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Supervised Resistance Training Results in Changes in Postural Control in Patients with Multiple Sclerosis

Jessie M. Huisinga, Mary L. Filipi, and Nicholas Stergiou

Postural disturbances are one of the first reported symptoms in patients with Multiple Sclerosis (MS). The purpose of this study was to investigate the effect of supervised resistance training on postural control in MS patients. Postural control was assessed using amount of sway variability [Root Mean Square (RMS)] and temporal structure of sway variability [Lyapunov Exponent (LyE)] from 15 MS patients. Posture was evaluated before and after completion of three months of resistance training. There were significant differences between MS patients pretraining and healthy controls for both LyE ($p = .000$) and RMS ($p = .002$), but no differences between groups after training. There was a significant decrease in RMS ($p = .025$) and a significant increase in LyE ($p = .049$) for MS patients pre- to posttraining. The findings suggested that postural control of MS patients could be affected by a supervised resistance training intervention.

Keywords: exercise, motor control, rehabilitation, strength training

Multiple Sclerosis (MS) is a progressive neurological disorder that causes functional impairments such as abnormal walking mechanics, poor balance, muscle weakness, and fatigue due to axonal degeneration (White & Dressendorfer, 2004). Because MS patients have demyelination of the motor and sensory tracts within the central nervous system (CNS) which contributes to the disturbances in gait and postural control, disturbances in postural control and loss of postural stability are often some of the first reported symptoms while muscle weakness and fatigue can reduce standing and ambulation tolerance (Nelson, Di Fabio, & Anderson, 1995; White & Dressendorfer, 2004). These symptoms lead to atrophic changes associated with a decrease in physical activity which also contributes to the decline in muscle strength and functional capacity (White & Dressendorfer, 2004). Therefore, preventing muscle disuse and decline of physical activity may result in improvement of functional symptoms, including postural control.

Postural control disorders have been investigated in MS patients using both subjective and objective measures. Subjective postural control measures include

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clinical tests such as the Berg Balance Scale (Frzovic, Morris, & Vowels, 2000; Soyuer, Mirza, & Erkorkmaz, 2006). In such a study, Frzovic et al. (2000) were unable to distinguish between MS patients and controls on the ability to maintain standing balance with feet apart, feet together, or in stride stance. Soyuer et al. (2006) were also unable to distinguish differences between MS patients and controls in tests with eyes closed and feet apart. These studies illustrate the lack of specificity provided by subjective tests to determine postural control deficits in MS patients.

However, objective quantitative assessments of postural control have been performed utilizing center of pressure (COP) measurement in MS patients (Cameron, Horak, Herndon, & Bourdette, 2008; Cattaneo, Jonsdottir, Zocchi, & Regola, 2007; Cattaneo & Jonsdottir, 2009; Karst, Venema, Roehrs, & Tyler, 2005; Nelson et al., 1995; Van Emmerik, Remelius, Johnson, Chung, & Kent-Braun, 2010). Karst et al. (2005) were able to show decreased COP displacement during reaching in MS patients compared with healthy controls. In addition, Van Emmerik et al. (2010) showed that compared with controls, people with MS displayed greater postural sway, greater loading asymmetry, and shorter time-to-contact during quiet standing. These studies are both examples of COP measures which allowed for discrimination between individuals with and without MS. Nelson et al. (1995) investigated the effect of vestibular impairments in MS patients using COP measures and found that combined visual-vestibular, or somatosensory-vestibular impairment also existed. Cattaneo and Jonsdottir (2009) investigated the effect of sensory impairments in quiet standing in MS patients by performing a stabilometric assessment that yielded a composite score incorporating total sway displacement and velocity in the anterior-posterior and medial-lateral directions. The authors found that 75% of the examined MS patients exhibited abnormal scores including increased sway, increased sway velocity, increased sway length compared with controls even when no sensory inputs were removed. In addition, the alteration of one sensory input led to abnormal scores in 82% of the subjects while the largest effect of sensory alteration occurred in the vestibular condition where almost all subjects showed abnormal scores. Cameron et al. (2008) found that MS patients have large and delayed automatic postural response latencies compared with controls. They suggested that to improve these postural control responses in MS patients, rehabilitation interventions are necessary. These findings all support the use of posturography as a sound method to evaluate both functional deficits, to evaluate sensory impairments, and to quantify treatment efficacy.

