A Test of the Rambling and Trembling Hypothesis: Multiple Sclerosis and Postural Control

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The rambling-trembling analysis of postural control maintains that the center of pressure (COP) trajectory can be decomposed into deviations resulting from supraspinal (i.e., rambling; RM) and spinal processes (i.e., trembling; TM). The purpose of this investigation was to test the rambling and trembling hypothesis by comparing persons with multiple sclerosis (MS) who had either elevated or normal spinal reflexes to healthy controls. 16 subjects with MS and 16 age and gender matched control subjects completed a postural control task. The persons with MS were divided into groups with high (MS_high) or low (MS_low) H-reflex amplitude. The MS_high group had an elevated ratio of TM to COP compared with healthy controls, but no differences in the ratio between RM and COP. The findings are congruent with the assumptions of the rambling-trembling hypothesis. Further work is needed to determine if RM and TM represent distinct spinal and supraspinal mechanisms to postural control.

Keywords: balance, motor control, H-reflex, spasticity

The ability to maintain an upright stance is a fundamental function of the neuromuscular system. Its importance to human movement has made it a topic of scientific study. This body of research has revealed that postural control involves the integration of numerous sensory inputs (visual, vestibular and somatosensory) and precise muscular activation via spinal and supraspinal processes (Horak & Macpherson, 1996).

A popular method to examine postural control is to measure the ground reaction force of the center of mass, referred to as center of pressure (COP), during a balance task. It is maintained that migration of the COP is the neuromuscular response necessary to maintain an upright stance (Winter, 1995). Zatsiorsky and Duarte (1999, 2000) propose a theoretically based method of decomposing the COP trajectory into a unique supraspinal component and a spinal reflex component. They suggest that the supraspinal component (i.e., rambling (RM) is composed of the migration of resting position of the COP and the spinal reflex component (i.e., trembling (TM) is fluctuations around that resting position. In addition, the trembling component of the COP is also maintained to result from mechanical properties of the muscles and joints.

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Despite some critics of a two component model of postural control (Newell, Slobounov, Slobounova, & Molenaar, 1997), the approach of Zatsiorsky and Duarte has been empirically supported (Bottaro, Casadio, Morasso, & Sanguineti, 2005; Danna-Dos-Santos, Degani, Zatsiorsky, & Latash, 2008). For instance, Mochizuki and colleagues (2006) demonstrated differential changes in TM and RM with changes in base of support. In addition, de Freitas and colleagues (2009) illustrated that increasing the stiffness of lower limbs and trunk via joint immobilization causes differential increases in the TM component of the COP in healthy young adults. Although these investigations seemingly support that the RM and TM components of COP are distinct, they do not provide direct evidence that RM and TM components reflect supraspinal and spinal processes.

A common motor disorder suffered by persons with lesions of the central nervous system is spasticity (Lance, 1980). It is characterized by a velocity-dependent increase in tonic stretch reflexes and exaggerated tendon jerks resulting from hyperexcitability of the stretch reflex. Indeed ~80% of persons with multiple sclerosis (MS) reportedly suffer from spasticity—with lower limb (e.g., ankle) spasticity being the most prevalent (Rizzo, Hadjimichael, Preiningerova, & Vollmer, 2004).

As such, persons with MS with lower limb spasticity serve as an ideal population to examine the assumption of rambling and trembling analysis. If the TM component is due to spinal reflexes as proposed by Zatsiorsky and Duarte then individuals with exaggerated spinal reflexes (i.e., spasticity) should have a greater TM component in their COP during a postural control task compared with individuals without exaggerated spinal reflexes. Consequently, the purpose of this investigation is to test the assumptions of the rambling and trembling analysis of center of pressure profiles based on a secondary analysis of a previously published dataset (Sosnoff, Motl & Shin, 2010).

