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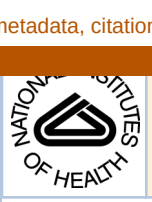

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Increased Static and Dynamic Postural Control in Children with Autism Spectrum Disorders

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Abstract

The purpose of this study was to investigate postural control in children with Autism Spectrum Disorders (ASD) during static and dynamic postural challenges. We evaluated postural sway during quiet standing and the center of pressure (COP) shift mechanism during gait initiation for thirteen children with ASD and twelve age matched typically developing (TD) children. Children with ASD produced 438% greater normalized mediolateral sway ($p<0.05$) and 104% greater normalized anteroposterior sway ($p<0.05$) than TD children. Consequently, normalized sway area was also significantly greater ($p<0.05$) in the group with ASD. Similarly, the maximum separation between the COP and center of mass (COM) during quiet stance was 100% greater in the anteroposterior direction ($p<0.05$) and 146% greater in the resultant direction ($p<0.05$) for children with ASD. No significant difference was observed in the mediolateral direction, in spite of the 123 % greater separation detected in children with ASD. During gait initiation, no group differences were detected in the posterior COP shift mechanism, suggesting the mechanism for generating forward momentum is intact. However, significantly smaller lateral COP shifts ($p<0.05$) were observed in children with ASD, suggesting instability or an alternative strategy for generating momentum in the mediolateral direction. These results help clarify some discrepancies in the literature, suggesting an impaired or immature control of posture, even under the most basic conditions when no afferent or sensory information have been removed or modified. Additionally, these findings provide new insight into dynamic balance in children with ASD.

Keywords

Center of Pressure (COP); Center of Mass (COM); Posture; Gait Initiation; Stability

Autism spectrum disorders (ASD) are a group of neurodevelopmental disorders (autistic disorder, Asperger s syndrome and pervasive developmental disorder-not otherwise

Conflict of Interest Statement

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

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specified) diagnosed according to impairments in communication, reciprocal interaction and stereotypic behavior [1]. Compared to the cardinal features mentioned, motor disturbances have received less attention although they are the most frequently reported non–verbal symptoms [2]. Previous research has identified deficits in motor development [3], coordination and general motor function [4], and the planning and execution of movement [5,6] in children with ASD. Of particular importance are the identified deficits in postural control [7–11]. An immature postural control system can be a limiting factor on the emergence of other motor skills, may constrain the ability to develop mobility and manipulatory skills, and is of significant importance to quality of life.

The ability to maintain an upright posture is a fundamental skill necessary for typical motor development in humans. Postural control observed in children with ASD appears to differ from that of typically developing (TD) children as well as children with intellectual disability [8–11]. Children with autistic disorder exhibit less age-related development, less stable and more variable postural control, particularly in the mediolateral direction [10]. Further, both children and adults with ASD have been observed to have decreased postural stability when compared to individuals with typical neuromotor development under conditions where one or more sensory inputs had been removed or modified [9–11]. However, when afferent inputs are not modified, differences in postural sway are not as apparent [8–11]. Despite this information, there is still a scarcity of research investigating postural control within a wider range of functional tasks.

Postural control during dynamic activities such as the initiation of gait requires the integration of multiple sensory and motor pathways so that the central nervous system can coordinate the anticipatory/postural and intentional movement components. Gait initiation (GI) is a functional task requiring voluntary destabilization of the whole body center of mass (COM) and a transition from a large to small base of support (BOS). GI has been studied to provide insight into dynamic postural control and the changes that occur in the control system with development, advancing age and disability [12–15]. Currently, there is a paucity of information on how children with ASD perform GI. This information would provide particular insight into whether the abnormally large sway observed in quiet stance affects functional locomotor tasks with a known balance component. Thus, the primary purpose of this study was to evaluate postural control impairments associated with ASD during both static and dynamic postural challenges. We extend upon previous research to evaluate the interactions between the center of pressure (COP) and COM, defined as the COP-COM moment arm, during quiet stance. The COP-COM moment arm accounts for individual segment movements in a multilink system that may otherwise be missed when using an inverted pendulum model [16].

We hypothesized that children with ASD would exhibit greater COP movements and thus greater sway during quiet standing. We believed the peak COP-COM moment arms would be greater in children with ASD, suggesting greater instability. Furthermore, we hypothesized that children with ASD would have difficulty with the postural challenge associated with transitioning from a stable to an unstable, dynamic BOS. As a result, children with ASD would have impaired abilities to uncouple the COP and COM via a reduced magnitude of the COP movements during GI, an essential component for propulsion in the forward and stance–directions.