Different exercise interventions have previously been employed to improve movement capabilities in MS patients (Giesser, Beres-Jones, Budovitch, Herlihy, & Harkema, 2007; Newman et al., 2007; White et al., 2004). Resistance training studies found improved walking parameters and decreased fatigue in MS patients following training (Giesser et al., 2007; Gutierrez et al., 2005; Newman et al., 2007; White et al., 2004). Dalgas, Stenager, & Ingemann-Hansen (2008) made recommendations for resistance, endurance, and combined exercise training in MS patients after the authors reported that resistance training was well tolerated by MS patients and resulted in improvements in muscle strength. Overall, strength improvements in MS patients likely involve neuromuscular strength adaptations as well as muscle hypertrophy, thus the neuromuscular adaptations resulting from resistance training were likely due to increased ability to coordinate specific muscle groups to perform a movement (Rutherford & Jones, 1986). Since MS patients experience a loss of

efferent signal conduction as a result of demyelination (Noseworthy, Lucchinetti, Rodriguez, & Weinschenker, 2000), the neuromuscular adaptations that occur as a result of strength training may improve efferent signal conduction and as a result, improve coordination of muscles that help stabilize the body during upright stance. This idea was also stressed by Chung, Remelius, Van Emmerik, & Kent-Braun (2008) who specifically recommended the use of therapeutic interventions that are designed to improve strength in MS patients to alleviate physiological, functional, and symptomatic problems. These authors also suggested that there is a direct relationship between strength in MS patients and postural instability. To improve postural control, strength training has been evaluated in several populations including elderly adults and stroke patients (Barrett & Smerdely, 2002; Ryushi et al., 2000; Weiss, Suzuki, Bean, & Fielding, 2000).

In MS subjects, however, the effect of strength training on postural control and standing balance of MS patients is not well understood since there are conflicting reports regarding the effect of resistance training on balance (Cakt et al., 2010; DeBolt & McCubbin, 2004; Romberg et al., 2004). Cakt et al. (2010) found that progressive resistance through cycling training can improve balance. However, DeBolt and McCubbin (2004) found that balance did not change as a result of a home-based resistance training program. Romberg et al. (2004) also reported no improvement in static balance after six months of exercise training. These conflicting results regarding the effect of resistance training on balance of MS patients warrants further study and points toward a more precise evaluation of postural control. Such an evaluation has lead researchers to examine other methods of studying postural control (Harbourne & Stergiou, 2003; Newell, 1997b; Yamada, 1995).

Analysis of postural control using methods developed from the field of nonlinear dynamics has the potential to provide new insights in the ways that the nervous system controls the complexities of maintaining balance of a continuously moving body. Thus, the structure of the time series of the COP can provide information regarding the behavior of the moving body over time since even during quiet stance, the center of mass of a person is continuously moving. The use of averaging procedures, i.e., taking the mean COP sway amount or mean COP sway velocity, during data analysis can mask the dynamical properties of the COP. Techniques from nonlinear dynamics can address this problem and can help in understanding the complexity of posture. These techniques are based on examining the structural characteristics of a time series that is embedded in an appropriately constructed state space. An appropriate state space is a vector space where one can define the dynamical system (in this case, a swaying body during quiet standing) at any point in time (Stergiou, Buzzi, Kurz, & Heidel, 2004). A dynamical system is highly dependent on initial conditions, which are the constraints (i.e., strength limits, joint flexibility, perceptual abilities) that underlie its function. The natural sway of the body, which is reflected in the COP time series, is a rhythmic activity and can be modeled as an inverted pendulum. Such a model can produce a limit cycle motion (i.e., closed periodic orbits) in state space (Harbourne & Stergiou, 2003). One can then examine the characteristics of that state space to gain insight into the motor control of posture. In this study, we define stability as the sensitivity of the dynamical system (in this case, sway of the body during stance) to perturbations, and local stability is the sensitivity of the system to internal perturbations, such as the natural fluctuations that occur during posture (Dingwell & Cusumano, 2000; Stergiou et al., 2004). Effects of these natural fluctuations are what researchers are trying to evaluate with different measures of postural sway.

However, one can estimate local stability directly using the Lyapunov Exponent. The Lyapunov Exponent is a measure of the local stability of a dynamical system and its dependence on initial conditions (Abarbanel, 1996; Stergiou et al., 2004).

The purpose of this study was to investigate the effect of supervised resistance training on postural control in MS patients. The study measured postural control by examining the COP sway during standing before and after training. We sought to assess COP sway in a more comprehensive and precise manner by utilizing both linear (root mean square (RMS)) and nonlinear (Lyapunov Exponent (LyE)) measures. As mentioned above, linear measures provide information about the magnitude of variability present in the system while nonlinear measures provide information about the temporal structure of this variability. Neither measure is considered to be a stronger tool for measuring variability, but instead, the combination of linear and nonlinear measures allows for a more holistic view of the variability present in the system (Harbourne & Stergiou, 2009). In addition and to the authors' knowledge, the use of nonlinear tools to evaluate postural sway variability has not been used previously to evaluate resistance training interventions in MS patients. Due to the decrease in sensory inputs contributing to postural control with pathology or aging, the magnitude of postural sway during quiet stance tends to increase (Shumway-Cook & Woollacott, 2001). Thus, it was hypothesized that before resistance training, differences would exist between the balance control measures of MS patients and healthy controls where MS patients would show increased amount of sway variability. It was also hypothesized that MS patients who completed the resistance training intervention would show significant changes in the postural controls measures.

Methods

Subjects

A total of fifteen MS patients and fifteen healthy controls participated in this study (Table 1). All MS patients completed three months of supervised, progressive resistance training. The healthy controls were selected to age- and gender-match to the MS group (Table 1). The controls completed only the pretraining postural control assessment and did not participate in the resistance training program. All subjects provided informed consent and all procedures were approved by the University's Medical Center Institutional Review Board.