**Methods**

**Participants**

Sixteen subjects with MS (2 male) and 16 age- and sex-matched controls participated in the investigation. All subjects with MS had Expanded Disability Status Scale scores between 0 and 4.5 and modified Ashworth Scale scores between 1 and 3. The MS group included 16 subjects with either relapsing-remitting (n = 14), primary progressive (n = 1), or secondary progressive (n = 1) MS. On average it had been 7.8 years since diagnosis of MS, with a range between 0.5 and 22 years. The MS group had a mean age of 44.4 years and ranged from 20 to 60 years old, whereas the control group had a mean age of 44.3 years and ranged from 20 to 60 years old.

**Procedures**

Upon providing informed consent persons with MS underwent H-reflex assessment using standardized procedures. In brief, the H-reflex of the soleus muscle of the right leg was elicited with the participant in a comfortable semireclined position. The H-reflex was evoked by stimulating the tibial nerve in the popliteal fossa through a monopolar stimulating electrode with an anode placed superior to the patella. The stimulus was a single, 1-ms rectangular pulse delivered every
10 s. The H-reflex was measured using bipolar electrodes placed 2 cm apart along the ipsilateral soleus muscle and standard EMG. The EMG signal was band-pass filtered, amplified by 1000, and sampled at 2500 Hz. The maximal H-wave and maximal M-wave were then measured as an average of 5 subsequent recordings of the largest obtainable H-wave and M-wave, respectively. The maximal H-wave was expressed as the maximal H-wave/maximal M-wave ratio.

All participants underwent postural control assessment, which consisted of participants standing on dual AMTI force platforms with each foot on an individual force platform shoulder width apart for 4 thirty second trials. Participants stood barefoot with their arms placed comfortably by their sides. Brief rests were provided between trials to minimize fatigue.

Data Analysis

The posture analysis was based on the motion of the center of pressure. This component of postural data may be considered a reflection of the system’s neuromuscular response to the imbalances of the body’s center of gravity (Winter, 1995). Center of pressure in the AP and ML directions was determined according to previously used techniques (Sosnoff et al., 2010). Briefly, data were collected with a sample frequency of 100 Hz with a low pass filter of 10.5 Hz. Four 30 s trials were completed.

Each time series was decomposed into RM and TR components according to rambling-trembling decomposition methods (Zatsiorsky & Duarte, 1999; 2000). Rambling and trembling decomposition maintains that:

\[ \text{COP} = \text{RM} + \text{TM} \]

The RM component is determined by first calculating the instant equilibrium point trajectory (IEP, or zero-force point, \( \sum F_{\text{horizontal}} \) where \( F_{\text{horizontal}} \) are external forces acting on the body in the horizontal direction). Once the IEPs were identified a piecewise cubic hermite polynomial was used to determine the IEP trajectory which is referred to as the rambling trajectory. According to Zatsiorsky and Duarte (1999; 2000) the continuous trajectory of the reference point (e.g., IEP trajectory) is the trajectory around the postural equilibrium point. The TM trajectory was calculated as the difference between the approximated rambling trajectory and the COP trajectory. Figure 1 provides a graphical depiction of the relation between COP and the rambling and trembling components along the mediolateral axis.

The dependent variables analyzed in this investigation were root mean square (RMS), in the anterior-posterior (AP) direction and the mediolateral (ML) direction of the COP, RM and TR trajectories and the 95% elliptical area of the COP, RM and TR components (Goldie, Bach, & Evans, 1989). To further examine whether persons with elevated spinal reflexes had greater TM or RM components in their postural profile the ratio of TM to the COP and RM to COP was computed for each variable.

Statistical Analyses

Cluster analysis was performed on H-reflex data as a means of generating 2 groups of subjects with MS who had elevated \( n = 9; \text{MS}_{\text{high}} \) or normal \( n = 7; \text{MS}_{\text{low}} \)
Figure 1 — Representative center of pressure, rambling and trembling trajectories of a single control (top panel) and multiple sclerosis subject (bottom panel) along the mediolateral (ML) axis.
spinal reflexes. The dependent variables of sway area, RMS in the AP and ML directions for COP, RM and TM components were averaged across the 4 trials and then entered into univariate ANOVAs with group (control, MS normal reflexes and MS exaggerated reflexes) as the between subject factor. Main effects were decomposed using post hoc analyses with a correction of alpha. Effect sizes associated with $F$-ratios were expressed as eta-squared ($\eta^2$).