Methods

Thirteen children diagnosed with ASD (age: 11.1±2.3 yrs, height: 1.45±0.17 m, mass: 50.2±21.8 kg, Leiter-R Brief IQ 81.8±32.8) were recruited from the University s Child & Adolescent Psychiatry Clinic. Twelve age–matched TD children (age: 12.9±2.1 yrs, height:

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1.57±0.12 m, mass: 48.2±10.3 kg, Leiter-R Brief IQ 104.9±17.1) were recruited from the community and served as controls. Clinical diagnoses of ASD were initially determined by a licensed professional (psychologist or physician) and confirmed using one of three diagnostic scales (Autism Diagnostic Observation Schedule [17], Social Communication Questionnaire [18], or Childhood Autism Rating Scale [19]). Children were excluded if known genetic/medical conditions, gross sensory deficits, use of assistive devices, or significant physical impairments were present. Furthermore, TD children were excluded if diagnoses of psychiatric or neurological disorders were present. The protocol for the study was approved by an institutional review board and prior to participation, parents or legal guardians authorized the informed consent for their children.

Ground reaction forces (GRF) and moments were recorded (360 Hz) from two adjacent forceplates (Type 4060–10, Bertec Corp., Columbus, OH). During quiet stance trials, children stood with their feet comfortably apart with one foot on each forceplate. Foot positioning was marked and used for all subsequent trials. Children were asked to stand as still as possible for 20 sec with their arms comfortably at their side and facing a bare laboratory wall. The testing area was clutter-free, had a homogenous floor and was isolated from outside distractions with the use of monochromatic curtains. Children performed four trials. Trials where voluntary movements were observed were rejected and additional trials were performed. During GI trials, children stood with one foot on each forceplate and upon hearing a verbal “ready” signal, were asked to take a short pause (1–2 sec) and then start walking to the end of a 4-meter walkway. The stepping foot and walking speed were self–selected. Children were allowed several practice trials to ensure comprehension of the task. Data from four trials were collected.

GRF and moments collected from the forceplates were processed and, the location of the combined COP_{net} was determined [20]. The peak displacements of the COP in the mediolateral and anteroposterior directions as well as sway area were subsequently calculated. Because differences in stance width and foot length can influence postural sway measures [21], displacements during quiet stance and GI trials were normalized to the individual s stance width (mediolateral movements) and foot length (anteroposterior movements).

Due to an intolerance by the majority of children with ASD to markers being affixed to their skin, the COM for the whole body was determined via an integration method rather than the more traditional kinematic methods which requires the use of marker and anthropometric data. The accelerations obtained from the GRF were doubly integrated with respect to the time and estimates for COM displacements were obtained using methodology previously described in the literature [22]. Integration methods for obtaining COM displacements have been reported to yield equivalent approximations when compared to kinematic methods and therefore can be used interchangeably during quiet standing and walking trials[22,23]. The distance between the COM and COP in the transverse plane, defined as the COP–COM moment arm, was calculated. Peak magnitudes of the moment arm ($COP–COM_{max}$) in the mediolateral and anteroposterior directions and subsequent peak resultant moment arm were identified and analyzed. Although there are various integrations methods for estimating the COM mathematically during standing balance and continuous gait trials, methods specific to gait initiation have not been fully validated. As a result, COP–COM moment arms were not calculated for GI trials.

The initial phase of GI represents the purposeful uncoupling of the COP and COM. From its initial position in quiet stance, the COP moves posteriorly and laterally towards the swing limb to propel the COM forward and towards the stance limb. The peak displacement of the

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COP during this phase in the mediolateral (d_ML) and anteroposterior (d_AP) directions were calculated and analyzed for GI trials.

An individual s data from the four trials were averaged to provide one representative score for each dependent variable. Examination of the data revealed heterogeneity of variance between groups. As a result, nonparametric Mann–Whitney ***U***–tests were used to test for group differences on COP trajectories and COP–COM separations during quiet standing and on COP trajectories during the first phase of GI. An á–priori alpha level of 0.05 was set for all statistical tests. All statistical tests were performed using SPSS 16.0 for Windows (Chicago, Illinois).

Results

No significant group differences were detected for age, height or mass (***p*** > 0.05 for all 3 measures). The TD group had significantly higher IQs when compared to the ASD group (***p*** = 0.044). However, all participants had age appropriate IQs, and were above clinical criteria for impaired IQ (Leiter Scores > 70).

Significant differences between groups were identified for all three traditional COP measures of postural control during quiet stance (Table 1; rows 1–3). Children with ASD produced greater (438%) normalized mediolateral sway (COP_{ML}) than their age–matched controls (***p***=0.034). Similarly, the magnitude of the anteroposterior sway (COP_{AP}) was 104% greater in the ASD group (***p***<0.001). Consequently, sway area (COP_{SWAY}) was also greater in the group with ASD (***p***<0.001).

