Gait & Posture 39 (2014) 420–423

Contents lists available at ScienceDirect

Gait & Posture

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

Decreased dynamical complexity during quiet stance in children with Autism Spectrum Disorders

Kimberly A. Fournier [a,*], Shinichi Amano [b], Krestin J. Radonovich [c], Tana M. Bleser [d], Chris J. Hass [b]

[a] Department of Kinesiology, University of Rhode Island, Kingston, RI 02881, United States
[b] Department of Applied Physiology and Kinesiology, University of Florida, Gainesville, FL, United States
[c] Department of Pediatrics, University of Florida, Gainesville, FL, United States
[d] Department of Psychology, University of Florida, Gainesville, FL, United States

ARTICLE INFO

Article history:
Received 22 October 2012
Received in revised form 1 August 2013
Accepted 14 August 2013

Keywords:
Autism Spectrum Disorders (ASD)
Center of pressure (COP)
Multiscale entropy (MSE)
Posture
Nonlinear

ABSTRACT

Background: Postural control deficits in individuals with Autism Spectrum Disorders (ASD) are widely acknowledged; however, the underlying biomechanical features of these deficits remain unknown. Nonlinear analyses provide insight into the nature of how movement is controlled and have the potential to provide new insight into the postural control abnormalities associated with ASD. The purpose of this study was to further investigate postural control deficits in children with ASD through linear and nonlinear analyses of center of pressure (COP) data.

Methods: We evaluated COP data during quiet standing for 16 children with ASD and 17 age-matched typically developing (TD) children. The magnitude of COP fluctuations (COP ranges, velocity, and sway area) and complexity of postural control dynamics, quantified by multiscale entropy (MSE), were compared across groups.

Results: Children with ASD displayed larger fluctuations in their COP data, observed in COP ranges (95.5% mediolaterally and 46.9% anteroposteriorly, $p < 0.05$ respectively) and COP sway area (885%, $p < 0.05$). Children with ASD also displayed less complexity in their COP data, observed in the MSE complexity index (C_I) (32.4% mediolaterally and 35.7% anteroposteriorly, $p < 0.05$ respectively).

Conclusions: The present study successfully revealed that children with ASD have more repetitive patterns in their COP data, indicating a less complex control of posture, on multiple time scales, during quiet stance. These findings suggest a more regular or restricted control of posture and may be an initial step in linking postural instability to stereotypic behavior and the neurobiology of ASD.

Published by Elsevier B.V.

1. Introduction

The ability to maintain posture is at the core of typical motor development in humans. Children diagnosed with Autism Spectrum Disorders (ASD) exhibit an impaired ability to control quiet stance when compared to typically developing children (TD) [1–3]. Abnormal movements, including deficiencies in postural control, appear to be pervasive across the spectrum of autism disorders [4–6]. While the presence of these impairments has been grossly described in the literature, very little has been done to investigate underlying features of postural performance beyond spatial evaluation of postural sway. Therefore, further elucidation of the nature of these disturbances may provide further insight into possible mechanisms contributing to impaired postural control.

Postural control has been studied extensively in clinical populations (for example; Parkinson's, Stroke, Cerebral Palsy, and ASD) and using a variety of experimental tasks (for example; sitting, standing, sit-to-stand, and gait initiation). Linear analytical techniques have been widely used to describe the gross output of the nervous system's response to maintaining balance (center of pressure (COP) sway area, COP path length, etc). More recently, nonlinear analytical techniques (i.e., approximate entropy, Lyupanov exponents, and multiscale entropy (MSE)) have been used to complement traditional measures in order to provide further insight into the structural nature or complexity of how movement is controlled [7]. Restrictive and repetitive behaviors are distinctive characteristics of children with ASD. This behavioral rigidity has been linked to potential deficits in frontal cortical and striatal function; circuitry which may also influence postural control [8]. Thus, this centrally mediated rigidity may carry over and manifest

* Corresponding author. Tel.: +1 401 874 5438; fax: +1 401 874 4215.
E-mail address: kimfournier@mail.uri.edu (K.A. Fournier).

0966-6362/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.gaitpost.2013.08.016

as less complex control of the COP time series during postural control tasks.

The purpose of this study was to further investigate the nature of the postural control deficits previously reported in children with ASD, through linear and nonlinear analysis of standing posturography data. We hypothesized that children with ASD would have more periodic COP patterns during quiet stance than TD children and thus have smaller entropy values observed on multiple time scales as indicated by lower MSE indices (Complexity Index in the mediolateral direction ($C_{I\text{-}X}$) and in the anteroposterior direction ($C_{I\text{-}Y}$))

2. Methods

2.1. Participants

Sixteen children diagnosed with ASD (age: 5.5 ± 1.1 years, height: 1.2 ± 0.1 m, mass: 24.0 ± 6.0 kg, Leiter-R Brief IQ: 81.6 ± 23.4) were recruited from the University's Child & Adolescent Psychiatry Clinic. Seventeen age-matched typically developing (TD) children (age: 6.2 ± 1.2 years, height: 1.2 ± 0.1 m, mass: 20.8 ± 3.0 kg, Leiter-R Brief IQ: 115.5 ± 13.5) 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 autism assessments (Autism Diagnostic Observation Schedule [9], Social Communication Questionnaire [10], or Childhood Autism Rating Scale [11]). 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.

