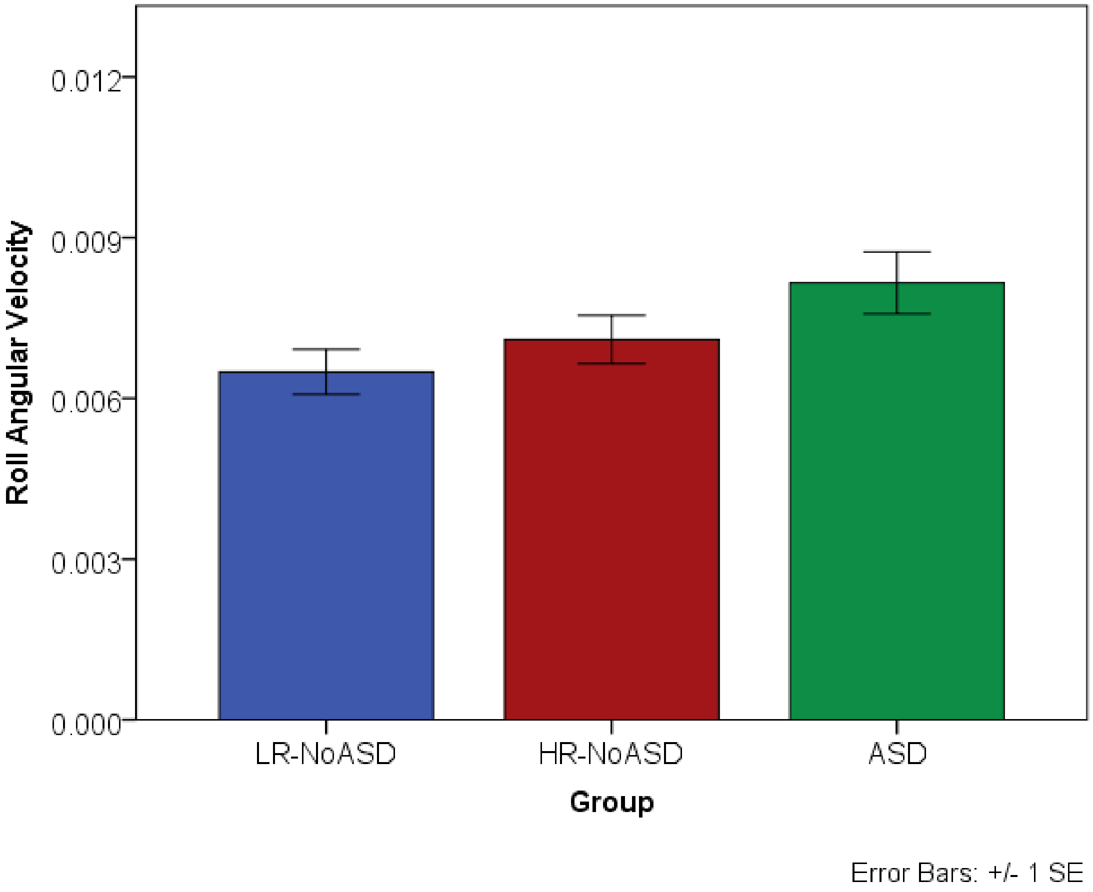


Figure 5. Interaction of pitch angular velocity by stimulus presentation

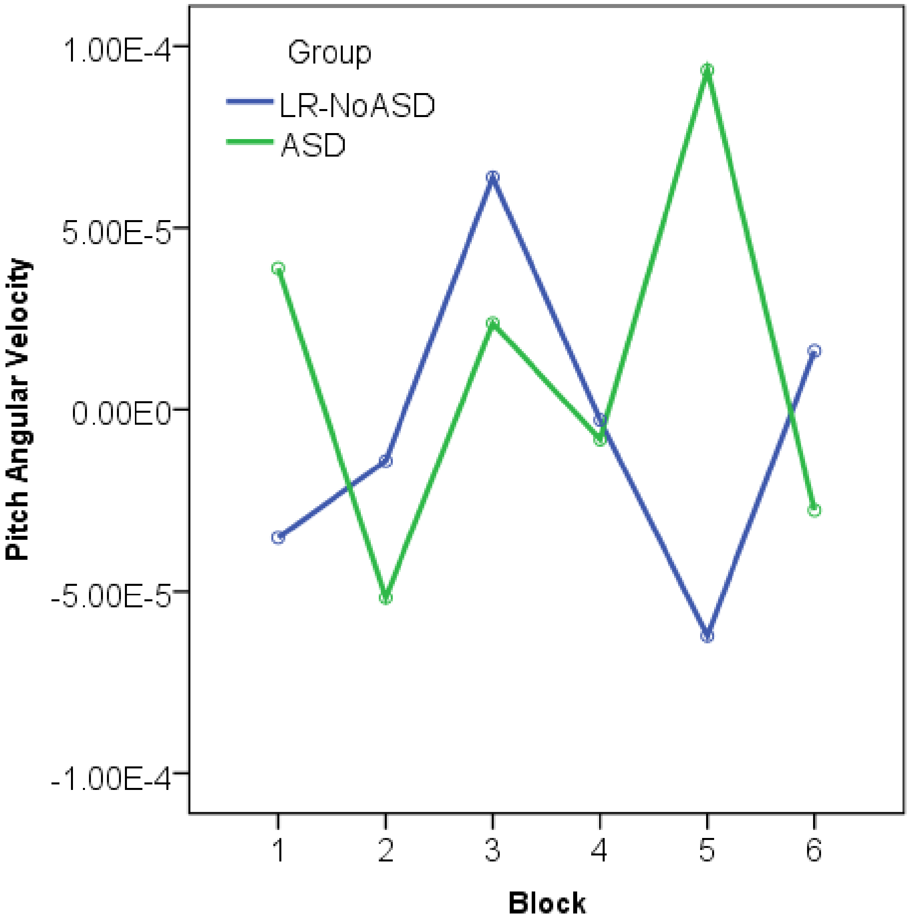