Table 1 Subject Demographics

	MS patients (<i>n</i> = 15) Mean ± SD	Healthy controls (<i>n</i> = 15) Mean ± SD	p-value
Age (yrs)	43.2 ± 10.1	39.3 ± 11.6	0.322
Gender	13 female / 2 male	14 female / 1 male	
Height (cm)	166.0 ± 8.6	169.6 ± 5.7	0.175
Mass (kg)	84.9 ± 19.3	68.7 ± 7.4	0.005*
EDSS	3.9 ± 1.5	-	

*Significant difference between groups. Independent *t* test, *p* < 0.05

EDSS—Expanded disability status scale.

Participants were recruited through the University's Medical Center. Inclusion criteria for MS patients and controls in the study included: 1) cognitive competency to give informed consent, 2) age ranging from 19 years to 65 years, 3) no pregnancy, breastfeeding, or being within three months post partum at the initiation of the study, and 4) no other neurological or vestibular disorders. Specific inclusion for MS patients only was 1) an Expanded Disability Status Scale (EDSS) score of 1.0–6.0 (Kurtzke, 1983), 2) no other comorbid conditions which would make participation in exercise unsafe, and 3) no current participation in a regular exercise program. Control subjects were not screened based on current exercise program or activity level. MS participants needed to be willing to comply with the evaluation schedule for the study including the participation in the supervised resistance training. Finally, it was necessary that there was evidence that the MS patient's physical and neurological examinations were "clinically acceptable" according to the clinical expert (author MF). Examinations were considered clinically acceptable when the MS patient's physical and neurological condition would not place the patient in undue risk by participating or interfere with outcome measures of the study.

Training Program

The resistance training intervention extended for three months, where subjects were trained two times per week at the same training facility in accordance with American College of Sports Medicine weight training duration and frequency recommendations (Franklin, Whaley, & Howley, 2000). During every exercise session, patients were supervised and instructed by certified trainers who were present to assist with one-on-one help as needed. While the same exercises were used for all patients, the progression within the protocol (i.e., using increased weights) was based on individual ability. To maintain a progressive training intervention, the entire training period was broken into three phases. Phase one focused purely on strength improvement, using stationary machines, to work the upper extremity, lower extremity, and the core muscles. All machines were handicapped accessible. In phase two, training was divided between the stationary machines and balance exercises to improve postural control and dexterity. Balance exercises were conducted with a combination of dumbbells, Swiss balls and balance boards to increase agility and strength. Phase three used free weight movements to address specific balance and muscle strength deficits. Each phase was circuit-training based with each participant completing 2–3 sets, 30 s each, at each exercise station before moving on to the next. Weight amounts were increased by five pounds when, according to the subject, the final set of the exercise could be accomplished with the same effort as the first. Increases in weight amounts for the lower extremities were done in 5 lb increments. See Table 2 for a list of all machine and free weight exercises. Based on this method of incrementing weight used for exercise, at baseline the average weight used by MS patients during leg extension was 25.6 ± 7.7 lbs and after three months of training, the average weight used was 34.7 ± 11.8 lbs.

Postural Control Assessment

Both pre- and posttraining postural control assessments took place at the Biomechanics Laboratory on the University's campus. Healthy controls completed only one assessment since they did not participate in the resistance training. Subjects

Table 2 List of exercises used in each training circuit. Each circuit was performed with 2 or 3 sets depending on individual fitness level. Each set was followed by 30 s of rest and all sets were completed before moving to the next exercise.

<i>Circuit</i>	
Machine Exercise	Free weight Exercise
Leg Curl	Swiss ball squats
Leg Extension	
Back Row	Seated dumbbell row
Lat Pulldown	
Shoulder Press	Dumbbell shoulder press
Chest Press	Dumbbell chest press
Bicep Curl	Dumbbell bicep curl
Tricep Extension	Dumbbell tricep extension
Abdominal Crunch	Bent knee abdominal crunch
Back Extension	Prone, back extensions

engaged in quiet standing without aid for five minutes with eyes open while COP data were collected. Ground reaction force data (Fx, Fy, and Fz) were collected using a Kistler force platform (Model: 9281-B11; Amherst, NY), amplified by a Kistler amplifier (Model: 9865; Amherst, NY), integrated to a Motion Analysis system (EvaRT 5.0, Motion Analysis Corp., Santa Rosa, CA). Force data were collected and analyzed unfiltered so as not to mask or remove any dynamical properties or variability present within the system (Harbourne & Stergiou, 2003). Since the same equipment was used for all data collections, it was assumed that measurement noise present in the data were the same for all trials (Harbourne & Stergiou, 2003). Patients stood on the force platform in the center of the laboratory with feet at approximately shoulder width apart facing the wall of the laboratory where they were instructed to face forward and not to look from side-to-side. The subject's field of view was not restricted in either side, so peripherally they could see to the left and right sides of the laboratory space. While the outcome measures (variability of COP; i.e., RMS) have been shown to be independent of foot placement for COP measures (Chiari, Rocchi, & Cappello, 2002), it should be noted that the COP measures of this study were not normalized to any anthropometric measures, and foot position was not standardized precisely. Patients stood with the instruction to face forward and not to speak to the researchers. There were no cognitive distractions present in the room. The sampling frequency was set at 10 Hz based on results from pilot work using power spectrum analysis that found signal frequencies of no more than 1.5 Hz present in the COP data of MS patients. Due to differences in disease severity within the MS group, some patients were unable to complete the full 5 min of quiet standing. As a result, all of the data were cropped so that analysis was done on time series of the same length. Therefore, each time series was cropped such that only the first 2000 data points, approximately 3 min and 20 s of standing time, were used.

