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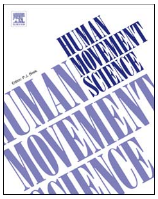

Full Length Article

Coherence analysis of trunk and leg acceleration reveals altered postural sway strategy during standing in persons with multiple sclerosis

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ABSTRACT

Balance task performance is affected in persons with multiple sclerosis (PwMS), but the control strategies used to perform specific tasks are not well understood. The purpose of this study was to evaluate segmental control during quiet standing in PwMS and controls to understand whether MS alters use of the ankle and hip strategies to manage postural sway. Coherence of acceleration between the trunk and legs was evaluated with accelerometers placed on the sacrum and lower leg. Thirty-six PwMS and 20 healthy control subjects performed quiet standing with eyes open and closed while center of pressure (CoP) and acceleration of postural sway was measured. Acceleration frequencies were divided into lower frequencies (≤ 1.0 Hz) and higher frequencies (> 1.0 Hz) to categorize sway characteristics. With eyes open, coherence was significantly lower in PwMS compared to controls at lower frequencies only. With eyes closed, coherence was significantly lower in PwMS compared to controls, who use an ankle strategy at lower frequencies only, at both lower and higher frequencies. Both groups showed decreased coherence with increasing frequency when eyes were open and closed. Coherence was significantly correlated with CoP sway area in PwMS during the eyes closed condition only. The reduced coherence in PwMS during both lower and higher frequency sway indicates PwMS utilize a mixed ankle-hip sway strategy regardless of sway frequency. This is in contrast to sway in healthy subjects which utilizes an ankle strategy at lower frequencies and a mixed strategy at higher frequencies. Lack of adaptability in segmental control strategy likely contributes to abnormal postural control, as reflected by CoP sway patterns, in PwMS.

1. Introduction

Persons with multiple sclerosis (PwMS) have altered postural control, as reflected by increased postural sway while standing (Karst, Venema, Roehrs, & Tyler, 2005; Van Emmerik, Remelius, Johnson, Chung, & Kent-Braun, 2010), reaching (Karst et al., 2005), and in response to external perturbations (Cameron, Horak, Herndon, & Bourdette, 2008; Huisinga, St George, Spain, Overs, & Horak, 2014). The relationship between altered postural sway and increased incidence of falls is often cited in PwMS, as well as other populations (Jacobs & Kasser, 2012; Kasser, Jacobs, Foley, Cardinal, & Maddalozzo, 2011; Rocchi, Chiari, & Horak, 2002). However, it is not clear how sway abnormalities reflect dysfunctional motor coordination patterns in PwMS. Postural sway is usually measured

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as center of pressure displacement in the antero-posterior or medio-lateral directions on a force plate or more recently from inertial sensors on the lower trunk. Increase in sway area, especially with eyes closed in PwMS, is thought to be related to slowed sensory and motor axonal conduction (Cameron et al., 2008; Huisinga et al., 2014). In addition, slowed propriospinal conduction time in PwMS has been related to prolonged latencies of automatic postural responses to surface perturbations (Cameron et al., 2008). While center of pressure sway measures are strong indicators of dysfunctional postural control, these measures do not directly reflect the postural movement strategies employed by PwMS during quiet stance. Directly examining the kinematics of body segments during standing in PwMS will allow for a better understanding of how persons with MS apply adaptive postural strategies to compensate for imbalance due to loss of somatosensory feedback, muscle weakness due to slowed axonal conduction velocities, and other central nervous system deficits (Cameron et al., 2008; Noseworthy, Lucchinetti, Rodriguez, & Weinshenker, 2000).

