Gait & Posture xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Attentional and sensory contributions to postural sway in children with autism spectrum disorder

John F. Stins *, Claudia Emck, Else M. de Vries, Siebe Doop, Peter J. Beek

MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 16 May 2014
Received in revised form 5 May 2015
Accepted 14 May 2015

Keywords:
Autism
Posture
COP
Attention

ABSTRACT

Postural control is known to depend on sensory and cognitive factors. Little is known about how children with autism spectrum disorder (ASD) regulate static balance, and to what extent vision and cognition contribute to the regulation of balance in this group. We compared a group of children with mild ASD and a group of age- and gender-matched controls on various postural tasks, standing on a Wii Balance Board. We tested a sensory disturbance (closing the eyes) and a cognitive disturbance (word memorization) on the control of quiet standing. Analysis of center-of-pressure excursions revealed moderate effects of cognitive load, but clear effects of vision. We found a greater destabilizing effect of closing the eyes (greater postural excursions in the medio-lateral direction) for the ASD group than for controls. No group differences were found on word recall and on a standardized balance test (Movement Assessment Battery for Children; M-ABC2). We suggest that the postural effects reflect tighter coupling between vision and motor adjustments in ASD than in controls, which is consistent with recent suggestions of greater reliance on vision in this group.

1. Introduction

Autism spectrum disorders (ASDs) are characterized by persistent deficits in social communication and social interaction, constrained, repetitive patterns of behavior, and restricted interests or activities [1,2]. These deficits manifest themselves in early childhood and impair every day functioning. With the introduction of the DSM-5 [2] motor abnormalities seem to figure more prominently in the diagnostic criteria of autism than in its predecessor (DSM-IV [1]). Motor problems have been frequently observed in ASD [3–5], and may involve motor planning deficits, motor coordination abnormalities, fine and gross motor skill deficits, clumsiness and postural instability [6–8]. A meta-analysis [6] showed large effects for substantial motor coordination deficits in all subtypes of ASD, associated with dysfunctions in cortical and subcortical areas including the motor cortex, supplementary motor area, basal ganglia, and cerebellum. In a similar vein, it has been argued [9] that motor abnormalities represent early and persistent clinical signs, which could serve as endophenotypes for ASD. Another review [10], however, designated it premature to relate movement disturbance as a core symptom of ASD, because empirical data were deemed not robust enough.

Yet, numerous studies have found balance problems and postural abnormalities in ASD. Balance problems in children with ASD have been found using standardized instruments, in particular the Movement Assessment Battery for Children (M-ABC) [11,12]. Poorly developed balance skills in children – regardless of pathology – may reduce the capability to develop more complicated movement skills, which, in turn, may hamper social development and the willingness to participate in sports [13]. Furthermore, a number of studies have analyzed postural sway, and have found postural abnormalities in ASD in various postural tasks, such as quiet standing and looking straight ahead [14–16], quiet standing and dual-tasking [17], quiet standing with the eyes closed [8], quiet standing on a sway-referenced platform [18], and quiet standing while performing visual search [19]. Also, postural instability appeared related to symptom severity regarding the occurrence of repetitive behaviors [8]. These latter authors suggested that postural instability is related to core ASD symptoms.

A possible factor mediating between postural control and ASD symptomatology is attention. However, remarkably few studies have looked at attentional contributions to the regulation of

* Corresponding author at: MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, van der Boechorststraat 9, 1081 BT, Amsterdam, The Netherlands. Tel.: +31 6 12046065; fax: +31 20 59 88529.
E-mail address: j.f.stins@vu.nl (J.F. Stins).

http://dx.doi.org/10.1016/j.gaitpost.2015.05.010
0966-6362/

balance in ASD. The role of attention in motor control in adolescents with ASD was highlighted in a recent study [20], which found that motor performance in this group, as measured by a tapping task, was related to attentional (dys)function. The authors found that motor performance was correlated to one particular attentional function, namely the efficiency by which a spatial cue is used to orient attention. If motor abnormalities are – in part – related to attentional (dys)function, then an attention-demanding secondary task should lead to even greater abnormal motor patterns. We decided to test this hypothesis in a quiet-standing paradigm. It has been shown that regulation of balance is attention demanding, even in highly skilled individuals such as dancers [21]. We tested the effect of an attention demanding cognitive activity on postural fluctuations in a group of children with a mild form of ASD, using a word memorization task [21,22]. If individuals with ASD employ excessive cognitive resources to regulate their balance, then cognitive dual-tasking should have a destabilizing effect on this group but not on controls.