Data Analysis

The coordinates of the center of pressure (COP) in the medial-lateral (Y direction) and anterior-posterior (X direction) were calculated from the component force data (F_x , F_y , and F_z) for each trial. A linear measure of the variability (root mean square (RMS)) present in postural sway was calculated from both trials (pre- and posttraining) using customized MatLab software based on the methodology of Prieto, Myklebust, Hoffmann, Lovett, & Myklebust (1996). RMS was calculated for the medial-lateral COP and anterior-posterior COP time series separately. Linear measures characterize the magnitude of variability present in the data (Stergiou et al., 2004). The RMS was selected according to Chiari et al. (2002) since it is independent of the effect of biomechanical factors (foot placement, height, weight, etc.) involved in maintaining posture. In addition, a nonlinear measure (Lyapunov Exponent (LyE)) was calculated for the medial lateral COP and anterior-posterior COP time series separately using Chaos Data Analyzer Professional software (Spratt & Rowlands, 1998) with an embedded dimension of 6 which was calculated using a Global False Nearest Neighbor analysis (Stergiou et al., 2004). The largest LyE is a measure of the rate at which nearby trajectories in state space diverge. LyE is also sensitive to the system's initial conditions (Stergiou et al., 2004). The exponent measures overall instability of the system as the path diverges rapidly over time. For a complete tutorial for the calculation of LyE, see Stergiou et al. (Stergiou et al., 2004). With respect to COP variability, the rate of divergence of the COP path (LyE) would indicate the presence of instability of the postural control system when LyE values are compared with healthy controls. Since LyE provides a postural stability measurement, it is sensitive to the natural perturbations of the system. The natural fluctuations that occur during posture are of particular interest to researchers evaluating postural control (Buchanan & Horak, 2001; Horak & Diener, 1994; Kuo, Speers, Peterka, & Horak, 1998) which makes LyE a strong tool to evaluate stability in postural control. While the directional control of movement (anterior-posterior, medial-lateral) is performed independently (Shumway-Cook & Woollacott, 2001), the focus of this paper was to investigate the overall sway variability regardless of sway direction with linear and nonlinear tools. Therefore, the variability values for both directions were grouped where variable values were calculated for each person's anterior-posterior and medial-lateral direction and both of the values for each person were included in the group mean. This provided one group mean (MS pretraining, MS posttraining, healthy controls) for RMS and for LyE.

Nonlinear measures of the variability in postural sway were calculated from the COP time series as described by Harbourne and Stergiou (2003). To apply nonlinear measures in any time series, it is important to know a-priori if the data are actually deterministic in nature. For adults, the deterministic nature of COP sway data has already been shown (Yamada, 1995). Yamada (1995) reported determinism in COP data during standing in normal adults using the LyE, revealing inherent complexity.

Statistical Analysis

Group means for LyE and RMS were calculated for healthy controls and for pre- and posttraining in MS patients. A pre/posttest design was not used for the healthy controls prohibiting the usage of ANOVAs. Such a design was not used in the current study because the task used (standing still with your eyes open) is a common

everyday activity, thus negating the need to control for learning effects. Therefore, paired *t* tests were used to compare pre- and posttraining outcomes in MS patients and independent *t* tests were used to compare pretraining MS patients to healthy controls and posttraining MS patients to healthy controls. Statistical analysis was performed using SPSS 17.0 (SPSS, Inc., Chicago, IL). The level of significance was set at $\alpha = .05$.

Results

Linear Measures

For the root mean square (RMS), MS patients pretraining had significantly higher values ($p = .002$) compared with healthy controls. Posttraining RMS values were significantly decreased ($p = .025$) within the MS patients. After training, there was no significant difference ($p = .289$) between MS patients and healthy controls.

Nonlinear Measures

For the Lyapunov Exponent (LyE), MS patients pretraining had significantly lower values ($p < .01$) compared with healthy controls (Table 3). Posttraining, LyE values were significantly increased ($p = .049$) within the MS patients. After training, there was no significant difference ($p = .056$) in LyE values between MS patients and healthy controls.

Table 3 Lyapunov Exponent (LyE) and Root Mean Square (RMS) Values for MS Patients and Healthy Controls. Reported as Mean \pm SE.

