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Effect of Visual Information on Postural Control in Adults with Autism Spectrum Disorder

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Abstract

Sensory processing difficulties affect the development of sensorimotor skills in individuals with autism spectrum disorder (ASD). However, the effect of sensory information on postural control is unclear in the ASD adult population. The present study examined the effect of visual information on postural control as well as the attentional demands associated with postural control in fourteen adults with ASD and seventeen typically developed adults. The results showed that postural sway and attention demands of postural control were larger in adults with ASD than in typically developed adults. These findings indicate that visual processing used for postural control may be different in adults with ASD. Further research in visual field processing and visual motion processing may elucidate these sensorimotor differences.

Keywords Autistic disorder · Sensory information · Visual processing · Attention · Postural balance · Sensorimotor

Introduction

Although autism spectrum disorder (ASD) is a neurodevelopmental disorder primarily associated with impairments in socio-communicative interaction, restricted interests, and/or repetitive patterns of behaviors (American Psychiatric Association 2015), difficulties with sensory processing are also found in individuals with ASD (Tomchek and Dunn 2007; Simmons et al. 2009; Marco et al. 2011). Many of those with ASD exhibit a pattern of elevated sensory modulation (Ben-Sasson et al. 2009), reflecting an impaired capacity to

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regulate and organize sensory information in an adaptive manner (Lane et al. 2000), which may have a substantial impact on the development of social, cognition, and sensorimotor skills in individuals with ASD (Dunn 1997).

Earlier research suggests difficulties with processing sensory information might contribute to the differences in postural control observed between individuals with ASD and typically developed individuals (Memari et al. 2014; Lim et al. 2017). Postural control is a fundamental motor skill that involves multiple sensorimotor processes, in which some processes rely on visual, somatosensory, and vestibular information (Peterka and Loughlin 2004; Horak 2006). When sensory processing is compromised, the reliability of sensory information may be reduced, resulting in postural instability (Horak et al. 1990; van der Kooij et al. 1999). This linkage of sensory processing capabilities with postural control difficulties is important because it provides contextual evidence of the challenges individuals with ASD may face during participation in daily life. The impact of sensory processing difficulties on individuals with ASD may not be easily observable, but its impact on postural control may affect the motor and social development of children with ASD (Memari et al. 2014; Casartelli et al. 2016), and increase risk factor for falls in older adults with ASD (Melzer et al. 2004).

Despite the growing research in sensory information and postural control in the ASD literature, the effect of sensory

information on postural control remains unclear in the adult population. Many of these studies focused on the influence of visual input on postural control but findings have been inconsistent (Minshew and Keller 2010; Travers et al. 2013; Morris et al. 2015; Doumas et al. 2016). Travers et al. (2013) assessed postural responses of adults in the eyes open condition and found that there was no difference between adults with ASD and typically developed adults. In contrast, Minshew et al. (2004) found that postural responses were larger in the ASD group than in the control group. The discrepancies may be due to the use of various measures of postural control in different studies. Each measure of postural control represents a specific aspect of postural control (Memari et al. 2014); for instance, measures of sway displacement reflect the effectiveness of the postural control system to achieve stability while the measure of velocity reflects the amount of control activity to achieve stability (Prieto et al. 1996). Existing research has mainly reported on measures related to the extent of sway displacement along the respective anteroposterior (AP) and mediolateral (ML) planes (Minshew et al. 2004; Morris et al. 2015; Doumas et al. 2016). However, a combined analysis of measures that represent both effectiveness of the postural control system and the amount of control activity may provide a more comprehensive evaluation of the influence of visual information on postural control in adults with ASD.

Besides visual information, postural control relies on attention, one aspect of the information processing capacity of an individual (Woollacott and Shumway-Cook 2002). The demand for attention typically increases when a postural task becomes more difficult (Siu and Woollacott 2007). Signal analysis using *sample entropy* quantifies the automaticity of postural control, so reflecting the attentional demand (Richman and Moorman 2000). While the amount of attention invested in standing has been reported to be different between pathology and typically developed groups (Donker et al. 2007; Roerdink et al. 2011), there is a paucity of information about attentional demands in relation to postural control for adults with ASD. Therefore, the aims of the present study were to examine the effect of visual information on static standing postural control and the attentional demands associated with postural control between adults with ASD and typically developed controls in the eyes open and eyes closed conditions.