Significant differences between groups were also identified in two of the three moment arms during quiet stance (Table 1; rows 4–6). The maximum COP-COM was 100% greater in the anteroposterior direction (***p***=0.006) and 146% greater in the resultant direction (***p***=0.023) for children with ASD. No difference was observed in the mediolateral direction during quiet stance, in spite of the 123 % greater separation detected in children with ASD.

One child from the ASD group was unable to complete gait initiation trials successfully due to difficulty with comprehending the task instructions. As a result, his data were not included in the gait initiation analyses. While no group differences were observed in the COP displacement in the posterior direction (d_AP), children with ASD displaced their COP significantly less (40%) towards the swing leg (d_ML; ***p***=0.007) during gait initiation (Table 1; rows 7–8).

Discussion

An effective postural control system is a necessary foundation for individuals to acquire skills inherent to functional independence. Initially, there must be an ability to maintain equilibrium during static conditions where the COM remains within the BOS such as during quiet stance; however, that ability must be further developed to include stability during dynamic conditions where the COM moves away from the BOS, such as during GI. During quiet stance, the postural control system tightly couples movement of the COP and COM and sway is minimized. Dynamic postural stability is often defined as the ability to tolerate separation of the COM and COP while transitioning from one posture to the next or between a static to a dynamic state. The current investigation has highlighted systematic postural instabilities in children with ASD using functional tasks representative of two different categories of postural challenges. Our hypotheses that children with ASD would have increased postural sway during quiet standing and a decreased COP shift mechanism which functions to separate the COP and COM during GI, were partially supported by the data. It

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therefore appears that the sequelae of ASD includes a retarded development or disruption of postural control abilities during quiet standing and GI.

Using quantitative measures of both COP movements and COP and COM interactions, we were able to identify differences in postural control between children with ASD and TD children during quiet stance. Although the outcome measures of COP sway and COP–COM moment arms were normalized in the present investigation, the absolute values for these measures appear to be consistent with values reported elsewhere for various young adolescent populations. As a result, our findings appear to support previous reports that children with ASD have increased postural instability [9–11].

Sway area, a commonly reported outcome measure, is useful because it combines the postural sway in both the anteroposterior and mediolateral directions. Sway areas for TD children in the present investigation are similar to those reported in the literature [24,25]. However, the sway area for our children with ASD appear to have greater sway than children with known postural deficits [24,25]. When combining the findings of the current cross–sectional investigation with those of previously observed in ASD [8], it appears postural sway decreases as age increases for TD children, but remains relatively unchanged for children with ASD. Although the current investigation was not a longitudinal study, these observations lend support to previous findings that the development of the postural system in children with ASD is delayed, and may never reach adult levels [9,10]. Herein, we documented that the differences in COP measures between ASD and TD children were much larger in the mediolateral (438%) vs. the anteroposterior (100%) which supports the “directionally inconsistent and sporadic lateral sway” observed by Kohen–Raz et al. (1992).

The greater the COP–COM distance during quiet stance, the more inherently unstable the individual is and the more active postural control is needed. Children with ASD had larger peak COP–COM moment arms in the anteroposterior and resultant directions when compared to TD children. The peak absolute COP–COM moment arms observed herein appear to be larger than those previously reported for TD children and children with postural deficits [25], which further suggest impaired postural control in the children with ASD. Although no difference between groups was detected for peak COP–COM moment arms in the mediolateral direction, children with ASD were observed to have over 100% larger moment arms when compared to the TD children. It is plausible that the lack of significance may have been the result of a relatively small sample size and inherent variability in this population. When compared to the directional group differences observed in the traditional COP measures (438% mediolateral and 104% anteroposterior), the COP-COM moment arms appears to be more proportional for the two directions (123% mediolateral and 100% anteroposterior). Given a significant difference in traditional COP sway measures but a non–significant difference in peak COP–COM moment arms during quiet stance, it is speculated that the COM and COP may not be moving as a simple inverted pendulum in the mediolateral direction for children with ASD, and an inability to constrain weight shifting may present.

The ability to uncouple the COP and COM is essential for the development of momentum to efficiently initiate gait; however it simultaneously requires active postural control for balance maintenance [13]. Decreased COP displacements in either direction may be indicative of instability [15] or perhaps the use of an alternative, possibly less efficient strategy for generating momentum [12]. Normalized displacements in the posterior direction did not differ between TD children and children with ASD and the absolute magnitudes appear to be similar to those reported elsewhere for various populations [12,14,15]. The momentum generated from the anteroposterior shift is thought to be mainly responsible for propelling the body through subsequent steps in the forward direction. The non–significant

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difference between groups indicates that the COP shift mechanism for generating forward momentum appears to be intact in children with ASD.