In addition, we tested the contribution of visual input to the regulation of balance in this group. Previous studies [8,23] have found decreased postural performance in ASD when the eyes are closed. Closing the eyes leads to a shift toward other sensory modalities to regulate balance, necessitating more attention-demanding control of balance. The second aim of this study was to assess whether dual-tasking and removal of visual input leads to additive or interactive effects on postural parameters.

So, our hypotheses were that (1) cognitive dual-tasking has a destabilizing effect in ASD, and (2) standing with eyes closed also has a destabilizing effect in this group, possibly mediated by an inward attentional focus.

2. Methods

2.1. Participants

Nine children who were diagnosed with ASD (8 males and 1 female; mean age: 10.8 ± 1.2 years; mean height: 1.50 ± 0.13 m; mean weight: 41.3 ± 13.3 kg) and nine age- and gender-matched typically developing [TD] children (mean age: 10.8 ± 1.2 years; mean height: 1.49 ± 0.09 m; mean weight: 36.7 ± 7.75 kg) were recruited from a regular primary school in Ermelo, the Netherlands. The clinical diagnosis of ASD was determined by a licensed child psychologist or psychiatrist and several combinations of research and clinical tools were used to support and confirm the clinical diagnosis according to DSM-IV criteria (Table 1). Most frequently, the Achenbach System of Empirically Based Assessment (ASEBA) School-age forms and profiles were used to assess competencies, adaptive functioning and problems – that is, the Child Behavior Checklist (CBCL), Teacher's Report Form (TRF) and the Youth Self Report (YSR). DSM-IV GAF (Global Assessment of Functioning) scores were all between 50 and 70, implicating mild to moderate symptoms and some difficulty in social or school functioning. Exclusion criteria were (neurological) diseases, physical impairments or handicaps that precluded participation. Three children of the ASD group used methylphenidate for ADHD symptoms. The study was approved by the local ethics committee before it was conducted. Parents/caregivers of the participating children signed an informed consent.

2.2. Data collection

Prior to postural recordings we administered the balance subtests[1] of the Movement Assessment Battery for Children (M-ABC version 2, age band 7–10 years and age band 11–16 years [24]). The M-ABC is a test for early detection of motor problems in children aged 3–16 years. The following subtests were administered: (1) static balance; depending on age, standing on one leg, or standing on two legs heel-to-toe; (2) dynamic balance_1: hopping in squares; (3) dynamic balance_2: depending on age, walking forwards or backwards along a piece of rope. Raw scores were converted to percentile scores.

Participants stood on a Nintendo© Wii Balance Board that collected postural data, which were transmitted via bluetooth to a laptop. The Wii Balance Board has excellent reliability (intra-class correlation coefficient = 0.77–0.89 [25]) and has been used in studies with other clinical populations [26]. We know of one study that used a Wii Balance Board to assess postural control in people with ASD [8].

The Balance Board (511 mm × 316 mm) was located in a clutter-free area with homogenous floor and monochromatic curtains to prevent distractions. Participants stood barefoot on the board. Center-of-Pressure (CoP) excursions were registered under four experimental conditions: (1) standing with eyes open, (2) standing with eyes closed, (3) standing while performing a cognitive dual task, eyes open, and (4) standing while performing a cognitive dual task, eyes closed. During all tasks participants were instructed to stand as quietly as possible while facing a bare wall. Each condition was repeated three times, for 30 s each. Sampling frequency was irregular and fluctuated around 18 Hz. We used linear interpolation to obtain a constant sampling interval (cf. [27]), using the function *interp1* in Matlab.

During the cognitive dual task participants listened to a list of pre-recorded words that were presented at a frequency of 0.5 Hz, resulting in a total number of fifteen different words per trial. Words were nouns belonging to a certain category (animals, fruit and vegetables, tools, sports, toys and occupations). Participants were instructed to fully concentrate on the words and to memorize as many of the words as they could. After completion of the trial, participants had thirty seconds to report the words they memorized. The experimenter scored the number of correctly remembered words.