Methods

Participants

Fourteen adults with ASD (18–50 years old) were recruited through the expression of interest from a participant recruitment database maintained by the Curtin

Autism Research Group at Curtin University in Western Australia. Seventeen typically developed adults (18–37 years old) were recruited through word of mouth and advertising on flyers. Detailed characteristics of the groups are presented in Table 1. All participants had no history of seizure or epilepsy, had normal or corrected to normal vision, and had a score greater than 70 on the Wechsler Abbreviated Scale of Intelligence—Second Edition (Wechsler 2011). Visual acuity was tested with the 2 Meter 2000 Series Revised Early Treatment Diabetic Retinopathy Study Chart (Prevision Vision 2014). All participants provided written consent to participate in the research. Ethical approval was obtained from the Curtin University Human Research Ethics Committee (Approval Number HR28/2016) and was performed in accordance with the guidelines of the Helsinki Declaration.

Adults with ASD were excluded if they did not have a diagnosis of ASD by licensed clinical professionals, had a history of severe brain injury or other neurological disorders, and were prescribed antipsychotic medication at the time of testing. Two participants with ASD took stimulant medication and three participants took antidepressant medication for treatment of anxiety. Seven adults with ASD also had comorbidities including anxiety (n=4), depression (n=4), obsessive–compulsive disorders (n=1), and ankylosing spondylitis (n=1).

Typically developed adults were excluded if they had a history of neurological or musculoskeletal deficits that could affect postural control, had known family history of autism, and obtained a score greater than 59 on the Social Responsiveness Scale (SRS)—Second edition (Constantino and Todd 2005). SRS is an assessment of ASD severity score with a cut-off score of 59 or less to indicate typical development in areas of socio-communication and behavior (Constantino and Todd 2005). None of the participants in the typically developed group had comorbidities.

Table 1 Participant characteristics

Characteristic	ASD (n=14)		Typical developed (n=17)		p
	Mean	SD	Mean	SD	
Age (years)	23.6	8.1	26.8	7.0	0.13
Gender (female/male)	3/11		1/16		0.30
WASI	105.0	14.5	110.7	10.9	0.22
SRS	65.6	6.8	51.5	6.1	<0.0001
Height (cm)	176.7	8.1	174.8	7.0	0.53
Weight (kg)	77.1	11.9	74.5	15.5	0.62

ASD autism spectrum disorder, *SD* standard deviation, *SRS* Social Responsiveness Scale, *WASI* Wechsler abbreviated scale of intelligence

Apparatus and Stimulus

Measures of static standing postural control were recorded using the AccuGait force platform (Advanced Mechanical Technology Inc.) at the sampling frequency of 100 Hz. Participants stood on the force platform 2 m from a 4-m diameter half-dome concave screen, with a 180° horizontal viewing surface (Fig. 1). Participants were shown a red dot with a white border, positioned in the center of a grey background. The resolution of the stimulus was 2560×1600 pixels and was generated using the Projection Design F35 projector. The stimulus was controlled using the SMI Experimental Centre 3.5 software (SensoMotoric Instruments). An SMI RED250Mobile remote eye tracker, with a gaze position accuracy of 0.4°, was positioned approximately 60 cm in front of the participant. Two white circles were displayed on the computer screen when the eye tracker detected the pupils of the participant's eyes; however, a grey screen was displayed when the pupils of the eyes were not detected. This enabled the first author to monitor the compliance of the participants in the eyes open and eyes closed conditions.

Procedure

Participants followed a standardized procedure, which was to stand as still as possible in the middle of the force platform with their feet shoulder-width apart and arms placed comfortably at the side of the body. The first author stood close to each participant to supervise and provide support if required. Prior to the trial, the drapes surrounding the half-dome screen were drawn and the lights in the room were switched off. In the eyes open condition, participants had to fixate on the red dot throughout the trial. In the eyes closed

Fig. 1 Photo of a participant looking at the visual stimulus displayed on the half-dome concave screen while standing on the force platform. An eye tracker was placed in front of the participant

condition, participants had to keep their eyes closed. Each trial lasted for 30 s. There was no practice trial and only one trial of each condition was performed.