Figure 6. Children with ASD have greater yaw angular displacement than LR-NoASD

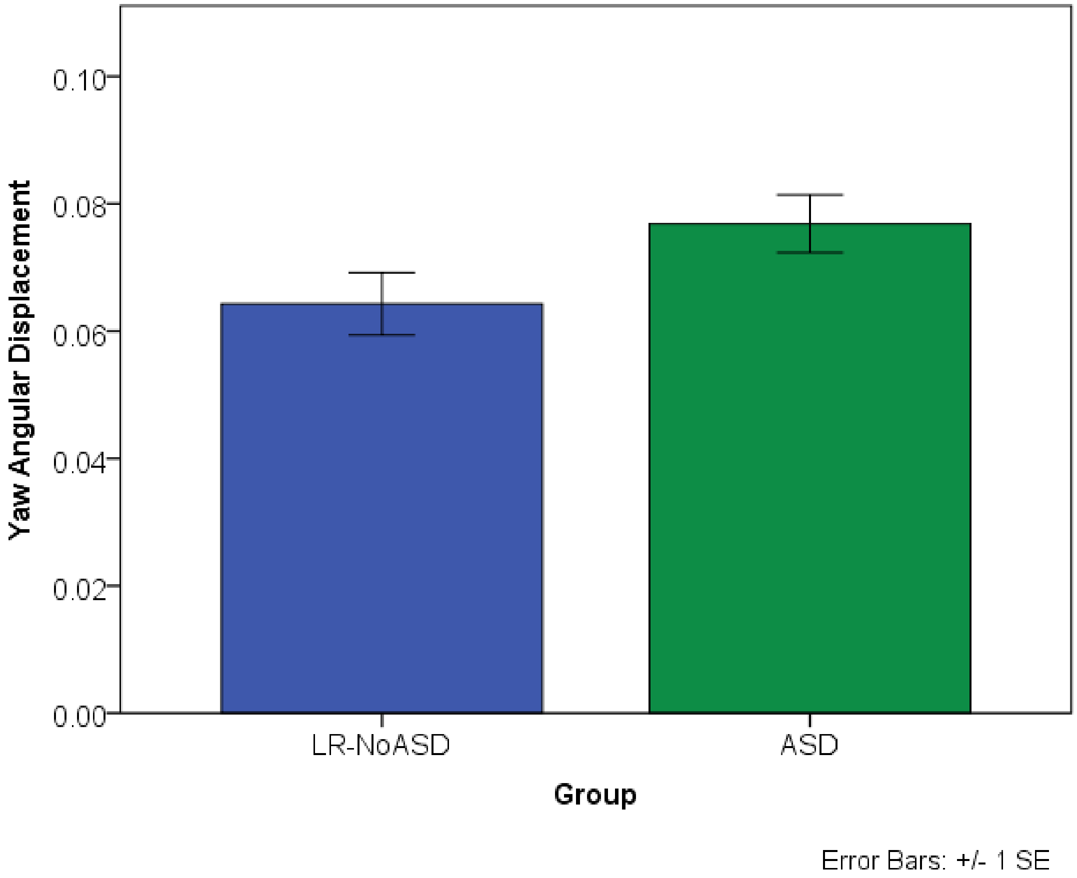


Figure 7. Children with ASD have greater