	MS Pretraining	MS Posttraining	Healthy Controls
LyE	0.116 \pm 0.015*¥	0.157 \pm 0.011	0.191 \pm 0.012
RMS (mm)	28.32 \pm 1.21*¥	24.78 \pm 0.88	23.52 \pm 0.73

*Significant ($p < 0.05$) difference compared with Healthy controls

¥Significant ($p < 0.05$) difference compared with MS posttraining

Discussion

The study sought to investigate changes in postural control in MS patients following a supervised resistance training program. Other studies have used clinical assessment tools to evaluate postural control in MS patients (Cattaneo et al., 2007; Frzovic et al., 2000; Fulk, 2005; Giesser et al., 2007) as well as center of pressure (COP) assessment techniques (Cattaneo & Jonsdottir, 2009; Chung et al., 2008; Karst et al., 2005; Nelson et al., 1995; Van Emmerik et al., 2010). While other research has investigated the effect of a specific exercise intervention on the postural control of MS patients (Cakt et al., 2010; DeBolt & McCubbin, 2004; Romberg et al., 2004), the findings were not consistent, possibly due to the types of outcome measures

employed. In the current study, it was hypothesized that differences would exist between MS patients and healthy controls before training and that the resistance training intervention would result in significant changes on both linear and nonlinear assessment measures of postural control.

The findings of this study showed that there is an increased amount of sway variability in MS patients compared with healthy controls before resistance training, which is in agreement with the original hypothesis. The reduced RMS values for the MS patients indicate that training may result in improvement in these values to the point that they will no longer be different than those of the healthy controls. The observed reduction in the amount of sway in the MS patients was originally speculated since strength training is predicted to improve postural stability (Chung et al., 2008). Compared with previous intervention studies which evaluated the effects of resistance training in MS, the current study found significant changes following training while other studies did not. DeBolt & McCubbin (2004) measured changes in sway velocity using posturography while Romberg et al. (2004) evaluated changes in a clinical balance test which rates the subject's performance on balance tasks. Neither study found changes in balance measures after an 8-week home based program (DeBolt & McCubbin, 2004) or a 6 month strength and aerobic conditioning program (Romberg et al., 2004). The length of training for this study was three months, which has been suggested as sufficient time for neuromuscular adaptations to occur (Jones & Rutherford, 1987; Rutherford & Jones, 1986). To further verify these results and since linear measures of COP may actually mask dynamical patterns within the COP sway path (Delignieres, Deschamps, Legros, & Caillou, 2003), nonlinear measures of variability were also calculated to complement the RMS findings.

Previous studies have used LyE to evaluate local stability during both gait and postural control tasks. During a walking task, Lockhart & Liu (2008) examined fall-prone elderly individuals using LyE and found that the fall-prone elderly have decreased local stability. Lamothe, van Lummel, & Beek, (2009) evaluated body sway in three groups with differing athletic abilities and found that altering sensory input and athletic skill significantly altered local stability. The findings from these studies suggest that use of local stability, as represented by LyE, could be used to differentiate between groups or between conditions within the same group. In addition, the use of other linear and nonlinear analysis techniques has been performed in both healthy and pathological groups to outline postural control strategies in different groups. Recently, Kyvelidou, Harbourne, Shostrom, & Stergiou (2010) demonstrated that the LyE had the highest intra- and intersession ICC values in comparison with all other linear and nonlinear parameters evaluated in a study where they analyzed the COP time series during the development of infant sitting postural control in infants with or at risk for cerebral palsy. Cavanaugh et al. (2006) evaluated concussed athletes at different time points following concussion and found that nonlinear measures of postural sway identified persistent symptoms of the concussion where amplitude only of COP oscillations did not. Cavanaugh, Guskiewicz, & Stergiou (2005) specifically recommended that supplemental assessment tools should be used to determine an athlete's readiness to return to activity. The same logic could be used to support the use of different postural assessment techniques to determine the effect of training interventions or pharmacological treatment on the postural control of patients with MS.

LyE values significantly increased from pre- to posttraining and moved closer to the values obtained from healthy controls such that after training, there was no

longer a difference between the MS patients and healthy controls. This result also agrees with the original hypothesis and suggests that the temporal structure of the postural sway variability changed after training. The increase in LyE values could be interpreted by considering the underlying system complexity (Cavanaugh et al., 2005; Harbourne & Stergiou, 2009). Newell (1997a; 1997b) proposed that a more rigid system has fewer degrees of freedom and therefore is more constrained while a more complex system has more degrees of freedom and is less constrained. The implication is that fewer degrees of freedom reduce the adaptive capability of an individual (Newell, 1997b). Reduced adaptive capability, due to fewer degrees of freedom and increased system constraints, indicates that a system may be less able to produce a physiological response to a particular task or to a system perturbation (Cavanaugh et al., 2005). Similarly, Harbourne and Stergiou (2009) proposed that neuromuscular health is characterized by higher complexity of the movement pattern, which indicates that more degrees of freedom can be used to adapt to the task or the environment and to explore the environmental stimuli present. Our results suggest that such changes are possible in the MS patients by training. In the current study, pretraining LyE values were lower than posttraining values suggesting that the posttraining postural control mechanisms may exhibit more degrees of freedom and more adaptive capability. The supervised resistance training may improve the MS patient's adaptive capabilities to the task demands and to new environmental constraints. Therefore, it is possible that following resistance training, MS patients may improve the cooperative strategies of the postural control system.