Postural Control Data

Measures of postural control consisted of center-of-pressure mean displacement, standardized deviation of mean displacement (RMS), and velocity. Center-of-pressure is a point that represents the weighted average of the pressure of the surface area in contact with the force platform (Berencsi et al. 2005). A Butterworth low pass filter at 10 Hz was performed on the center-of-pressure measures, with the exception of data used to measure attentional demands associated with postural control (Deffeyes et al. 2009). In addition, these measures were corrected to the baseline position of each participant two seconds before the start of each experimental condition. Mean displacement indicated the central tendency of the center-of-pressure recorded during the trial. RMS indicated the variation of the displacement traveled about the central tendency of the center-of-pressure during the trial. In the AP plane, a positive value specified a forward leaning position from the baseline while a negative value specified a backward leaning position from the baseline. In the ML plane, a positive value specified a leaning position right of the baseline while a negative value specified a leaning position left of the baseline. Velocity refers to the total distance traveled over the total time of the trial (Memari et al. 2013). Data were processed using MATLAB 2015b (The MathWorks).

Sample entropy, a measure of regularity of the signal in a time series data, was used to assess the attentional demands associated with postural control (Richman and Moorman 2000). Sample entropy reports on the similarity of time series data, where *m* represents the length of a data sample to be compared and *r* represents the tolerance range for accepting matched comparisons (Richman and Moorman 2000). A smaller sample entropy indicates regular changes in the sway displacement and relates to a lower automaticity of postural control, reflecting an increase in attentional demands (Roerdink et al. 2011). The algorithm used for calculating sample entropy was obtained from PhysioNet (Lake et al. 2016).

Statistical Analysis

The *a priori* alpha was set at 0.05 for all tests and a more stringent *p* value of 0.01 was used for pairwise comparisons to reduce the chance of a Type I error. All analyses were performed using SPSS 24 (IBM Corp.). Group comparisons for participant characteristics were performed with Mann–Whitney U test on the age variable, Fisher's exact test on the gender variable, and independent samples *t*-test for all

other variables. All data performed with independent samples t-test fulfilled the assumption of normality. Measures of postural control and attentional demands were analyzed with linear mixed model using fixed factors of group (ASD and typically developed) and visual condition (eyes open and eyes closed). The model also contained a random effect of participant. Main effects and two-way interaction between factors were computed. A separate analysis was performed for each dependent variable. Transformations were applied to improve the fit of the model and to satisfy the assumption of the multiple regression model. Cube root transformation was applied to models with variables consisting of zero and negative values while logarithm transformation was applied to models with variables consisting of positive values. In addition, the magnitude of the mean postural response differences between groups was calculated with Cohen's d (Cohen 1988).

Two post hoc analyses were undertaken to supplement the findings of the primary analysis. Firstly, the ratio of postural responses obtained from the eyes closed condition and the eyes open condition (EC/EO) was used to evaluate the effect of visual input on postural stabilization during standing (Hufschmidt et al. 1980). A ratio greater than 1 indicated a functional use of visual processing during standing (Cornilleau-Peres et al. 2005; Teng et al. 2016). Secondly, the directional ratio of RMS AP and RMS ML in both visual conditions was calculated to determine the predominant sway pattern of each group. A ratio greater than 1 indicated a predominant AP sway pattern in standing. Mean displacement was excluded from the post hoc analyses due to the positive and negative limits recorded in this measure.

Results

Statistical analyses performed using data with and without the participant with ankylosing spondylosis did not alter the results. Therefore, results presented are from statistical analyses that included the participant with ankylosing spondylosis.