Prior to analysis we smoothed the postural data using a 5-point moving average. We calculated the following parameters related to postural (in)stability:

1) Standard deviation of sway, separate for the anterio-posterior (AP) and mediolateral (ML) direction.
2) $COP_{RANGE-ML}$ and $COP_{RANGE-AP}$, i.e., the distance between the maximal postural excursions in the mediolateral direction and the anterio-posterior direction, respectively (cf. [15]).
3) Sway path length (SPL), i.e., the summed length of the postural excursions in the AP–ML plane over the measurement interval.

We also administered a subset of the M-ABC (balance subtests only), as an independent standardized test of balance movement ability, to assess whether postural parameters and balance test scores co-vary.

2.3. Statistical analysis

The three subtests of the M-ACB2 and the total score (sum total of the subtests) were entered into an unpaired *t*-test. All COP variables were first averaged over the three trial repetitions, and were then entered into a 2 (task: baseline vs. dual task) × 2 (vision: eyes open vs. eyes closed) × 2 (group: ASD vs. TD) mixed factors analysis of variance (ANOVA). For the analysis of memory performance we first averaged the number of correctly recalled words over trial repetitions, and we then submitted these scores to

[1] The M-ABC consists of 3 sub-tests, involving the component motor domains *Manual Dexterity*, *Ball Skills*, and *Balance*. For present purposes only performance on the balance component area was measured.

Table 1

P	DSM-IV axis 1 and 5	CBCL	TRF	CSBQ	Tea-ch	SEV	HTP	15w	CFT	SPPC
1	1. PDD NOS (299.80) 5. GAF 60	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
2	1. PDD NOS (299.80) 5. GAF 55	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	1. PDD NOS (299.80); ADHD-C (314.01) 5. GAF 51–60	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	1. PDD NOS (299.80); ADHD-C (314.01) 5. NA	No	No	No	Yes	No	No	No	No	Yes
5	1. PDD NOS (299.80) 5. GAF 50–60	Yes	Yes	Yes	No	No	No	No	No	No
6	1. PDD-NOS (299.80); ADHD-C (314.01) 5. GAF 61–70	Yes	Yes	Yes	No	Yes	No	No	No	No
7	1. PDD-NOS (299.80) 5. GAF 55	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	1. Asperger's disorder (299.80) 5. GAF 50	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	1. PDD-NOS (299.80) 5. GAF 51–55	NA	NA	NA	NA	NA	NA	NA	NA	NA

CBCL = Child Behavior Checklist; TRF = Teachers Report Form; CBSQ = Children's Social Behavior Questionnaire; Tea-Ch = Test of Everyday Attention for Children; SEV = Sociaal Emotionele Vragenlijst (Social Emotional Questionnaire; Dutch only); HTP = House Tree Person test; 15w = 15 word test; CFT = Complex Figure Test; SPPC = Self-Perception Profile for Children. Yes = this test was used, No = this test was not used, NA = no information available.

a 2 (vision) × 2 (group) mixed factors ANOVA. Alpha-level was set at 0.05. Effect sizes are reported as partial eta-squared (η_p^2).

3. Results

3.1. Movement ABC

None of the M-ABC2 subtests, nor the total score, significantly differentiated the groups. For the ASD group and the TD group, respectively, scores were as follows; static: 3.4/3.4, dynamic_1: 10.1/10.7, dynamic_2: 19.1/21.0; total: 34.8/36.8.

3.2. Memory performance

No main or interaction effects were significant. The average number of correctly recalled words was 6.5 (SD .75).

3.3. Postural performance

Means and standard deviations of all postural measures are reported in Table 2.

3.3.1. Standard deviation

There was only a main effect of vision, both for AP sway, $F(1, 16) = 20.27$, $p < .001$, $\eta_p^2 = .56$, and ML sway, $F(1, 16) = 26.15$, $p < .001$, $\eta_p^2 = .62$, indicating that the standard deviation of postural fluctuations was larger with eyes closed than with eyes open (AP: 5.8 vs. 4.3 mm; ML: 6.0 vs. 4.8 mm, respectively).