When standing quietly, human stance is often modeled as a combination of a single (ankle strategy) and double (hip strategy) inverted pendulum which pivots around the ankle primarily, with increasing contribution of hip motion with larger postural sway (Horak & Macpherson, 1996; Jeka, Oie, Schoner, Dijkstra, & Henson, 1998; Peterka, 2002). Previous sway modeling (Creath, Kiemel, Horak, Peterka, & Jeka, 2005) found that at sway oscillations below 1 Hz, healthy young individuals move with the trunk and legs in-phase simulating an ankle strategy while at frequencies greater than 1 Hz, trunk and leg motion is anti-phase, simulating a hip or mixed (hip-ankle) strategy. This in-phase or anti-phase strategy was identified by examining the coherence between the angles of the two segments but coherence can be examined between any signals which represent segment motion, including segment acceleration and can be thought of as a correlation coefficient in the frequency domain between two signals (Creath et al., 2005). Selection of in-phase (single segment inverted pendulum, ankle strategy) and anti-phase (dual segment pendulum, hip or mixed strategy) movement patterns, and transitions between patterns, may depend on loss of stability as well as pre-selected movement strategy based on the task (Bardy, Marin, Stoffregen, & Bootsma, 1999; Bardy, Oullier, Bootsma, & Stoffregen, 2002; Creath et al., 2005).

In PwMS, the segmental coordination patterns utilized during quiet standing are unknown. It has been speculated based on variability analysis of center of pressure sway patterns, that PwMS are less adaptable in their movement patterns (Huisinga, Yentes, Filipi, & Stergiou, 2012). In the present study, we evaluated the postural strategies in PwMS using accelerometry during quiet standing. Specifically, we evaluated the coherence of the acceleration patterns between the trunk and the legs. Coherence analysis allows for the calculation of the relationship between two segments across frequencies (Zhang, Kiemel, & Jeka, 2007). We hypothesized that PwMS would display coherence patterns between the trunk and the legs that differ from healthy controls across a range of frequencies. We also expected that within PwMS, coherence would be similar across both low (≤ 1.0 Hz) and higher (> 1.0 Hz) frequencies since PwMS may be more inflexible in adapting movement patterns (Huisinga, Yentes, et al., 2012). Similar coherence across low and higher frequencies in PwMS would not follow the coherence seen in healthy controls who display more of an ankle strategy at low frequencies and mixed hip-ankle strategy at higher frequencies. Finally, to help further understand the ankle and hip strategies, we hypothesized that lower coherence of trunk-leg would be related to longer latencies of postural responses and to larger sway area during quiet stance in PwMS.

2. Methods

2.1. Participants

All participants were recruited through the Oregon Health & Science University MS Clinic. All participants provided informed consent according to the Oregon Health & Science University Institutional Review Board. Inclusion criteria for all MS subjects were 1) diagnosis of MS made by a neurologist, 2) ability to perform the Timed 25 Foot Walk test without a walking aid, 3) no clinical relapses within the previous 60 days, 4) free from any other problems which may affect gait such as vestibular issues, orthopedic problems, and diabetic neuropathy. Healthy control subjects were also free of any conditions that could affect their walking. On the day of testing, all PwMS completed the self-reported Expanded Disability Status Scale (srEDSS) as a general classification of global MS-related disability level. The EDSS is a standard and heavily used disability classification scale for patients with MS (Kurtzke, 1983). The srEDSS correlates strongly (Bowen, Gibbons, Gianas, & Kraft, 2001) with the clinician administered version and was utilized in this study to reduce participant burden due to the remote location of the testing laboratory.

2.2. Standing protocol and data analysis

Subjects were equipped with 6 MTX Xsens inertial sensors (49A33G15, Xsens, Enschede, NL, USA), containing 3D accelerometers, gyroscopes, and magnetometers mounted on: (i) sternum, 2 cm below the sternal notch, (ii) sacrum (L5 level, approximately at the body's center of mass), (iii) on the dorsum of the right and left wrist, (iv) right and left shin. Only accelerometry data from the sacrum and lower leg, collected at 50 Hz, were used for analysis.

2.2.1. Task 1 – standing posture

Subjects stood with arms folded across the chest with their feet at a fixed heel-to-heel distance of 10 cm (Craig, Bruetsch, Lynch, Horak, & Huisinga, 2017; Huisinga et al., 2014). Concurrently, subjects stood on a double force plate with one foot on each plate while ground reaction forces were sampled at 100 Hz. Ground reaction forces were filtered at 20 Hz and used to calculate center of pressure (CoP) sway area. Three, 30 s trials of quiet standing were performed for each condition: eyes open (EO) and eyes closed (EC). In the EO condition, patients were asked to focus on one point on the wall, 5 ms away, directly in front of them for the duration of the trial.