Measurement of Postural Control

There was a significant main effect of group on RMS ML, F $(1, 29) = 5.850$, $p = 0.022$, but no effect of visual condition, F $(1, 30) = 0.421$, $p = 0.521$. No interaction term was observed. In the eyes open condition, differences between groups were statistically significant, Cohen's $d = 0.93$, 95% CI [0.20, 1.62], indicating that postural sway in the ML plane was larger in the ASD group than in the typically developed group (Table 2). However, differences between groups in the eyes closed condition were not statistically significant, Cohen's $d = 0.63$, 95% CI [−0.11, 1.34]. Figure 2 shows the ellipse boundaries of the ASD and the typically developed group in both the eyes open and eyes closed conditions.

There was a significant main effect of group on velocity, F $(1, 29) = 3.651$, $p = 0.066$, as well as a main effect of visual condition, F $(1, 29) = 14.901$, $p = 0.001$. A significant two-way interaction was also observed, F $(1, 29) = 8.036$, $p = 0.008$. Post-hoc pairwise comparisons in the eyes open condition showed that postural sway was significantly faster in the ASD group than in the typically developed group, $p = 0.010$, Cohen's $d = 0.96$, 95% CI [0.19, 1.68] (Table 2). There was no difference between groups in the eyes closed condition, $p = 0.390$, Cohen's $d = 0.36$, 95% CI [−0.36, 1.06]. The within-group pairwise comparison showed that the typically developed group had a faster postural sway when vision was occluded than when vision was available, $p < 0.0001$, whereas no systematic differences were detected in the postural sway of the ASD group across visual conditions, $p = 0.494$. No significant interaction terms, main effect of group and visual condition were observed for mean displacement AP, mean displacement ML, and RMS AP.

Measures of Attentional Demands

There was a significant main effect of group on sample entropy ML, F $(1, 29) = 6.458$, $p = 0.017$, but no effect of visual condition, F $(1, 29) = 0.001$, $p = 0.979$. A significant two-way interaction was also observed, F $(1, 29) = 7.844$, $p = 0.009$. Post-hoc pairwise comparisons in the eyes open

Table 2 Measurement of postural control for the autism spectrum disorder (ASD) and typically developed groups in the eyes open and eyes closed conditions

Measurement	ASD		Typically developed	
	Eyes open	Eyes closed	Eyes open	Eyes closed
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Mean displacement AP (mm)	3.81 (11.31)	2.65 (6.26)	0.73 (6.40)	0.60 (8.83)
Mean displacement ML (mm)	1.58 (5.34)	0.76 (1.89)	−0.41 (1.04)	0.12 (3.08)
RMS AP (mm)	6.38 (4.24)	6.67 (3.92)	4.61 (1.58)	5.41 (1.76)
RMS ML (mm)	2.15 (2.38)	1.49 (1.14)	0.75 (0.30)	0.97 (0.42)
Velocity (mm/s)	12.93 (5.77)	13.51 (4.92)	8.90 (2.17)	12.07 (3.04)

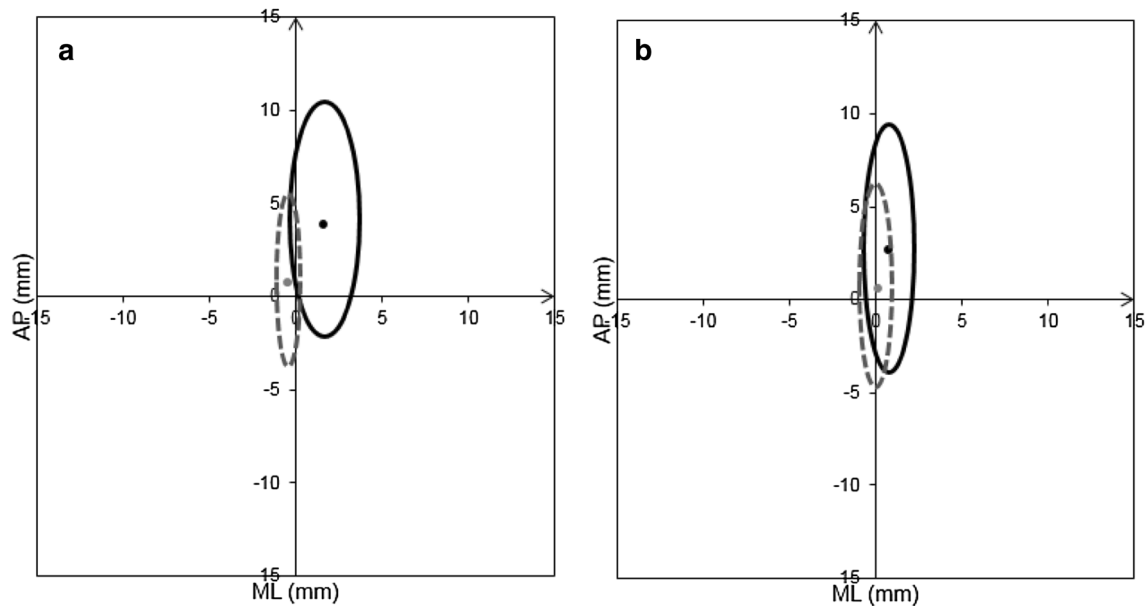*AP* anteroposterior, *ML* mediolateral, *RMS* root mean square, *SD* standard deviation