yaw angular velocity than LR-NoASD

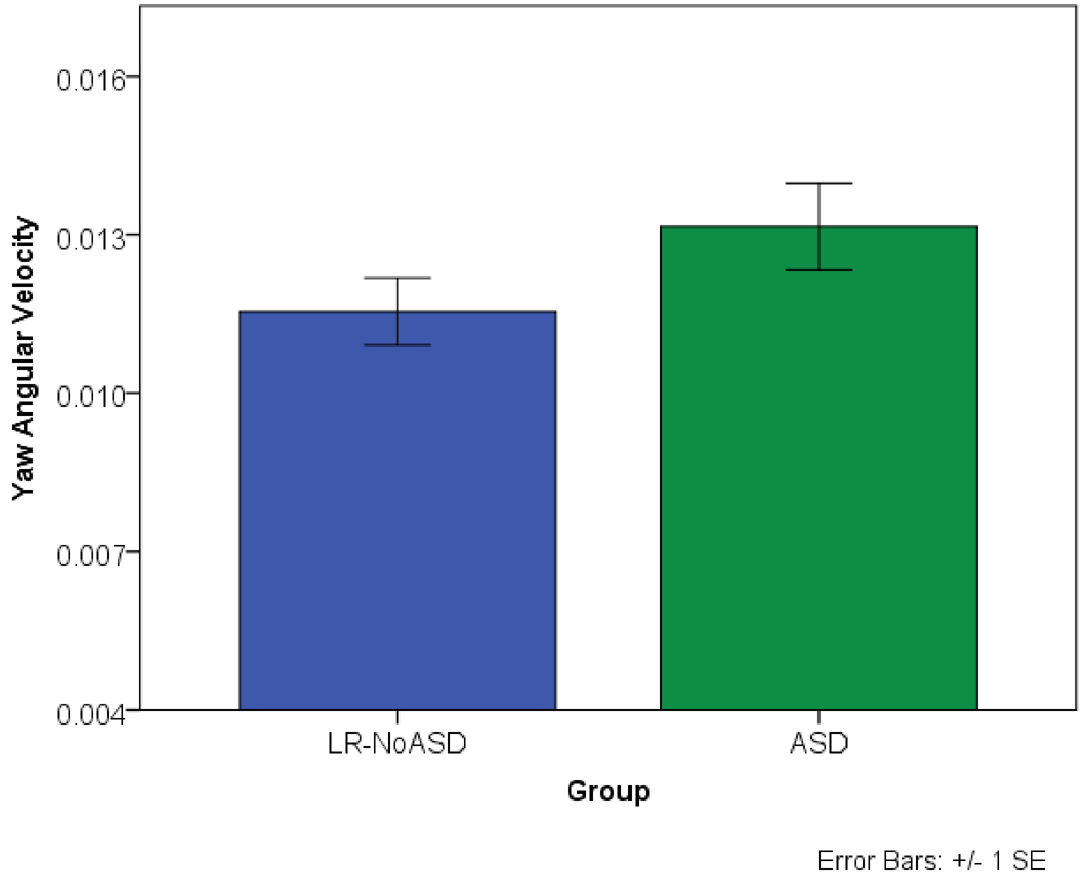


Figure 8. Children with ASD have greater roll angular velocity than LR-NoASD