Stance-side momentum is generated via muscle activations that lead to the COP moving laterally towards the swing limb. This mediolateral momentum is believed to contribute to mediolateral stability during gait initiation. In the current investigation, values in the lateral direction were observed to be significantly smaller for children with ASD when compared to TD children. Decreased displacements have been observed in older adults with disability and those transitioning to frailty and have been reported to be the result of decreased hip muscle functions [12,13,15]. The reduced swing side COP displacement observed in children with ASD will limit the extent to which the COM shifts towards the stance limb. As a result, during the transition from double limb support to single limb support, the COM will be farther away from the BOS, resulting in a greater need for active postural control. It therefore seems plausible that the significantly shorter displacements in the current investigation may indeed impart a dynamic postural instability in children with ASD.

An estimated 75% of children diagnosed with autistic disorder are also diagnosed with mental retardation (MR). Of the limited literature investigating posture in the ASD population, some have controlled for MR [8,9] while others have not [10,11]. Investigations including individuals diagnosed with ASD and MR together, only ASD, and only MR have reported increased postural instability in all three groups when compared to controls [8–11]. It appears that both ASD and general cognitive impairment contribute to postural instability, but the extent of each individual contribution remains unclear. Although a group difference in IQ was observed for the current investigation, all participants were above the threshold value of 70 for MR. It is plausible that the lower IQ of the ASD group may have contributed to the group s increased postural instability. However, given the prevalence of co-morbidity, MR was not controlled for in the current investigation.

Neuroanatomical and behavioral studies of ASD have implicated numerous areas of the brain responsible for the observed clinical impairments. Alterations in both the structure and functionality of the cerebellum [26] and the basal ganglia [27,28] have been observed and have been related to disturbances in posture control and gait. Several interconnected structures in the brain play a role in integrating sensory information and executing movement. Studies of postural control and gait in ASD have lead to the belief that the postural control impairments may be due to a dysfunction in sensory input integration occurring in the cerebellum [10,29]. Other findings suggest generalized postural dysfunction and gait initiation patterns in ASD may be similar to those seen in Parkinson s disease [9,30], thereby implicating dysfunction in the basal ganglia, primary motor and secondary motor cortices. The hypothesized differences in these neuroanatomical structures may explain the performance discrepancies observed during these functional tasks of quiet standing and gait initiation.

The results of the current investigation have systematically highlighted postural instabilities in children with ASD using two different categories of postural challenges. These findings have helped clarify some of the uncertainties existing in the literature, indicating that children with ASD (8–16 yrs) have postural instabilities during quiet standing even when no sensory manipulations have been performed. Further, we have provided new insight into postural instabilities associated with the dynamic task of GI. By better characterizing the impairment associated with these disorders, behavioral treatments that include balance training early in development may help to prevent subsequent emergence of deficits in other motor abilities.

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Table 1

Normalized means (no units) and standard deviations (SD) for traditional COP measures and COP-COM moment arms during quiet stance and COP displacements during the initial phase of gait initiation.

Quiet Stance Measures	ASD (n=13)		TD (n=12)	
	Mean	(SD)	Mean	(SD)
COP_{ML}	0.388*	(0.567)	0.072*	(0.033)
COP_{AP}	0.192*	(0.076)	0.094*	(0.043)
COP_{Sway}	0.104*	(0.159)	0.007*	(0.005)
$COP\text{-}COM_{max\_ML}$	0.029	(0.032)	0.013	(0.008)
$COP\text{-}COM_{max\_AP}$	0.016*	(0.010)	0.008*	(0.003)
$COP\text{-}COM_{max\_R}$	0.037*	(0.033)	0.015*	(0.008)
Gait Initiation Measures	**ASD (n=12)**		**TD (n=12)**	
	Mean	**(SD)**	**Mean**	**(SD)**
d_ML	0.120*	(0.069)	0.200*	(0.069)
d_AP	0.143	(0.085)	0.131	(0.042)

*Significant difference between ASD and TD at $p<0.05$.

COP_{ML}, COP_{AP} and COP_{SWAY} represent the range of center of pressure (COP) sway in the mediolateral and anteroposterior directions during quiet stance and the subsequent sway area obtained by multiplying the ranges. COP-COM $_{max\_ML}$, COP-COM $_{max\_AP}$, and COP-COM $_{max\_R}$ represent the difference between the COP and center of mass (COM) in the transverse plane (defined as moment arm) in the mediolateral and anteroposterior directions during quiet stance and the subsequent resultant moment arm. d_ML and d_AP represent the peak COP displacement in the mediolateral and anteroposterior directions during gait initiation.