Fig. 2 Ellipse boundaries representing the mean displacement of the center of pressure in the anteroposterior (AP) and mediolateral (ML) planes in the **a** eyes open condition and **b** eyes closed condition for the autism spectrum disorder group (black solid circle) and typically developed group (grey dotted circle). The dot in the center of the ellipse represents the central tendency of the center-of-pressure during the trial

condition showed that sample entropy in the ML plane was significantly smaller in the ASD group than in the typically developed group, $p = 0.001$, Cohen's $d = 1.03$, 95% CI [$-1.75, -0.25$] (Fig. 3). There was no difference between groups in the eyes closed condition, $p = 0.244$, Cohen's $d = 0.42$, 95% CI [$-1.12, 0.31$]. No significant interaction terms, main effect of group and visual condition were observed for sample entropy AP. It is worth noting that the values of sample entropy ML in both groups were approximately four to six times greater than the values of sample entropy AP, indicating that postural stability in the ML plane required more control than in the AP plane.

Influence of Vision on Postural Control

The first post-hoc analysis was used to further determine the effect of visual input on postural stabilization during standing. EC/EO ratios in both groups were all greater than 1, indicating a functional use of visual processing during standing. All the lower and higher confidence limits were

Fig. 3 Mean and 95% confidence interval of sample entropy in the anteroposterior (AP) and mediolateral (ML) planes for adults with autism spectrum disorder (ASD) and typically developed adults in the eyes open and eyes closed conditions. The length of the data sample and the tolerance range were defined as $m = 2$ and $r = 0.2$. The asterisk symbolizes a significant difference between groups ($p \leq 0.05$)
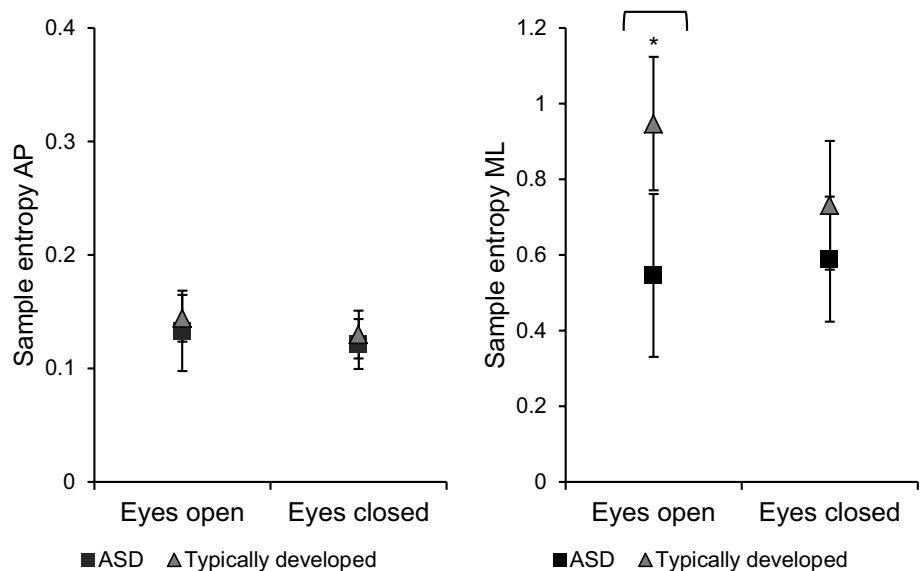
Table 3 Eyes closed/eyes open ratio in adults with autism spectrum disorder (ASD) and typically developed adults

