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Frequency analysis approach to study balance control in individuals with multiple sclerosis

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HIGHLIGHTS

- Frequency analysis of postural sway is a new approach in people with multiple sclerosis.
- The approach provides perspective understanding of changes in postural strategy.
- A new tool identifies the varying contributions of the different sensory systems.

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ABSTRACT

Background: The ability to control balance is often compromised in people with multiple sclerosis (MS) and is considered to be a strong contributing factor toward their increased risk of falls.
New method: The aim of the study was to demonstrate that frequency analysis of postural sway could be used to investigate postural control in people with MS. Ten individuals with MS and ten age-and-gender matched healthy subjects stood on the force platform with eyes open or closed. The displacements of center of pressure (COP) were used to calculate power spectrum using fast Fourier transform. Power spectrum was analyzed for anterior-posterior (AP) and medial-lateral (ML) directions using three frequency bands: 0–0.3 Hz, 0.3–1 Hz, and 1–3 Hz reflecting contributions from the visual, vestibular/somatosensory, and proprioceptive systems, respectively.
Results: The mean COP velocity in the eyes closed condition was significantly larger for the MS than the healthy control group. Additionally, the MS group showed a significant decrease in the magnitude of COP power spectrum in the low frequency band and a pattern of increase in the medium and high frequency bands in the medial–lateral direction.
Conclusion: The observed redistribution of the COP power spectrum when vision is absent indicates that people with MS relied more on the vestibular/somatosensory and proprioceptive systems. However, such a strategy change was ineffective in maintaining postural stability, thus highlighting the impaired ability of the somatosensory system in regulation of postural control in people with MS. The outcome of the study suggests that the COP frequency analysis could be used in identifying the possible sources of balance impairment in people with MS.

1. Introduction

Multiple sclerosis (MS) is a chronic demyelinating disease of the central nervous system that generally involves an immune-mediated process of degenerative and inflammatory damage to the myelin sheath covering nerve cells. Disruption of the myelin sheath and the underlying axons results in slowing of neural transmission which causes a wide range of impairments affecting sensory, motor and/or cognitive functions (Bjartmar et al., 2000; White, 2001). The most common symptoms of MS are fatigue, numbness, gait, balance and coordination problems, bladder and bowel dysfunction, vision problems, and cognitive dysfunction. Amongst the mobility limitations seen in MS, the ability to control balance is often compromised and is considered to be a strong contributing factor toward their increased risk of falls (Cameron and Lord, 2010; Cattaneo et al., 2002; Prosperini et al., 2012; Sosnoff et al., 2011). Accurate and efficient control of posture requires appropriate functioning and integration of multiple sensory and motor systems. As such, the critical contributions of the visual, somatosensory, and vestibular inputs to balance performance have long been established (Shumway-Cook and Woollacott, 2007). Particularly, in people with MS impairments of postural control are evident in

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the absence of visual inputs (Cattaneo and Jonsdottir, 2009; Van Emmerik et al., 2010) and are correlated with slowed somatosensory conduction (Cameron et al., 2008), reduced vibration and two-point discrimination sense (Citaker et al., 2011), proprioceptive losses (Rougier et al., 2007), and with deficits of central integration (Lanzetta et al., 2004). Additionally, decreased performance on the sensory organization tests indicates vestibular involvement in people with early MS with low functional disability (Cattaneo and Jonsdottir, 2009; Williams et al., 1997).

Multiple studies on balance control in MS have used static posturography measures to describe impairments of standing postural control in MS. Specifically; these impairments have been illustrated in the form of increased postural sway in standing (Cameron and Lord, 2010), which further increases in the absence of vision (Cattaneo and Jonsdottir, 2009; Soyuer et al., 2006; Van Emmerik et al., 2010; Williams et al., 1997) and with reduced base of support (Frzovic et al., 2000; Soyuer et al., 2006). While instability has been consistently demonstrated in MS, it may not sufficiently characterize the postural system correlates of such instability.

Spectral analysis of body sway has been used in the evaluation of postural control in young and elderly subjects (Bizid et al., 2009; Golomer et al., 1999; Golomer and Dupui, 2000; Golomer et al., 1997; Nagy et al., 2004; Singh et al., 2011). For this analysis, the power spectrum of the center of pressure (COP) excursions is generally divided into three frequency bands: low, medium and high (Bizid et al., 2009; Golomer et al., 1999; Nagy et al., 2004). Such investigations of the body sway in the frequency domain provide information on the postural strategies used: low frequencies are associated with visual regulation, medium frequencies with vestibular and somatosensory regulation, and high frequencies with proprioceptive regulation (Dichgans et al., 1976; Nagy et al., 2004; Njiokiktjien et al., 1978). Studies on quiet standing have demonstrated a decrease in the low-frequency band in the absence of vision, particularly in the medial–lateral direction (Nagy et al., 2004), moreover, an increase in the high-frequency band has been observed after triceps surae muscle fatigue (Bizid et al., 2009). These results not only provide a confirmation of the low frequency band association with visual control and the high frequency band with proprioceptive control, but also offer a spectral analysis approach in assessing postural control.