**Results**

As previously reported persons with MS with exaggerated spinal reflexes had poorer postural control as indexed by $\text{RMS}_{\text{AP}}$, $\text{RMS}_{\text{ML}}$, and sway area compared with the healthy control group and the MS group with normal reflexes (p’s > .05) (See Figure 2; Sosnoff et al., 2010).

![Figure 2](image-url)

**Figure 2** — A) Root mean score (RMS) of the rambling and trembling component in the anterior-posterior (AP) axis as a function of group. B) Root mean score (RMS) of the rambling and trembling component in the mediolateral (ML) axis as a function of group.
Novel to the current investigation was the examination of the RM and TM component of the postural sway. Figure 1 depicts a single control and MS\textsubscript{high} subject’s COP excursion and the corresponding RM and TM component in the mediolateral direction. It is clear in the figure that the subject with MS has greater excursion in the RM and TM trajectories than the healthy control subject.

Statistical analysis on the grouped data confirmed these observations. Specifically, there was a main effect of group when RMS\textsubscript{ML} of the RM component [F(2,29) = 8.45;\ p < .05;\ η\textsuperscript{2} = .37] and TM component [F(2,29) = 6.80;\ p < .05;\ η\textsuperscript{2} = .32] were examined (See Figure 2B). Post hoc analysis revealed that within the RM component the MS\textsubscript{high} group (1.47 ± 0.22 mm) had elevated RMS\textsubscript{ML} compared with the healthy controls (0.39 ± 0.15 mm) and the MS\textsubscript{low} group (0.90 ± 0.23 mm). The difference between healthy controls and MS\textsubscript{low} group was not significant. Similar findings were noted for the TM component with the MS\textsubscript{high} group (1.32 ± 0.25 mm) having greater RMS\textsubscript{ML} than the control group (0.23 ± 0.17 mm) and the MS\textsubscript{low} group (0.90 ± 0.27 mm).

It is clear in Figure 3 that the MS\textsubscript{high} group had greater rambling component and trembling component area than the MS\textsubscript{low} and healthy controls. Statistical analysis confirmed this observation with a main effect of group for RM area [F(2,29) = 8.51;\ p < .05;\ η\textsuperscript{2} = .37] and TM area [F(2,29) = 5.84;\ p < .05;\ η\textsuperscript{2} = .29]. Post hoc analysis revealed that the MS\textsubscript{high} group had greater RM area (72.2 ± 11.7 mm\textsuperscript{2}) than both the healthy control group (13.22 ± 8.8 mm\textsuperscript{2}) and the MS\textsubscript{low} group (34.2 ± 12.6 mm\textsuperscript{2}). The MS\textsubscript{low} group had significantly greater RM area than the control group. Post hoc analysis revealed that the MS\textsubscript{high} group had greater TM area (62.2 ± 13.4 mm\textsuperscript{2}) than both the healthy control group (6.7 ± 9.5 mm\textsuperscript{2}) and the MS\textsubscript{low} group (30.3 ± 14.4 mm\textsuperscript{2}).

It is possible that the elevated RM and TM components observed in persons with MS are simply a result of their greater overall postural sway. To further examine this possibility, ratios between the COP and RM and TM for each dependent

![Figure 3](image_url) — Area of the rambling and trembling component as a function of group.
variable were determined. It is clear in Figure 4A that there is minimal difference between groups in the ratio concerning RMS\textsubscript{AP} ($p > .05$). In contrast, examination of ratio of RMS\textsubscript{ML} revealed that the control group (0.84 ± 0.03) had a greater ratio than the MS\textsubscript{low} group (0.71 ± 0.04) [$F(2,29) = 3.77; p < .05; \eta^2 = .20$] (See Figure 4B). In addition, a group effect was noted when ratio of area between TM and COP was examined [$F(2,29) = 3.00; p < .05; \eta^2 = .17$] (See Figure 5A-B). Post hoc analysis revealed that the MS\textsubscript{high} group (0.73 ± 0.13) had greater ratio of TM component to COP area than the control group (0.35 ± 0.09). The MS\textsubscript{low} group was not significantly different from either group. There was no difference between groups concerning the ration of RM to COP area.