Measures	ASD		Typically developed	
	Mean (SD)	95% CI	Mean (SD)	95% CI
RMS AP	1.34 (0.70)	0.93–1.74	1.26 (0.50)	1.00–1.51
RMS ML	1.04 (0.60)	0.69–1.38	1.58 (1.48)	0.83–2.35
Velocity	1.09 (0.24)	0.95–1.23	1.38 (0.27)	1.24–1.51

AP anteroposterior, *CI* confidence interval, *ML* mediolateral, *RMS* root mean square, *SD* standard deviation

Table 4 Directional ratios in adults with autism spectrum disorder (ASD) and typically developed adults in the eyes open and eyes closed conditions

Measures	ASD		Typically developed	
	Mean (SD)	95% CI	Mean (SD)	95% CI
RMS eyes open	4.53 (2.52)	3.08–5.98	6.91 (3.11)	5.31–8.51
RMS eyes closed	5.51 (2.34)	4.16–6.86	6.35 (2.80)	4.91–7.79

CI confidence interval, *RMS* root mean square, *SD* standard deviation

at a close approximation to 1 or greater than 1, with the exception of RMS ML in the ASD group where the lower confidence limit was lesser than 1 (Table 3).

Direction of Postural Sway

The final post-hoc analysis was used to examine the predominant direction of postural sway in the ASD and typically developed groups. The directional ratios of RMS AP and RMS ML were greater than 1, with lower and upper confidence limits above 1 (Table 4), indicating a predominant AP sway pattern in both groups.

Discussion

The present findings showed that static standing postural control and the attentional demands associated with postural control between adults with ASD and typically developed adults appear different in the eyes open condition. In comparison to typically developed adults, the postural control system in the ML plane was less effective and the amount of control activity required to achieve stability was greater in adults with ASD. Additionally, the demand for attention associated with postural sway in the ML plane was greater in the ASD group. However, the various measures of postural control and attentional demands between groups did not differ when visual information was omitted.

Consistent with studies performed on children with ASD (Chang et al. 2010; Fournier et al. 2010, 2014; Memari et al.

2013; Smoot Reinert et al. 2015), adults with ASD displayed a larger variation of postural sway in the ML plane. This pattern of increased ML sway in the ASD group is similar to that detected in older adults with a history of falls (Lord et al. 1999). Earlier research suggested that ML sway is largely influenced by visual information whereas AP sway is influenced by somatosensory information (Warren et al. 1996). These findings, put together, suggest that processing of visual information during standing may be challenging for adults with ASD. This suggestion is further supported by the present finding of a greater demand for attention in the ML plane by adults with ASD. Paulus et al. (1984) found that the stimulation of the central visual field resulted in a reduction of postural sway in the ML plane; however, research examining visual field in the ASD population is limited. Further research focusing on visual field processing needs to be undertaken to validate the relationship between increased ML sway and visual processing differences in ASD. Other explanations for a larger ML sway in adults with ASD may include an abnormal hip strategy (Chen and Tsai 2015), inability to constrain weight shifting (Fournier et al. 2010), and a lack of coordination of the AP and ML stability muscles (Kohen-Raz 1991; Cheldavi et al. 2014).