Another possibility for the improvement in postural control is a possible overall increase in the ability to be physically active that the patients experienced while participating in the study. Motl, Snook, McAuley, & Gliottoni (2006) points out that physical activity levels are reduced in MS patients as well as reduced self-efficacy on many physical tasks. In addition, Snook & Motl (2009) showed that participating in exercise improves mobility in patients with MS. Perhaps by increasing the ability to be physically active and mobile, it is possible that our participants also experienced an increase in self-efficacy and self-worth for participation in more challenging tasks that may have improved overall postural control. Another possible explanation for the improvement in postural control in MS patients after resistance training is an improvement in lower extremity spasticity. Sosnoff, Shin, & Motl (2010) reported that MS patients with higher spasticity levels had had greater COP area, velocity, and mediolateral sway compared with the low spasticity and control group. It is possible that the resistance training and accompanying strength improvements resulted in reduced spastic tone and thus changes to postural control.

While this study investigated the effect of supervised training on MS patients by examining postural sway variability, there were some limitations to the study design. A dynamometer assessment of strength changes was not performed. However tracking of exercise progress indicated the average increase in weight used for knee extension exercise was approximately 10 lbs for the MS patients suggesting that an overall strength increase did occur. Specific assessment of strength changes would be constructive to determine if the resistance training was successful at improving overall strength. Thus, within this particular study, it is not possible to state whether increases in strength correlate with improvements in balance. Continuation of this work will include comprehensive strength assessment to establish a relationship between improvement of core and lower extremity strength in MS patients and how it may translate to specific improvements in postural stability. In addition, the sample

size of this study was relatively small with MS subjects being of relatively mild severity, so the outcomes should be viewed as preliminary and exploratory. Future study with larger sample sizes should also incorporate additional nonlinear measures (i.e., approximate entropy, detrended fluctuation analysis) than can shed more light to other aspects of the control that can be derived by examining the repeatability, regularity, and colored noise present in COP time series. Finally, foot placement was not precisely controlled and the outcome measures were not normalized to any anthropometric measures. However, subjects did stand with feet at approximately shoulder width apart which imparts some standardization of foot placement.

In summary, the preliminary and exploratory findings of the current study showed that in a small sample of 15 MS patients, COP assessment before and after supervised resistance training revealed significant changes in both the amount of sway variability and in the temporal structure of sway variability. In addition, after training, the COP characteristics were similar to those of healthy controls. Using a linear measure of variability (RMS) it was shown that our sample of MS patients exhibited significantly increased amount of sway as compared with a sample of similar size of healthy controls. After resistance training, the amount of sway seen in these MS patients was decreased such that there was no longer any difference compared with healthy controls. Using a nonlinear measure (LyE), this study found that before training these MS patients had significantly less variability in the temporal structure of their sway pattern. After resistance training, our sample of MS patients significantly increased the complexity of the COP sway, which suggests the postural control system has more degrees of freedom and will be more adaptable to the task or the environment (Harbourne & Stergiou, 2009; Newell, 1997a; Newell, 1997b). Further study is necessary to determine the specific relationship between strength improvements and balance in MS patients and strengthen these preliminary findings. Our results suggest that supervised resistance training may have a significant and positive impact on the postural control of MS patients. If further study with a larger sample size confirms these encouraging preliminary results, clinicians should consider the prescription of resistance training exercise as a viable rehabilitation program for MS patients.

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References

- Abarbanel, H.D. (1996). *Analysis of observed chaotic data*. New York: Springer-Verlag.
- Barrett, C.J., & Smerdely, P. (2002). A comparison of community-based resistance exercise and flexibility exercise for seniors. *The Australian Journal of Physiotherapy*, 48(3), 215–219.
- Buchanan, J.J., & Horak, F.B. (2001). Transitions in a postural task: Do the recruitment and suppression of degrees of freedom stabilize posture? *Experimental Brain Research*, 139(4), 482–494.
- Cakt, B.D., Nacir, B., Genc, H., Saracoglu, M., Karagoz, A., Erdem, H.R., et al. (2010). Cycling progressive resistance training for people with multiple sclerosis: A randomized controlled study. *American Journal of Physical Medicine & Rehabilitation*, 89(6), 446–457.