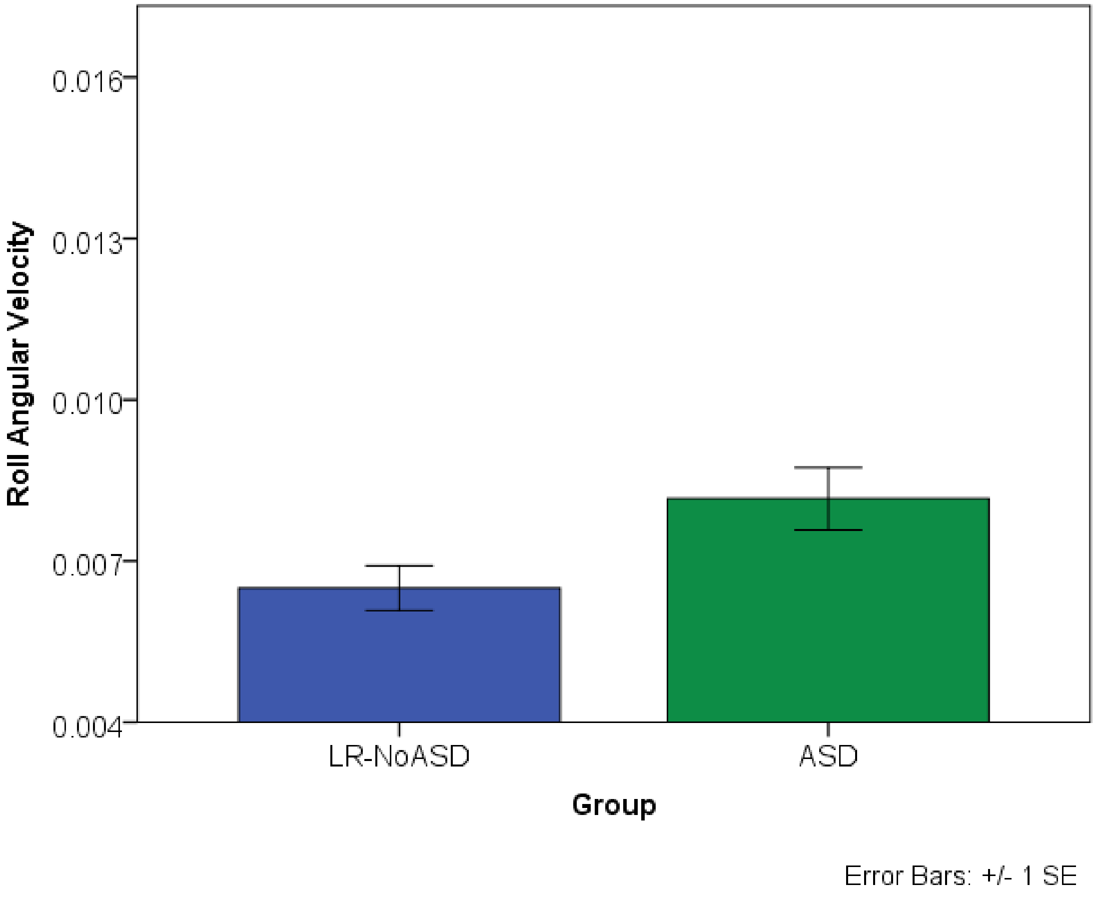


Figure 9. Interaction of yaw angular displacement by stimulus presentation

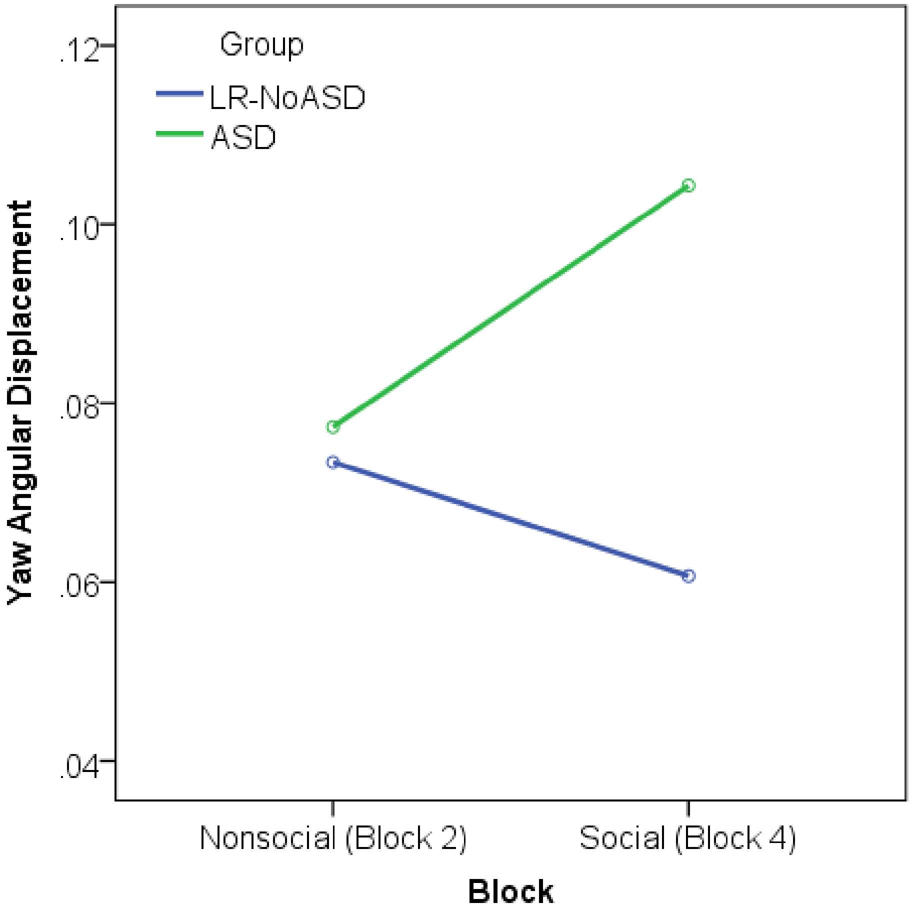