2.2. Data collection

Ground reaction forces (GRF) and moments were recorded (360 Hz) from a forceplate (Type 4060-10, Bertec Corp., Columbus, OH) embedded in and level to the laboratory floor. During quiet stance trials, children stood with their feet comfortably apart on the forceplate. Foot positioning was marked and used for all subsequent trials. During each trial, children were asked to stand as 'still as possible' for 20 s with their arms 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. GRF and moments collected from the forceplate were used to calculate the location of the COP in a time-series and these data were then filtered using a second order, low pass frequency Butterworth filter (cut-off frequency of 20 Hz). The filtered locations of the COP were then outputted for further analyses [12]. The COP ranges in the mediolateral ($COP_{RANGE\text{-}X}$) and anteroposterior ($COP_{RANGE\text{-}Y}$) directions, the COP velocity (COP_{VEL}) and an elliptical sway area containing 95% of the COP data ($Area_{CE95}$) were calculated and used to characterize the magnitude of the movement present in the COP time series.

The postural dynamical complexity was quantified using the MSE algorithm described previously in the literature [13]. Knowing that biological systems are generally not classified as perfectly regular or completely random but rather have a complex structure on multiple spatial and temporal scales [14], nonlinear analyses using MSE would thus be appropriate for evaluating the regularity of physiologic data. MSE aims to measure information content in a time series on multiple time scales and is achieved through successive smoothing of that time series [13]. Briefly, smoothing is achieved by averaging data points in non-overlapping windows. These non-overlapping windows are defined by the number of data points in them, known as the time-scale factor (τ) [13]. The time series is said to be more coarse-grained with increasing τ values. Entropy values (ApEn in the present study) were obtained for every smoothing using previously described methodology [7,15,16] Briefly, ApEn examines the points in a COP time series in search of short, repeating patterns and assesses the disorderliness of movement [7]. The algorithm identifies an average count of the recurrence of vectors of length m and $m+1$ within a tolerance range of r for a given unit-variance normalized time series. Based on typical values previously reported in COP time series data, the length of vector and the tolerance range were defined as $m = 2$ and $r = 0.2$ of the time series COP standard deviation [15,16]. ApEn values were plotted against τ in both the mediolateral and anteroposterior directions, to create MSE curves. The MSE curves were then used to interpret the information content on multiple time scales ($\tau = 1$–20) of the series [13]. The area under the MSE curves were calculated and defined as the Complexity Index (C_I) for both the mediolateral ($C_{I\text{-}X}$) and anteroposterior ($C_{I\text{-}Y}$) directions. Nonlinear measures applied to physiologic data such as posturography data, tend to decrease in value when postural control deficits are present due to disease/pathology or due to experimental manipulation of sensory input or task complexity [15,17–22], although alternative observations are reported in the literature [13,23,24]. Larger C_I values are therefore believed to be representative of healthy biological systems and smaller values representative of degradations in complexity associated with diseased systems [24]. Linear measures ($COP_{RANGE\text{-}X}$, $COP_{RANGE\text{-}Y}$, COP_{VEL} and $Area_{CE95}$) and nonlinear measures ($C_{I\text{-}X}$ and $C_{I\text{-}Y}$) of variability in the COP time series were calculated using a customized MatLab program (MathWorks, Natick, Massachusetts) based on previous methodology [7,25,26].

2.3. Statistical analysis

Independent t-tests were used to identify differences in the dependent variables (Linear: $COP_{RANGE\text{-}X}$, $COP_{RANGE\text{-}Y}$, COP_{VEL}, $Area_{CE95}$, Nonlinear: $C_{I\text{-}X}$, $C_{I\text{-}Y}$) between children diagnosed with ASD and TD children. An a' priori alpha level of 0.05 was set for all statistical tests. All statistical tests were performed using SPSS 16.0 for Windows (Chicago, IL).

3. Results

Children with ASD exhibited significantly smaller C_I values when compared to TD children. The C_I values were 32.4% smaller in the mediolateral direction ($C_{I\text{-}X}$) and 35.7% smaller in the anteroposterior direction ($C_{I\text{-}Y}$). Entropy values associated with each time scale analyzed are presented in MSE curves for both the mediolateral and anteroposterior directions (Figs. 1 and 2). As expected, COP ranges were significantly larger in children with ASD when compared to TD children (95.5% larger and 46.9% for $COP_{RANGE\text{-}X}$ and $COP_{RANGE\text{-}Y}$, $p < 0.05$ respectively). Similarly, COP_{VEL} was 126% larger in those with ASD ($p < 0.05$). Although $Area_{CE95}$ did not reach significance, it was 885% larger in children with ASD when compared to TD children (Table 1).

4. Discussion

Appropriate postural control is a necessary foundation for individuals to acquire skills inherent to functional independence. Herein, we applied nonlinear analyses (MSE) of the COP time series to extract more information about the nature of differences in postural control previously described in the literature between