3.3.2. $COP_{RANGE\text{-}ML}$

There was a main effect of vision, $F(1, 16) = 40.42$, $p < .001$, $\eta_p^2 = .72$, indicating that the postural sway range was larger with eyes closed than with eyes open (3.1 vs. 2.3 cm, respectively). Also the interaction of vision and group was significant, $F(1, 16) = 6.24$, $p < .05$, $\eta_p^2 = .28$. Means for eyes open vs. eyes closed were 2.4 cm and 3.4 cm for the ASD group, and 2.3 vs. 2.7 cm for the TD group. In order to explore the interaction we submitted the difference scores ($COP_{RANGE\text{-}ML}$ closed minus $COP_{RANGE\text{-}ML}$ open) to an unpaired *t*-test, which yielded significance, $t(16) = 2.45$, $p < .05$. In other words, postural instability in the ML-direction due to closing the eyes was larger with the ASD group than the TD group.

3.3.3. $COP_{RANGE\text{-}AP}$

There was a main effect of vision, $F(1, 16) = 33.35$, $p < .001$, $\eta_p^2 = .68$, indicating that the postural sway range was larger with eyes closed than with eyes open (2.9 vs. 2.2 cm, respectively). Also, the three-way task × vision × group interaction was significant, $F(1, 16) = 4.85$, $p < .05$, $\eta_p^2 = .23$. To further explore this interaction we performed separate ANOVAs for both groups. The ASD group showed a borderline significant effect of task, $F(1, 8) = 5.35$, $p = .05$, $\eta_p^2 = .40$, indicating higher values during dual-tasking than at baseline (3.1 vs. 2.4 cm, respectively). There was also an effect of vision, $F(1, 8) = 16.21$, $p < .01$, $\eta_p^2 = .67$, demonstrating again the destabilizing effects of closing the eyes, regardless of task (3.3 vs. 2.3 cm). For the TD group the main effect of vision was also significant, $F(1, 8) = 30.55$, $p < .001$, $\eta_p^2 = .79$, but the effect was superseded by the vision × task interaction, $F(1, 8) = 6.74$, $p < .05$, $\eta_p^2 = .46$. Pair wise *t*-tests revealed that for the TD group the contrast between eyes open and eyes closed was not significant during dual-tasking, but was significant during the baseline task, $t(8) = 5.47$, $p < .001$ (1.94 vs. 2.76 cm, respectively). Means for all conditions are shown in Fig. 1.

3.3.4. Sway path length

There was a main effect of vision, $F(1, 16) = 90.45$, $p < .001$, $\eta_p^2 = .85$, indicating that there was more sway during eyes closed than with eyes open (35.6 vs. 24.6 cm, respectively). There was also a main effect of task, $F(1, 16) = 6.26$, $p < .05$, $\eta_p^2 = .28$, indicating that there was more sway during cognitive dual-tasking than at baseline (34.0 vs. 26.2 cm, respectively). No other effects were significant.

3.3.5. ADHD comorbidity check

In order to test whether the three children that used methylphenidate for ADHD symptoms displayed different postural performance from the other six children, we ran the same tests as above, but now only on the ASD group, with type (presence or absence of comorbid ADHD) as between subject factor. No main or interaction

Table 2

	ASD group				TD group			
	Baseline		Dual task		Baseline		Dual task	
	(Eyes) Open	(Eyes) Closed	(Eyes) Open	(Eyes) Closed	(Eyes) Open	(Eyes) Closed	(Eyes) Open	(Eyes) Closed
Standard deviation AP (mm)	4.4 (1.2)	6.1 (2.6)	4.8 (1.8)	6.9 (3.3)	4.0 (1.3)	5.5 (1.4)	4.2 (1.0)	4.8 (1.5)
Standard deviation ML (mm)	4.3 (1.5)	5.7 (2.6)	5.6 (2.7)	7.8 (4.2)	4.6 (1.5)	5.4 (1.6)	4.5 (1.0)	5.2 (1.0)
COP range AP (cm)	2.04 (.58)	2.85 (.95)	2.49 (.87)	3.66 (1.79)	1.94 (.72)	2.76 (.76)	2.18 (.42)	2.43 (.73)
COP range ML (cm)	2.02 (.71)	2.82 (1.17)	2.81 (1.19)	3.99 (2.07)	2.27 (.73)	2.60 (.69)	2.23 (.47)	2.76 (.71)
Sway path length (cm)	19.01 (5.73)	29.52 (10.07)	29.20 (12.62)	45.36 (23.89)	22.49 (5.12)	31.37 (8.17)	25.34 (6.44)	33.54 (7.26)

ASD = Autism Spectrum Disorder; TD = Typically developing; AP = anterio-posterior; ML = mediolateral.