Figure 10. Interaction of yaw angular velocity by stimulus presentation

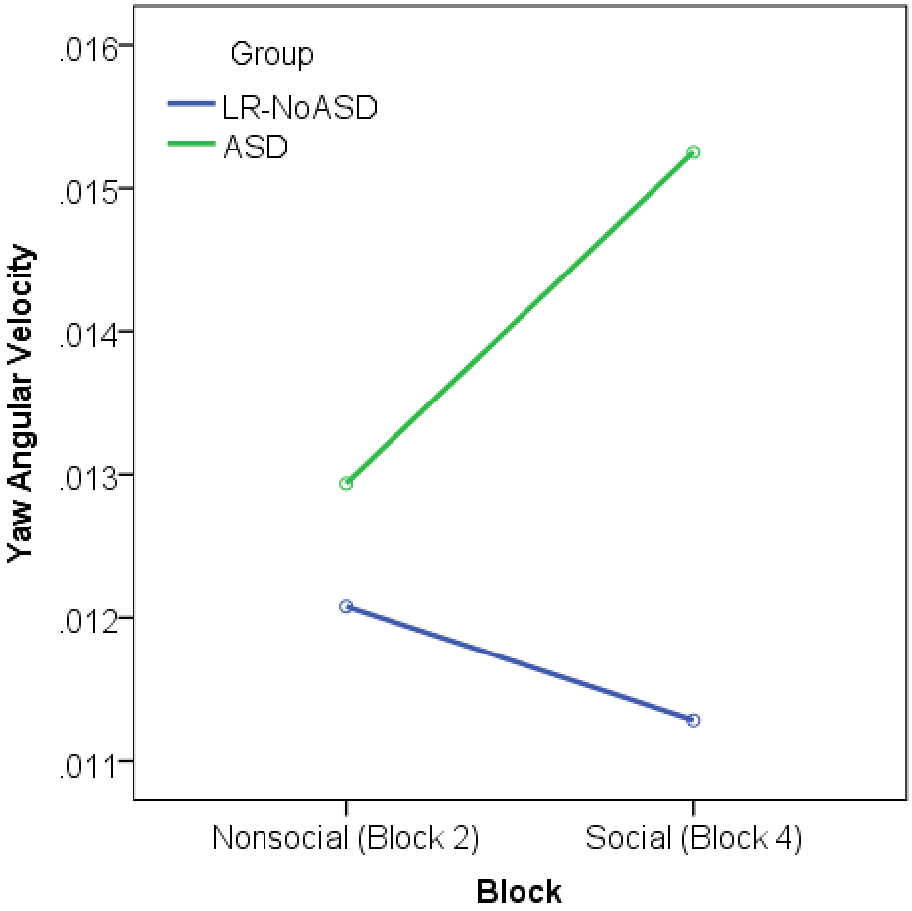


Figure 11. Interaction of roll angular