Gait & Posture 48 (2016) 19–23

Contents lists available at ScienceDirect

Gait & Posture

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

Time dependent structure of postural sway in individuals with multiple sclerosis

Kathleen L. Roeing, Douglas A. Wajda, Jacob J. Sosnoff*

Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign, United States

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form 10 March 2016
Accepted 5 April 2016

Keywords:
Multiple sclerosis
Posture
Balance
Non-linear analysis
Approximate entropy

ABSTRACT

Non-linear analyses, which examine the time dependent structure of physiological output have been found to be able to detect subtle differences in postural control between pathological groups and healthy controls while traditional linear parameters do not. This investigation examines whether a specific non-linear metric, approximate entropy, may provide a novel biomarker for balance impairment in individuals with multiple sclerosis (MS) who have normal sway. This analysis included a sample of 30 individuals with MS with normal postural sway and 36 controls. Participants stood on a force platform for two trials of 30 s with eyes open. Postural control was indexed by sway area, mean velocity along the antero-posterior (AP) and mediolateral (ML) axis. The time dependent structure of the COP along the AP and ML axes was indexed with approximate entropy ($ApEn_{AP}$; $ApEn_{ML}$). *T*-tests and Mann–Whitney *U* tests were utilized to analyze differences between groups. Per design there were no differences in sway area between the MS and control groups. Additionally, there were no differences in sway velocity. The MS group had lower $ApEn_{ML}$ values compared to the control group ($U = 376$, $p = .026$). The results indicate that individuals with MS who have normal sway area had greater time dependent structure in ML sway. This investigation highlights the utility of non-linear analyses when assessing balance impairment in MS samples that present with minimal sway area.

1. Introduction

Multiple sclerosis (MS) is a neurodegenerative disease that impacts over 2 million people worldwide [1]. MS is characterized as an immune mediated demyelination and inflammation of nervous tissue [2]. While the etiology of MS is unknown, it is believed to be caused by the interplay of genetic and environmental factors [2]. Individuals with MS experience a heterogeneous array of symptoms with ~75% experiencing balance impairment over the course of the disease [3]. Balance impairment represents a key symptom in MS as it has been associated with increased fall risk and disengagement with daily activities [4,5].

Posturographic analyses are considered the gold standard for detecting balance impairment in the general MS population [6]. However, some have argued that their utility decreases when examining individuals with minimal impairments [7–9]. The vast majority of postural control investigations in MS have focused on linear measures that quantify postural sway through averaged statistics ignoring the time-evolving structure inherent in physiological signals [6,7,10,11]. In order to combat this limitation, non-linear measures, such as approximate entropy (ApEn), can be used to describe the intrinsic dynamics or regularity of the system [12].

In general, non-linear analyses of physiological function have been found to be more sensitive to declines in physiological health in a myriad of conditions compared to standard distribution analyses [13–16]. Non-linear analyses have the potential to identify impairments in postural control in individuals with MS who present with subtle balance impairment undetectable with traditional linear measures. Indeed, these measures have previously been shown to be sensitive to subtle deficits in postural control in various other clinical populations such as mild traumatic brain injury [10,12,17]. Early detection of balance impairment is key in that it may identify those individuals who could benefit from targeted rehabilitation before severe loss of function sets in.

Preliminary evidence indicates that there is greater time dependent structure as indexed by ApEn in postural sway in individuals with MS compared to control participants. For instance, a small investigation ($n = 15$) demonstrated decreased

* Corresponding author at: University of Illinois at Urbana-Champaign, Department of Kinesiology and Community Health, 301 Freer Hall, 906 South Goodwin Avenue, Urbana, IL 61801, United States. Tel.: +1 217 333 9472; fax: +1 217 244 7322.
E-mail address: jsosnoff@illinois.edu (J.J. Sosnoff).

http://dx.doi.org/10.1016/j.gaitpost.2016.04.023
0966-6362/

ApEn and therefore more regular COP movement in the mediolateral (ML) direction during a standing balance test when compared to healthy controls. The authors argued that this increased structure was indicative of a decline in adaptability [18]. Additionally, individuals with MS demonstrate greater time dependent structure compared to individuals with stroke and Parkinson's disease [17]. However, these observed differences in time dependent structure have only been demonstrated in samples with elevated amounts of postural sway. Consequently, it is not clear whether fluctuations in the pattern of postural sway are impacted in individuals with MS who do not display balance impairment based on traditional postural sway measures. Non-linear analysis could potentially provide a novel means to detect subtle balance impairment in individuals with normal amounts of sway.

The purpose of this study was to evaluate the fluctuation pattern of postural sway in a sample of individuals with MS who had normal amount of postural sway compared to healthy controls. Due to the differences between linear and non-linear measures, we hypothesized that a sample of individuals with MS with normal amounts of postural sway would demonstrate lower ApEn indicating greater amounts of time dependent structure in a static postural task compared to healthy controls.