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**Figure 4** — A) Ratio of root mean score (RMS) of the rambling and trembling component in the anterior-posterior (AP) axis to that of the RMS of the center of pressure (COP) as a function of group. B) Ratio of root mean score (RMS) of the rambling and trembling component in the mediolateral (ML) axis to that of the RMS of the COP as a function of group.
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Discussion

Postural control results from the dynamic interplay of various sensory inputs (e.g., visual, proprioceptive and vestibular information) and appropriate motor responses to maintain the center of mass within the limits of stability. The vast majority of scientific investigation on postural control focus on the ground reaction force of the center of mass, referred to as center of pressure (COP). It is maintained that migration of the COP is the neuromuscular response necessary to maintain an upright stance (Winter, 1995) and that this neuromuscular response stems from a combination of supraspinal and spinal processes. There is ongoing debate within the motor control community concerning the actual contribution of supraspinal and spinal processes to postural control (Loram, Maganaris, & Lakie, 2009; Morasso & Schieppati, 1999; Winter, Patla, Ishac, & Gage, 2003) as well as the appropriateness of separating them out (Newell, et al., 1997).

Contributing to this debate, Zatsiorsky and colleagues (Zatsiorsky & Duarte, 1999, 2000) introduce a theoretically based method of decomposing the COP trajectory into a unique supraspinal component and a spinal reflex component. They suggest that the supraspinal component (i.e., rambling (RM) is composed of the migration of resting position of the COP and the spinal reflex component (i.e., trembling (TM) reflects fluctuations around that resting position. The trembling component was also suggested to stem in part from mechanical properties of the involved musculature. Although it has received some empirical support (Bottaro, et al., 2005; Danna-Dos-Santos, et al., 2008; Mochizuki, Duarte, Amadio, Zatsiorsky, & Latash, 2006), the assumption that the unique components reflect a supraspinal and spinal reflex component has as of yet been untested. The current investigation, utilizing a population shown to have greater spinal reflexes, provides the first test of this assumption.

The current investigation extends the findings of previous research examining the predictions of the rambling and trembling approach in several ways. To date,
the majority of research supporting the rambling-trembling hypothesis has been based on manipulating experimental conditions (de Freitas, Freitas, Duarte, Latash, & Zatsiorsky, 2009). For instance, Danna-Dos-Santos and colleagues (2008) found that manipulating accuracy requirements for a postural control task differentially influence the rambling and trembling component of the COP. Specifically when visual feedback of postural sway was provided with an accuracy requirement there was a reduction in RM component. This observation is congruent with the notion that the RM component results from supraspinal processing.

A novel component of the current investigation is that differential changes in RM and TM components of the COP during quiet stance were found based on neurophysiological differences between groups. It is well known that persons with MS have postural control deficits (Cattaneo & Jonsdottir, 2009; Cattaneo, Jonsdottir, & Repetti, 2007; Cattaneo, Regola, & Meotti, 2006; Frzovic, Morris, & Vowels, 2000; Karst, Venema, Roehrs, & Tyler, 2005; Martin et al., 2006; Porosinska, Pierzchala, Mentel, & Karpe, 2010; Van Emmerik, Remelius, Johnson, Chung, & Kent-Braun, 2010). Recently, it has been suggested that elevated spinal reflexes contribute to postural dysfunction in persons with MS (Sosnoff, Shin, & Motl, 2010). This proposition made persons with MS an ideal population to empirically test the predictions of the rambling-trembling hypothesis of postural control.