velocity by stimulus presentation

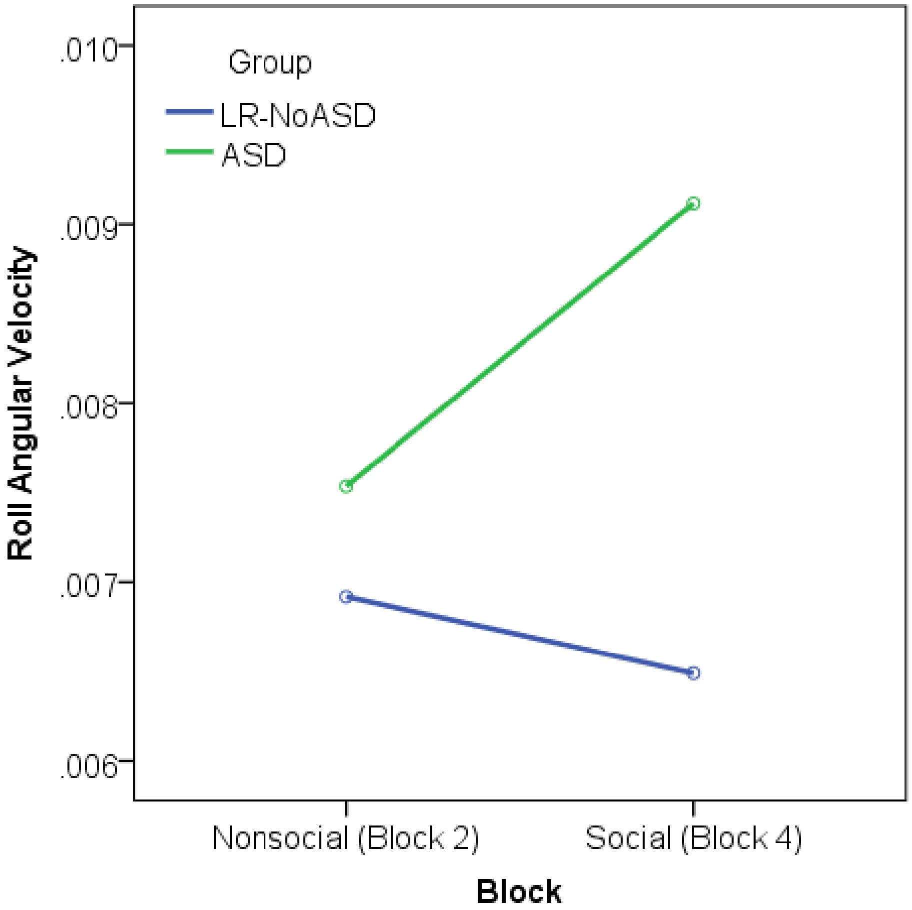


Figure 12. nRMS- Associations of yaw angular displacement with social affect severity