Please cite this article in press as: Stins JF, et al. Attentional and sensory contributions to postural sway in children with autism spectrum disorder. Gait Posture (2015), http://dx.doi.org/10.1016/j.gaitpost.2015.05.010

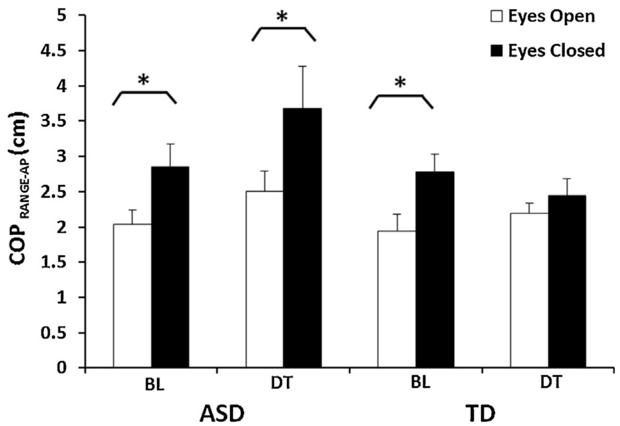

Fig. 1. Mean values of the COP range in the AP direction, separate for task (Baseline [BL] and dual task [DT]), vision (eyes open vs. eyes closed) and group (autism group [ASD] and typically developing children [TD] as controls). Asterisks denote a significant difference between conditions.

effects involving type were significant, so that comorbid ADHD did not differentially influence COP behavior.

4. Discussion

We examined the effect of a cognitive disturbance (word memorization) and a sensory disturbance (standing with eyes closed) on balance and postural control in a group of children with mild autism. We hypothesized that individuals with ASD might employ excessive cognitive resources to regulate their balance. As a result, (1) cognitive dual-tasking and (2) closing the eyes should have a destabilizing effect on individuals with ASD but to a lesser extent on controls.

First, we found no main effects of group on any of our postural parameters, indicating that – averaged over conditions – postural (in)stability was comparable in both groups. Also, both groups displayed equal recall of the verbal material, suggesting comparable levels of cognitive abilities. Second, we found the expected effects of vision: closing the eyes led to an increase in postural sway. Third, we found modest effects of cognitive task performance: dual tasking induced an increase in postural sway, suggesting that the memorization task led to a decrease in postural stability. It is unclear whether the effect is due to the attentional demands of the task, or due to unintentional motoric activities during listening, such as silent vocalizations.

Fourth, we found a number of interactions between group, task and/or vision. The groups reacted differently to the removal of vision: for the range of the COP in the ML direction, the destabilizing effect of closing the eyes was larger for the ASD group than for controls. This finding is consistent with earlier studies [8,23], and suggests that individuals with ASD have greater reliance on visual input for the regulation of balance, making it more difficult to maintain balance with the eyes closed. A recent study [28] revealed unexpected and substantial superiority in visual motion perception in children with ASD, compared to controls. Relatedly, a review [29] found that individuals with ASD consistently outperform controls on visual search tasks; possibly mediated by 'over-focused attention'. We speculate that this superiority is reflected in a tighter coupling between visual channels that register changes in optic flow (as a result of postural sway) and the motor system responsible for maintaining balance [23]. This tighter coupling, in turn, becomes manifest as faster postural adjustments. This notion is consistent with recent suggestions [12,30] that children with ASD have deficits in anticipatory control involving tasks where perception needs to be coupled to action, which, we argue, could entail a more reactive (vision-based) postural control strategy. Standing with eyes closed might necessitate a shift from a reactive (predominantly vision based) control strategy to a feedforward strategy, based on anticipation of postural consequences of motor adjustments. If it is true that this latter type of control is poorly developed in ASD [12,30], this would explain the destabilizing effects of standing with eyes closed.