Spectral analysis of body sway may also be useful in identifying the various origins of imbalance in people with balance problems. Such additional information may be of particular use in evaluating body sway in people with MS, where incipient balance impairments exist as well as help in differentiating the balance impairments between different types of MS. The present study was thus aimed at identifying the postural system correlates of instability in people with MS, through the use of spectral analysis of COP displacements. We hypothesized that absence of vision would cause a decrease in the low frequency band of the COP power spectrum in healthy individuals and in people with MS. We also expected a shift in the COP power spectrum distribution of the three frequency bands in people with MS as compared to the healthy individuals.

2. Materials and methods

2.1. Participants

Ten individuals (8 females and 2 males) with relapsing-remitting MS (age 52 (SD14) years, height 169.4 (SD11.4) cm, weight 68 (SD12) kg, Expanded Disability Status Scale (EDSS) score 2.1 (SD1.1), MS duration 18.4 (SD10.9) years) and ten age and gender matched healthy control subjects (HC) (age 50 (SD14) years, height 167.3 (SD10.0) cm, weight 74 (SD12) kg) participated in the study. The inclusion criteria for the individuals with MS were: normal or corrected to normal vision, an EDSS (Kurtzke, 1983) score of 5 or less, and the ability to stand independently without any aid or orthosis for at least 1 min. EDSS scores 1.0–4.5 refer to people with MS who are ambulatory (with smaller number reflecting lesser level of disability. Patients were excluded if they had other medical illnesses, any kind of pain that interfered with their daily activities, or if they were unable to perform the experimental tasks. The experimental procedure was approved by the university's Institutional Review Board and the participants provided their written informed consent.

2.2. Instrumentation and procedure

The subjects were required to stand on a force platform (OR-5, AMTI, USA) barefoot, upright with feet shoulder width apart, and with eyes open (EO) or closed (EC). In the EO conditions, subjects were instructed to look at a marker located in front of them at the eye level; in the EC conditions, eyes were covered with a mask. Two 30-s trials were collected for each (EO and EC) condition. The order of experimental conditions was randomized for each subject. The experiment was carried out in one session and subjects were allowed to rest during testing if necessary. All the tests were conducted in the morning to minimize the effects of fatigue later in the day, that are commonly reported in individuals with MS (Bakshi, 2003).

Ground reaction forces and the moments of forces were digitized with a 16-bit resolution at 1000 Hz by means of an analog-to-digital converter and stored for further processing.

2.3. Data analysis

All signals from the force platform were processed offline using MATLAB software (MathWorks, Natick, MA, USA). The vertical component of the ground reaction force (F_z), the horizontal components in the anterior–posterior (AP) direction (F_y) and in the medial–lateral (ML) direction (F_x) and the moments of forces around the frontal axis (M_x) and the sagittal axis (M_y) were filtered with a 20 Hz low-pass, 2nd order, zero-lag Butterworth filter. Time-varying COP_{AP} and COP_{ML} displacements were calculated using the following approximations (Winter et al., 1996):

$$COP_{AP} = \frac{M_x - (F_y \cdot dz)}{F_z} \quad \text{and} \quad COP_{ML} = -\frac{M_y + (F_x \cdot dz)}{F_z}$$

where dz pertains to the distance from the surface to the platform origin.

Subsequently, the displacements of COP_{AP} and COP_{ML} were used to calculate the mean COP excursion and the mean COP velocity in the AP and the ML directions using following equations (Prieto et al., 1996):

$$\text{excursion}_{AP} = \frac{1}{N}\Sigma|COP_{AP}[n]| \quad \text{and} \quad \text{excursion}_{ML} = \frac{1}{N}\Sigma|COP_{ML}[n]|$$

$$\text{velocity}_{AP} = \frac{\text{trajectory}_{AP}}{T} \quad \text{and} \quad \text{velocity}_{ML} = \frac{\text{trajectory}_{ML}}{T}$$

where N is the number of data points included (30,000) and T is the period of time (30 s) used in the present analysis. For the spectral analysis, displacements of the COP were calculated by fast Fourier transform, following which the power density spectrum was obtained (Vieira et al., 2009). The power spectrum was then divided into three frequency intervals: the low-frequency (LF) band (0–0.3 Hz), the medium-frequency (MF) band (0.3–1 Hz), and the high-frequency (HF) band (1–3 Hz). This was done based on previous literature connecting the LF band with contribution of visual information to body sway, MF to vestibular and somatosensory, and HF to proprioceptive information (Golomer et al., 1999; Nagy