Furthermore, unlike typically developed adults who used visual information to enhance their postural response, adults with ASD did not seem to use visual information systematically to stabilize their posture in the present study. Standing postural response is generally larger when vision is omitted than when visual information is available (Asslander and Peterka 2014). This is consistent with the observation of the typically developed group in the present study where their postural sway velocity increased as they underwent a transition from looking at a visual stimulus to closing their eyes. In contrast, postural sway velocity in adults with ASD remained unchanged regardless of the availability or the omission of visual information. This finding suggests that visual processing used for postural control may be different in individuals with ASD. Morris et al. (2015) suggested that this anomalous response during standing might be a result of adults with ASD ignoring visual information. However, the post-hoc analysis in the present study was unable to ascertain if the ASD group was indeed not using visual input for postural stabilization. Rather than a complete neglect of visual information during postural control, the difference in visual processing may relate to a lower weighting of visual input during standing in adults with ASD. The lower weighting may reflect a compensatory mechanism in response to a loss of accurate visual information (Allison et al. 2006). It is worth noting that the lack of group difference in postural sway velocity when vision was occluded suggests that somatosensory and vestibular processing used for postural control are the same in both groups. Therefore, it may be hypothesized that visual information used for postural control is less

reliable in individuals with ASD, resulting in the tendency to rely less on visual information and more on somatosensory information for motor performance (Haswell et al. 2009; Izawa et al. 2012).

The results also showed that adults with ASD displayed a predominant AP sway pattern, similar to that of typically developed controls. This is inconsistent with an earlier study that reported a predominant ML sway pattern in the younger ASD population (Lim et al. 2017). It is unclear if developmental maturity affects sway patterns of individuals with ASD; therefore, further research in postural control needs to involve both the younger and older ASD populations.

Visual processing differences in ASD have been linked to an impairment of the magnocellular processing, a visual pathway in the human early visual system (Milne et al. 2002; McCleery et al. 2007; Sutherland and Crewther 2010; Robertson et al. 2012; Crewther et al. 2015). A deficit in this pathway may result in difficulties with motion processing (Milne et al. 2002; Parrish et al. 2005; Robertson et al. 2012) and may disrupt judgment of self-motion even when standing on a stable surface (Vaina 1998). Recent research has suggested that reduced top-down modulation and inhibitory modulation of visual input may alter the use of visual motion information in those with ASD (Takarae et al. 2014). Further research into visual motion processing may provide more insight into visual processing and sensorimotor differences observed between the ASD and typically developed populations.

Although the exact mechanism underlying visual processing differences in ASD remains uncertain, the findings in the present study highlight the need to shift the focus of ASD research from one that emphasizes on the symptomatology of poor socio-communication and repetitive patterns of behavior, to one with an emphasis on sensory and movement. Behaviors and communication in ASD are highly interpretable due to the complex nature of human interaction that may sometimes be over-simplified (Donnellan et al. 2012). In contrast, sensorimotor responses are fundamental and objective, and may result in markers that predict the subsequent deficits in socialization and communication that defines ASD (Mostofsky et al. 2007).

Study Limitations

The findings in the present study need to be interpreted in the context of the existing limitations. This study represents a small sample of adults with ASD. Adults were between 18 and 50 years old, reflecting a wide age range. As age may be a confounding factor on postural control, future studies may consider applying more stringent age criteria to minimize the effect of aging on postural control. In addition, differences observed in the ASD group and the typically developed group may not be specific to all individuals with ASD. Further evidence for the specificity of the association between visual processing differences and postural control difficulties in ASD could come from examining other population of adults with motor difficulties, for instance, those with developmental coordination disorder.

Conclusion

The investigation on the effect of visual information on static standing postural control and the attentional demands associated with postural control suggests that visual processing used for postural control in adults with ASD is different from their typically developed peers. Postural sway in adults with ASD tended to be more unstable in the ML plane and required more attention to maintain stability when visual information is available. These differences may reflect a lower weighting of visual input during standing, possibly because the visual information used for postural control is less reliable in the ASD group. Additionally, visual processing differences in adults with ASD may relate to an impairment of the magnocellular pathway. For a more comprehensive understanding of how visual processing influences the sensorimotor processes of individuals with ASD, research needs to be broadened to include other areas of visual processing such as visual field processing and visual motion processing. Further investigation to explore the mechanism of visual information used by individuals with ASD for postural control is warranted.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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