2. Methods

2.1. Participants

This analysis consisted of a sample of 30 individuals with MS who were identified from a larger sample of 137 who participated in one of five different mobility research investigations (ClinicalTrials.org #NCT02274935, #NCT01992679, #NCT01837017, #NCT01956227). Individuals were included if their total sway area was within one standard deviation of the mean sway area for a healthy control sample. Thirty-six healthy controls were recruited to be similar in age and gender to the MS group. All measurements were collected at the baseline assessment of the respective investigations with consist procedures. Inclusion criteria for the MS group included a neurologist confirmed diagnosis and the ability to stand unsupported for 30 s. Control subjects were screened prior to enrollment to confirm the absence of any neurologic conditions, balance disorders, or medication use that might interfere with postural control.

2.2. Procedure

All testing procedures were approved by the local institutional review board. All measurements were collected during one visit to the research laboratory. Upon arriving at the research laboratory, participants were given a verbal explanation of the study, an informed consent document, and the ability to ask questions regarding the research study. After providing written informed consent participants were asked to fill out a series of questionnaires and perform the standing balance test. All participants provided demographic information including age and gender. MS participants additionally provided MS subtype, year since diagnosis, and self-reported expanded disability status scale ($EDSS_{SR}$) through the self-administered Kurtzke questionnaire [19]. This questionnaire examines seven neurological functions including pyramidal, cerebellar, brainstem, sensorial, bladder and bowel, visual and mental and walking ability [20]. The self-administered ($EDSS_{SR}$) has shown to have a strong correlation ($r = 0.9$) with the neurologist administered EDSS [20].

Assessment of static postural control was performed on a Bertec force platform (Bertec Corporation, Columbus, OH). Participants performed a total of two trials standing on the force plate with their eyes open for 30 s. Participants were instructed to stand as still as possible with their feet shoulder width apart and hands resting at their sides. They were asked to keep their vision fixated at a point at eye level approximately 1 m in front of them.

2.3. Data analysis

The posture analysis was based on the motion of the center of pressure (COP) as calculated by the force plate. The force platform simultaneously measures force and moment components in the AP, ML, and vertical axes which can be combined to provide the COP location throughout the measurement period. Custom MATLAB (Mathworks Inc., Natick, MA) scripts were used to calculate all measures. Linear measures included total sway area (SA), mean velocity along the mediolateral (MV_{ML}) axis, and mean velocity along the anteroposterior (MV_{AP}) axis. Measures were averaged across the two trials for each participant. These measures are commonly used to examine balance in individuals with MS [6].

The non-linear analysis used in the current investigation was Approximate Entropy (ApEn). ApEn of postural sway was calculated from the ML ($ApEn_{ML}$) and AP axis ($ApEn_{AP}$) COP time series. ApEn is a unit-less statistic that quantifies the time dependent structure of a time series. ApEn values range from 0 to 2. Higher ApEn values indicate a system has lower amounts of time dependent structure and lower ApEn values indicate a system has greater time dependent structure [21]. From a theoretical standpoint, a lower ApEn value indicates a decreased ability to adapt. ApEn values were calculated based on established procedures [21], using MATLAB (Mathworks Inc., Natick, MA) with a lag value of 10, m value of 2 and an r value of 0.2. The force platform sampled posture data at a frequency of 1000 Hz. Prior to the analysis of the COP signals, the data was down-sampled to a rate of 100 Hz and filtered with a 4th order low pass Butterworth filter. The calculated ApEn values were averaged across the two balance trials.

2.4. Statistics

Mean, standard deviation, and range were determined for age and posturographic measures. Median and interquartile range was determined for $EDSS_{SR}$. The Shapiro–Wilk test was utilized to examine the normality of the outcome measures. Differences in age and gender were analyzed by Mann–Whitney U tests and chi-squared tests, respectively. Due to the non-normality of MV_{AP}, SA, and $ApEn_{ML}$ values, Mann–Whitney U tests were utilized to analyze differences between groups. MV_{ML} and $ApEn_{AP}$ were normally distributed, therefore independent sample T-tests were used to determine differences between the controls and MS sample. All levels of statistical significance were set at $p \leq .05$. All statistical analyses were performed in SPSS version 22 (IBM Inc., Armonk, NY).

3. Results

Descriptive statistics for the demographic and posturographic measures are presented in Tables 1 and 2, respectively. There were no differences in age ($U = 403$, $p = .08$) or gender composition ($\chi^2 = 1.656$, $p = .25$) between the MS and control group. All linear balance measures were similar between the MS and control groups. There was no difference is SA ($U = 416$, $p = .11$), MV_{AP} ($U = 514$, $p = .74$), or MV_{ML} ($t = -.958$, $p = .34$). There was also no difference in $ApEn_{AP}$ between the MS and control groups ($t = .660$, $p = .51$). There was a significant difference between the MS and control groups in $ApEn_{ML}$ ($U = 367$, $p = .03$) with the MS group demonstrating lower levels of ApEn compared to controls (see Fig. 1).