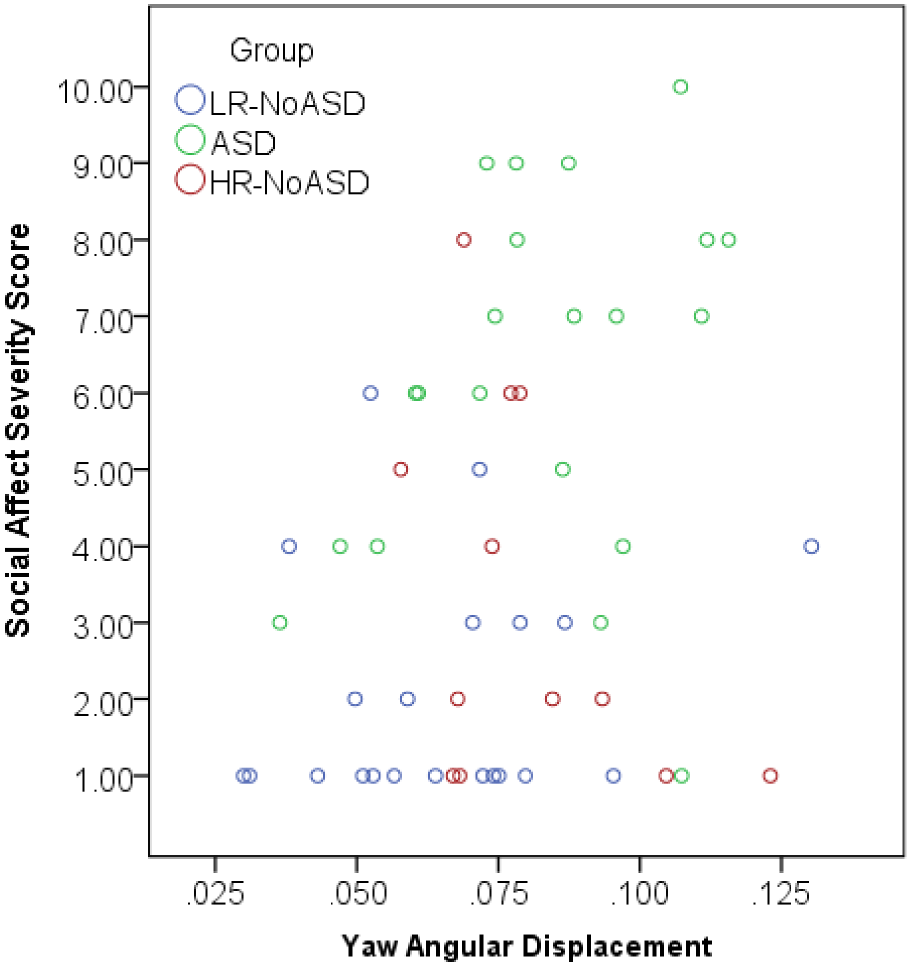
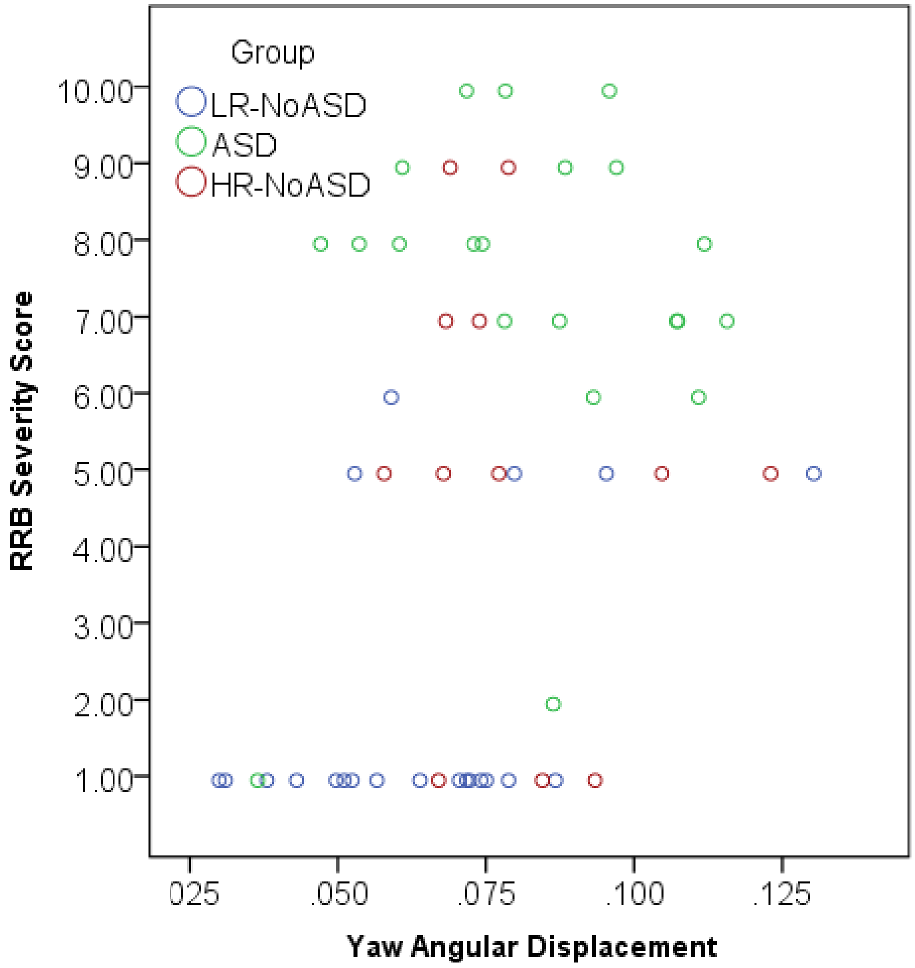