To quantify spinal reflexes, the H-reflex of persons with MS was quantified within the current investigation. The H-reflex is a low threshold spinal reflex that results from the electrical stimulation of Ia fibers in a peripheral nerve and recording the muscular response in the homonymous muscle. It is indicative of alpha motor neuron excitability. Individuals with increased spinal reflex sensitivity have increased alpha motor neuron excitability and increased H-reflex amplitude (Voerman, Gregoric, & Hermens, 2005). The H-reflex amplitude was used to separate participants into groups within the current investigation. There was a healthy normal control group, a group with MS without elevated H-reflex (MSlow) and a group with MS with elevated H-reflex (MShigh). These groupings allowed for the examination of the predictions of the rambling-trembling hypothesis. Specifically, if the RM component relates to supraspinal control process than the normal healthy control group should have smaller RM than persons with MS; who have deficits in supraspinal processing. In addition, if the TM component relates to spinal processes only persons with exaggerated spinal reflexes (e.g., MShigh) should have greater TM component than healthy controls and those with MS without altered spinal reflexes (e.g., MSlow).

As predicted, the MShigh group not only had elevated postural sway but had a greater percentage of postural sway resulting from the trembling component. This observation suggests that the increase in trembling was not simply the result of an increase of overall postural sway, but rather due to the increase of contribution of the spinal component. Moreover, the trembling of the MSlow group, the group without elevated spinal processes, was not statistically elevated compared with the healthy control group. The observations of the current investigation are some of the strongest evidence to date in support of the interpretation of the rambling and trembling decomposition.

Despite this support of the rambling and trembling decomposition technique, it is worthwhile to note that two-component models of postural control such as the rambling-trembling hypothesis are not without critics. For instance, Newell
and colleagues (Newell, et al., 1997) demonstrate that a one-component model of postural control can account for postural sway as well two-component models. In addition, Loram and colleagues (Loram, et al., 2009) have suggested that the stretch reflexes acting at the ankle play a minimal role in maintaining balance. The observations of the current investigation should not be taken as definitive evidence that the rambling-trembling technique truly separates between spinal and supraspinal control. Further work is needed to examine whether the rambling-trembling technique truly does delineate between spinal and supraspinal postural control.

Although it is maintained that postural control deficits in persons with MS are multifaceted, there is growing evidence that alteration in spinal processing plays a key role. For instance, Cameron and colleagues (2008) demonstrate that MS postural dysfunction in MS is associated with decreases in somatosensory spinal conduction and not supraspinal mechanisms. However, such findings do not rule out that adverse alterations in the supraspinal processing of sensory information (vision, vestibular and proprioception) which are common in persons with MS (Clanet & Brassat, 2000) do not contribute to postural control dysfunction. Further research is required to understand the processes and mechanism that contribute to postural control dysfunction in persons with MS. A more refined understanding of these mechanisms will facilitate postural control training (Cameron & Lord, 2010).

Despite the novel findings of this investigation there were several limitations. For instance, H-reflex was only recorded in persons with MS and not in the healthy controls participants. As such it was assumed that the control group had normal spinal reflexes. However, potential control subjects were excluded if they reported any neuromuscular dysfunction. This seemingly minimizes the possibility that the control subjects did not have normal spinal reflexes. An additional limitation is that postural control was only assessed in one standing posture (i.e., feet shoulder width apart). It is possible that the current results are not generalizable to other standing postures.

Future work should examine whether other populations (e.g., stroke, traumatic brain injury) with alteration in spinal reflexes also demonstrate elevated trembling component in their COP trajectory. It would also be of interest to examine whether various rehabilitative treatments of exaggerated spinal reflexes differentially influence the trembling or rambling components. For instance, recently it has been shown that acute cycling reduces H-reflex amplitude in persons with MS (Sosnoff & Motl, 2010), but it is not clear whether this reduction in spinal reflexes would lead to a reduction of the trembling component.

References


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