- Cameron, M.H., Horak, F.B., Herndon, R.R., & Bourdette, D. (2008). Imbalance in multiple sclerosis: A result of slowed spinal somatosensory conduction. *Somatosensory & Motor Research*, 25(2), 113–122.
- Cattaneo, D., & Jonsdottir, J. (2009). Sensory impairments in quiet standing in subjects with multiple sclerosis. *Multiple Sclerosis*, 15(1), 59–67.
- Cattaneo, D., Jonsdottir, J., Zocchi, M., & Regola, A. (2007). Effects of balance exercises on people with multiple sclerosis: A pilot study. *Clinical Rehabilitation*, 21(9), 771–781.
- Cavanaugh, J.T., Guskiewicz, K.M., Giuliani, C., Marshall, S., Mercer, V.S., & Stergiou, N. (2006). Recovery of postural control after cerebral concussion: New insights using approximate entropy. *Journal of Athletic Training*, 41(3), 305–313.
- Cavanaugh, J.T., Guskiewicz, K.M., & Stergiou, N. (2005). A nonlinear dynamic approach for evaluating postural control: New directions for the management of sport-related cerebral concussion. *Sports Medicine (Auckland, N.Z.)*, 35(11), 935–950.
- Chiari, L., Rocchi, L., & Cappello, A. (2002). Stabilometric parameters are affected by anthropometry and foot placement. *Clinical Biomechanics (Bristol, Avon)*, 17(9-10), 666–677.
- Chung, L.H., Remelius, J.G., Van Emmerik, R.E., & Kent-Braun, J.A. (2008). Leg power asymmetry and postural control in women with multiple sclerosis. *Medicine and Science in Sports and Exercise*, 40(10), 1717–1724.
- Dalgas, U., Stenager, E., & Ingemann-Hansen, T. (2008). Review: Multiple sclerosis and physical exercise: Recommendations for the application of resistance-, endurance- and combined training. *Multiple Sclerosis*, 14(1), 35–53.
- DeBolt, L.S., & McCubbin, J.A. (2004). The effects of home-based resistance exercise on balance, power, and mobility in adults with MS. *Archives of Physical Medicine and Rehabilitation*, 85(2), 290–297.
- Delignieres, D., Deschamps, T., Legros, A., & Caillou, N. (2003). A methodological note on nonlinear time series analysis: Is the open- and closed-loop model of Collins and de Luca (1993) a statistical artifact? *Journal of Motor Behavior*, 35(1), 86–97.
- Dingwell, J.B., & Cusumano, J.P. (2000). Nonlinear time series analysis of normal and pathological human walking. *Chaos (Woodbury, N.Y.)*, 10(4), 848–863.
- Franklin, B.A., Whaley, M.H., & Howley, E.T. (Eds.). (2000). *ACSM's guidelines for exercise testing and prescription* (6th ed.).
- Frzovic, D., Morris, M.E., & Vowels, L. (2000). Clinical tests of standing balance: Performance of persons with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation*, 81(2), 215–221.
- Fulk, G.D. (2005). Locomotor training and virtual reality-based balance training for an individual with multiple sclerosis: A case report. *Journal of Neurologic Physical Therapy; JNPT*, 29(1), 34–42.
- Giesser, B., Beres-Jones, J., Budovitch, A., Herlihy, E., & Harkema, S. (2007). Locomotor training using body weight support on a treadmill improves mobility in persons with multiple sclerosis: A pilot study. *Multiple Sclerosis*, 13(2), 224–231.
- Gutierrez, G.M., Chow, J.W., Tillman, M.D., McCoy, S.C., Castellano, V., & White, L.J. (2005). Resistance training improves gait kinematics in persons with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation*, 86(9), 1824–1829.
- Harbourne, R.T., & Stergiou, N. (2003). Nonlinear analysis of the development of sitting postural control. *Developmental Psychobiology*, 42(4), 368–377.
- Harbourne, R.T., & Stergiou, N. (2009). Movement variability and the use of nonlinear tools: Principles to guide physical therapist practice. *Physical Therapy*, 89(3), 267–282.
- Horak, F.B., & Diener, H.C. (1994). Cerebellar control of postural scaling and central set in stance. *Journal of Neurophysiology*, 72(2), 479–493.
- Jones, D.A., & Rutherford, O.M. (1987). Human muscle strength training: The effects of three different regimens and the nature of the resultant changes. *The Journal of Physiology*, 391, 1–11.