For the range of the COP in the AP direction, the groups reacted differently to the manipulations. In the ASD group the destabilizing effects of closing the eyes and of cognitive dual-tasking were additive. So, in accordance with our hypothesis we found that dual tasking negatively affected postural performance. In the control group, however, we found an interaction, in that the destabilizing effects of closing the eyes was only evident at baseline, and not during dual tasking. This could reflect some sort of trade-off between postural performance and cognitive performance, but this is very speculative.

Finally, scores obtained with the M-ABC2 revealed no significant differences between the groups. Our participants were mildly autistic, so motor problems were probably in the sub-clinical domain, making it harder to detect these with a coarse-grained measure such as the M-ABC. Interestingly, a study by [12] involved an in-depth analysis of M-ABC2 scores, and it was found that children with autism scored significantly worse than matched controls on only 2 of the 8 subtests of the M-ABC2, namely static balance, and ball catching (not tested by us). The authors suggested that movement abnormalities in ASD reside predominantly in static balance performance, as this involves rapid online adjustments to subtle changes in posture. Hence, the authors argued that analysis of COP parameters might yield more insight into the fine online regulation of balance, which indeed is what we did.

We would like to stress a major limitation of this study; not only did we have a modest sample size; our clinical sample was also heterogeneous, especially regarding comorbid symptoms of ADHD, and in addition the diagnosis was established using different procedures and instruments.

In conclusion, we found evidence of abnormal postural control in children with mild ASD. Even though there were clear main effects of cognitive dual tasking on COP parameters, the effects hardly differentiated between the groups, suggesting that the attentional regulation of balance was mildly affected in our ASD sample. We found clear effects of vision on balance, suggesting a greater reliance on vision in ASD than controls, which could be due to superiority in visual information processing and deficits in perception–action coupling [12].

Acknowledgments

We would like to thank the children and parents who participated in the study, the staff of the primary school in Ermelo and Research Institute TNO Soesterberg assistance with the Wii Balance Board©. Special thanks to Wilma de Vries, remedial teacher at the primary school, who assisted in recruiting the participants.

Conflict of interest: None of the authors have financial or other conflicts of interest in regards to this research.

References

[1] American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4th ed. Washington: APA; 1994.
[2] American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5th ed. Arlington, VA: American Psychiatric Publishing; 2013.
[3] Emck C, Bosscher R, Beek P, Doreleijers T. Gross motor performance and self-perceived motor competence in children with emotional, behavioural, and pervasive developmental disorders: a review. Dev Med Child Neurol 2009;51(7):501–17.

Please cite this article in press as: Stins JF, et al. Attentional and sensory contributions to postural sway in children with autism spectrum disorder. Gait Posture (2015), http://dx.doi.org/10.1016/j.gaitpost.2015.05.010