Figure 13. nRMS- Associations of yaw angular displacement with RRB severity



TABLES

Table 1. Chronological Age and Mental Age by Group

		N	Mean	SD
Age at Visit (months)	LR-NoASD	21	51.05	15.46
	HR-NoASD	12	53.75	10.02
	ASD	21	61.76	16.29
Mental Age (months)	LR-NoASD	20	14.6	3.26
	HR-NoASD	12	12.66	3.65
	ASD	19	22.95	5.26

Table 2. Intercorrelations of Pitch, Yaw, and Roll

		Means								
		Displacement			Velocity			Acceleration		
		Pitch	Yaw	Roll	Pitch	Yaw	Roll	Pitch	Yaw	Roll
Displacement	Pitch	1	-0.109	0.082	-	-	-	-	-	-
	Yaw		1	-.289*	-	-	-	-	-	-
	Roll			1	-	-	-	-	-	-
Velocity	Pitch				1	-.715*	.934*	-	-	-
	Yaw					1	-.731*	-	-	-
	Roll						1	-	-	-
Acceleration	Pitch							1	0.002	0.193
	Yaw								1	-0.468
	Roll									1

Table 3. Intercorrelations of Pitch, Yaw, and Roll

		Means of Absolute Values								
		Displacement			Velocity			Acceleration		
		Pitch	Yaw	Roll	Pitch	Yaw	Roll	Pitch	Yaw	Roll
Displacement	Pitch	1	-0.089	-0.224	-	-	-	-	-	-
	Yaw		1	0.248	-	-	-	-	-	-
	Roll			1	-	-	-	-	-	-
Velocity	Pitch				1	.864*	.911*	-	-	-
	Yaw					1	.911*	-	-	-
	Roll						1	-	-	-
Acceleration	Pitch							1	0.865*	0.964*
	Yaw								1	0.915*
	Roll									1

Table 4. Intercorrelations of Pitch, Yaw, and Roll

		nRMS								
		Displacement			Velocity			Acceleration		
		Pitch	Yaw	Roll	Pitch	Yaw	Roll	Pitch	Yaw	Roll
Displacement	Pitch	1	0.561*	0.575*	-	-	-	-	-	-
	Yaw		1	0.540*	-	-	-	-	-	-
	Roll			1	-	-	-	-	-	-
Velocity	Pitch				1	0.847*	0.790*	-	-	-
	Yaw					1	0.861*	-	-	-
	Roll						1	-	-	-
Acceleration	Pitch							1	0.890*	.900*
	Yaw								1	.906*
	Roll									1

Table 5. Associations of nRMS with Severity

		Social Affect Severity	RRB Severity
Displacement	Pitch	0.206	0.153
	Yaw	.277*	.354*
	Roll	0.025	0.179
Velocity	Pitch	0.071	-0.082
	Yaw	0.149	0.062
	Roll	0.203	0.11
Acceleration	Pitch	-0.028	-0.162
	Yaw	0.026	-0.071
	Roll	0.063	-0.074

*p<.05

Table 6. Associations of nRMS with Severity

			Social Affect Severity	RRB Severity
LR-NoASD	Displacement	Pitch	0.017	0.071
		Yaw	0.199	0.427
		Roll	-0.162	0.162
	Velocity	Pitch	0.11	-0.11
		Yaw	0.208	0.163
		Roll	0.174	0.181
	Acceleration	Pitch	0.061	-0.084
		Yaw	0.105	0.036
		Roll	0.166	0.092
ASD	Displacement	Pitch	0.443*	0.176
		Yaw	0.285	0.132
		Roll	0.192	0.074
	Velocity	Pitch	-0.202	-0.446*
		Yaw	-0.19	-0.462*
		Roll	-0.035	-0.460*
	Acceleration	Pitch	-0.29	-0.489*
		Yaw	-0.278	-0.449*
		Roll	-0.217	-0.552*
HR-NoASD	Displacement	Pitch	-0.514	-0.342
		Yaw	-0.422	-0.182
		Roll	-0.45	-0.08

Velocity	Pitch	-0.133	-0.347
	Yaw	-0.125	-0.153
	Roll	-0.427	-0.215
Acceleration	Pitch	-0.058	-0.36
	Yaw	0.021	-0.28
	Roll	-0.347	-0.488

*p<.05

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