- Karst, G.M., Venema, D.M., Roehrs, T.G., & Tyler, A.E. (2005). Center of pressure measures during standing tasks in minimally impaired persons with multiple sclerosis. *Journal of Neurologic Physical Therapy; JNPT*, 29(4), 170–180.
- Kuo, A.D., Speers, R.A., Peterka, R.J., & Horak, F.B. (1998). Effect of altered sensory conditions on multivariate descriptors of human postural sway. *Experimental Brain Research*, 122(2), 185–195.
- Kurtzke, J.F. (1983). Rating neurologic impairment in multiple sclerosis: An expanded disability status scale (EDSS). *Neurology*, 33(11), 1444–1452.
- Kyvelidou, A., Harbourne, R.T., Shostrom, V.K., & Stergiou, N. (2010). Reliability of center of pressure measures for assessing the development of sitting postural control in infants with or at risk of cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, 91(10), 1593–1601.
- Lamoth, C.J., van Lummel, R.C., & Beek, P.J. (2009). Athletic skill level is reflected in body sway: A test case for accelerometry in combination with stochastic dynamics. *Gait & Posture*, 29(4), 546–551.
- Lockhart, T.E., & Liu, J. (2008). Differentiating fall-prone and healthy adults using local dynamic stability. *Ergonomics*, 51(12), 1860–1872.
- Motl, R.W., Snook, E.M., McAuley, E., & Gliottoni, R.C. (2006). Symptoms, self-efficacy, and physical activity among individuals with multiple sclerosis. *Research in Nursing & Health*, 29(6), 597–606.
- Nelson, S.R., Di Fabio, R.P., & Anderson, J.H. (1995). Vestibular and sensory interaction deficits assessed by dynamic platform posturography in patients with multiple sclerosis. *The Annals of Otolaryngology, Rhinology, and Laryngology*, 104(1), 62–68.
- Newell, K.M. (1997a). Applications of nonlinear dynamics to developmental process modeling. *Degrees of freedom and the development of center of pressure profiles*. in *KM newell and PMC molenaar (eds)*. (pp. 63-84). Hillsdale, NJ: Erlbaum.
- Newell, K.M. (1997b). Degrees of freedom and the development of center of pressure profiles. In K.M. Newell & P.M.C. Molenaar (Eds.), *Applications of nonlinear dynamics to developmental process modeling* (pp. 63). Hillsdale, NJ: Erlbaum.
- Newman, M.A., Dawes, H., van den Berg, M., Wade, D.T., Burrige, J., & Izadi, H. (2007). Can aerobic treadmill training reduce the effort of walking and fatigue in people with multiple sclerosis: A pilot study. *Multiple Sclerosis*, 13(1), 113–119.
- Noseworthy, J.H., Lucchinetti, C., Rodriguez, M., & Weinshenker, B.G. (2000). Multiple sclerosis. *The New England Journal of Medicine*, 343(13), 938–952.
- Prieto, T.E., Myklebust, J.B., Hoffmann, R.G., Lovett, E.G., & Myklebust, B.M. (1996). Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Transactions on Bio-Medical Engineering*, 43(9), 956–966.
- Romberg, A., Virtanen, A., Ruutiainen, J., Aunola, S., Karppi, S.L., Vaara, M., et al. (2004). Effects of a 6-month exercise program on patients with multiple sclerosis: A randomized study. *Neurology*, 63(11), 2034–2038.
- Rutherford, O.M., & Jones, D.A. (1986). The role of learning and coordination in strength training. *European Journal of Applied Physiology and Occupational Physiology*, 55(1), 100–105.
- Ryushi, T., Kumagai, K., Hayase, H., Abe, T., Shibuya, K., & Ono, A. (2000). Effect of resistive knee extension training on postural control measures in middle aged and elderly persons. *Journal of Physiological Anthropology and Applied Human Science*, 19(3), 143–149.
- Shumway-Cook, A., & Woollacott, M.H. (2001). *Motor control: Theory and practical applications* (2nd ed.). New York, NY: Lippincott Williams & Wilkins.
- Snook, E.M., & Motl, R.W. (2009). Effect of exercise training on walking mobility in multiple sclerosis: A meta-analysis. *Neurorehabilitation and Neural Repair*, 23(2), 108–116.
- Sosnoff, J.J., Shin, S., & Motl, R.W. (2010). Multiple sclerosis and postural control: The role of spasticity. *Archives of Physical Medicine and Rehabilitation*, 91(1), 93–99.

- Soyuer, F., Mirza, M., & Erkorkmaz, U. (2006). Balance performance in three forms of multiple sclerosis. *Neurological Research*, 28(5), 555–562.
- Sprott, J.C., & Rowlands, G. (1998). *Chaos datas analyzer: The professional version*. Raleigh, NC: Physics Academic Software.
- Stergiou, N., Buzzi, U.H., Kurz, M.J., & Heidel, J. (2004). Nonlinear tools in human movement. In N. Stergiou (Ed.), *Innovative analyses for human movement* (pp. 63–90). Champaign, IL: Human Kinetics.
- Van Emmerik, R., Remelius, J., Johnson, M., Chung, L., Kent-Braun, J. (2010) Postural control in women with multiple sclerosis: effects of task, vision and symptomatic fatigue. *Gait & Posture*, 32(4), 608-614.
- Weiss, A., Suzuki, T., Bean, J., & Fielding, R.A. (2000). High intensity strength training improves strength and functional performance after stroke. *American Journal of Physical Medicine & Rehabilitation*, 79(4), 369–376.
- White, L.J., & Dressendorfer, R.H. (2004). Exercise and multiple sclerosis. *Sports Medicine (Auckland, N.Z.)*, 34(15), 1077–1100.
- White, L.J., McCoy, S.C., Castellano, V., Gutierrez, G., Stevens, J.E., Walter, G.A., et al. (2004). Resistance training improves strength and functional capacity in persons with multiple sclerosis. *Multiple Sclerosis*, 10(6), 668–674.
- Yamada, N. (1995). Chaotic swaying of the upright posture. *Human Movement Science*, 14, 711.