[4] Matson ML, Matson JL, Beighley JS. Comorbidity of physical and motor problems in children with autism. Res Dev Disabil 2011;32:2304–8.
[5] Ming X, Brimacombe M, Wagner GC. Prevalence of motor impairment in autism spectrum disorders. Brain Dev 2007;29(9):565–70.
[6] Fournier KA, Hass CJ, Naik SK, Lodha N, Cauraugh JH. Motor coordination in autism spectrum disorders: a synthesis and meta-analysis. J Autism Dev Disord 2010;40:1227–40.
[7] MacDonald M, Lord C, Ulrich D. The relationship of motor skills and adaptive behaviour skills in young children with autism spectrum disorders. Res Autism Spectr Disord 2013;7:1383–90.
[8] Travers BG, Powell PS, Klinger LG, Klinger MR. Motor difficulties in autism spectrum disorder: linking symptom severity and postural stability. J Autism Dev Disord 2013;43:1568–83.
[9] Esposito G, Paşca S. Motor abnormalities as a putative endophenotype for autism spectrum disorders. Front Integr Neurosci 2013;7(43):1–5.
[10] Miyahara M. Meta review of systematic and meta analytic reviews on movement differences, effect of movement based interventions, and the underlying neural mechanisms in autism spectrum disorder. Front Integr Neurosci 2013;7:16.
[11] Liu T, Breslin CM. Fine and gross motor performance of the MABC-2 by children with autism spectrum disorder and typically developing children. Res Autism Spectr Disord 2013;7:1244–9.
[12] Whyatt C, Craig CM. Motor skills in children aged 7–10 years, diagnosed with autism spectrum disorder. J Autism Dev Disord 2012;42:1799–809.
[13] Mickle KJ, Munro BJ, Steele JR. Gender and age affect balance performance in primary school-aged children. J Sci Med Sport 2011;14:243–8.
[14] Memari AH, Ghanouni P, Gharibzadeh S, Eghlidi J, Ziaee V, Moshayedi P. Postural sway patterns in children with autism spectrum disorder compared with typically developing children. Res Autism Spectr Disord 2013;7:325–32.
[15] Fournier KA, Amano S, Radonovich KJ, Bleser TM, Hass CJ. Decreased dynamical complexity during quiet stance in children with autism spectum disorders. Gait Posture 2014;39:420–3.
[16] Fournier KA, Kimberg CI, Radonovich KJ, Tillman MD, Chow JW, Lewis MH, et al. Decreased static and dynamic postural control in children with autism spectrum disorders. Gait Posture 2010;32(1):6–9.
[17] Memari AH, Ghanouni P, Shayestehfar M, Ziaee V, Moshayedi P. Effects of visual search vs. auditory tasks on postural control in children with autism spectrum disorder. Gait Posture 2014;39:229–34.
[18] Minshew NJ, Sung K, Jones BL, Furman JM. Underdevelopment of the postural control system in autism. Neurology 2004;63(11):2056–61.
[19] Chang C-H, Wade MG, Stoffregen TA, Hsu C-Y, Pan C-Y. Visual tasks and postural sway in children with and without autism spectrum disorders. Res Dev Disabil 2010;31:1536–42.
[20] Ravizza SM, Solomon M, Ivry RB, Carter CS. Restricted and repetitive behaviors in autism spectrum disorders: the relationship of attention and motor deficits. Dev Psychopathol 2013;25:773–84.
[21] Stins JF, Michielsen ME, Roerdink M, Beek PJ. Sway regularity reflects attentional involvement in postural control: effects of expertise, vision and cognition. Gait Posture 2009;30:106–9.
[22] Stins JF, Ledebt A, Emck C, van Dokkum EH, Beek PJ. Patterns of postural sway in high anxious children. Behav Brain Funct 2009;5(1):42.
[23] Molloy CA, Dietrich KN, Bhattacharya A. Postural stability in children with autism spectrum disorder. J Autism Dev Disord 2003;33(6):643–52.
[24] Henderson SE, Sugden DA, Barnett AL. Movement assessment battery for children. 2nd edition, London: Pearson Assessment; 2007.
[25] Clark RA, Bryant AL, Pua Y, McCrory P, Bennell K, Hunt M. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait Posture 2010;31:307–10.
[26] Shih C, Shih C, Chu C. Assisting people with multiple disabilities actively correct abnormal standing posture with a Nintendo Wii Balance Board through controlling environmental stimulation. Res Dev Disabil 2010;31:936–42.
[27] Clark RA, Pua Y-H, Fortin K, Ritchie C, Webster KE, Denehy L, et al. Validity of the Microsoft Kinect for assessment of postural control. Gait Posture 2012;36:372–7.
[28] Foss-Feig JH, Tadin D, Schauder KB, Cascio CJ. A substantial and unexpected enhancement of motion perception in autism. J Neurosci 2013;33:8243–9.
[29] Kaldy Z, Giserman I, Carter AS, Blaser E. The mechanisms underlying the ASD advantage in visual search. J Autism Dev Disord 2015 [in press].
[30] von Hofsten C, Rosander K. Perception-action in children with ASD. Front Integr Neurosci 2012;8:115.

Please cite this article in press as: Stins JF, et al. Attentional and sensory contributions to postural sway in children with autism spectrum disorder. Gait Posture (2015), http://dx.doi.org/10.1016/j.gaitpost.2015.05.010