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Acute effects of whole-body vibration on lower extremity muscle performance in persons with multiple sclerosis

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ABSTRACT

Background and Purpose: Whole-body vibration (WBV) is a relatively new form of exercise training that may influence muscle performance. This study investigated the acute effects of high (26 Hz) and low (2 Hz) frequency WBV on isometric muscle torque of the quadriceps and hamstrings in persons with multiple sclerosis (MS).

Participants and Method: Fifteen individuals (mean age = 54.6 years, SD = 9.6) with MS and Expanded Disability Status Scale (EDSS) scores ranging from 0-6.5 (mean = 4.2, SD = 2.3) participated in this randomized cross-over study. Following baseline measures of isometric quadricep and hamstring torque, subjects were exposed to 30 seconds of WBV at either 2 or 26 Hz. Torque values were measured again at 1, 10 and 20 minutes post vibration. Subjects returned one week later to repeat the same protocol at the alternate vibration frequency.

Results: There were no significant differences in isometric torque production between the 2 and 26Hz WBV conditions. There was also no significant difference between baseline torque values and those measured at 1, 10 and 20 minutes following either vibration exposure. However, there was a consistent trend of higher torque values following the 26 Hz WBV when compared to the 2 Hz condition for both quadriceps and hamstrings.

Discussion and Conclusion: Although not statistically significant, peak torque values for both quadriceps and hamstrings were consistently higher following 30 seconds of WBV at 26 vs. 2 Hz. Whether or not WBV presents a viable treatment option as either a warm-up activity or a long-term exercise intervention is yet to be determined. Future studies should include a wider variety of WBV parameters and the use of functional outcome measures.

Introduction

Multiple Sclerosis (MS) is a chronic inflammatory, demyelinating disease of the central nervous system. The most prevalent symptoms of MS include sensory changes, visual disturbances, fatigue, and micturition disorders.¹ Motor weakness, including a loss of muscle power, strength and endurance is another common symptom that can impair functional performance.²⁻⁴ Moderate intensity strength training has been shown to improve strength and mobility in persons with MS.^{5,6} Unfortunately, some individuals with MS have difficulty performing traditional strength training exercises due to problems with balance, coordination, fatigue and generating a maximal voluntary contraction.^{2,3} Because of these difficulties, there is need to explore alternative methods of improving muscle performance in persons with MS. One potential option is the use of a relatively new form of exercise called whole-body vibration training.

Whole-body vibration (WBV), or vibration training, has become increasingly popular over the last several years in both health clubs and clinic settings. As its name implies, WBV involves the application of a vibratory stimulus to the entire body as opposed to local stimulation of specific muscle groups. This is typically performed by having a person stand on a vibrating platform. As a training device, WBV has most commonly been used in one of two ways. First, WBV has been used as a “warm-up” procedure that is thought to transiently increase muscle activity, strength and power associated with traditional neuromuscular training.^{7,8} When used for this purpose, the client/patient typically stands on the platform with the knees slightly flexed for a brief (30 sec – 2 min) period with the goal of enhancing muscle performance during an activity (e.g. jumping) performed immediately after the vibration. A second common use of WBV is for long-term training. When used for this purpose,

clients/patients generally train on the vibration unit several times per week while gradually increasing the time and intensity of the stimulus. Additionally, common exercise movements such as squats and heel raises are usually performed. It has been hypothesized that improvements in muscle strength and power after WBV may be related to an increase in neuromuscular activation during and following WBV.⁹ In a recent study by Abercromby et al,¹⁰ neurologically intact subjects who were exposed to WBV at a frequency of 30 Hz and 4 mm of amplitude demonstrated a significant increase in EMG activity in the knee flexors and extensors as well as the ankle plantar flexors and dorsiflexors during the vibration stimulus. Several researchers have also evaluated the acute effects of a single exposure to WBV in normal younger adults and have shown transient improvements in muscle performance post-vibration,¹¹⁻¹³ while others have found little or no effect.^{14,15} Training studies involving longer term (3 times per week for 11-12 wks) exposures to WBV in younger adults have also shown mixed results.^{16,17}

Recently, there has been an increased interest in the use of WBV in clinical populations including those with neurological disorders.¹⁸⁻²² Several studies have demonstrated improved postural control for individuals with MS¹⁹ and Parkinson's disease²⁰ following a single exposure to WBV. However, these studies used a low frequency (2-6 Hz) multi-directional vibration that is distinctly different from the higher frequency (20-40 Hz) vertical or rotational vibration used in most other WBV research. In a recent randomized controlled trial, sub-acute stroke patients exposed to a single bout (5 x 1 min) of WBV at 20 Hz demonstrated significant improvements in isometric and eccentric muscle torque as well as EMG amplitude in the quadriceps of their affected leg immediately following WBV.²³ However, there are currently no studies that have

evaluated the effects of higher frequency (20-40Hz) WBV on muscle performance in persons with MS.

Therefore, the purpose of this current investigation was to evaluate the acute effects of a brief exposure to WBV on quadricep and hamstring muscle performance in persons with MS. Our hypothesis was that a short, non-fatiguing, exposure to high frequency (26 Hz) vibration as compared to a low frequency (2 Hz) may lead to temporary improvements in the ability to generate isometric muscle torque. If the results confirmed our hypothesis, then WBV could possibly be used as neuromuscular “warm-up” activity prior to performing more traditional exercise and functional rehabilitation training. Additionally, if the vibration parameters used in this study were found to show transient benefit, using similar parameters in future long-term training studies may be warranted.

METHODS

Subjects

A convenience sample of 15 subjects (3 males, 12 females, age = 54.6 ± 9.6) with multiple sclerosis was recruited from the community using local support groups and their publications (Table 1).

Table 1. Subject Characteristics

Subject	Age (yr)	Gender	Diagnosis* (yr)	EDSS	Base Quad† (N·m)	Base Ham† (N·m)
1	52	F	11	6	120.8	36.5
2	44	F	3	6	113.1	31.7
3	73	F	10	6	66.4	31.0
4	51	F	15	2	80.5	37.6
5	43	M	3	1.5	219.9	69.4
6	49	F	7	0	143.3	43.9
7	61	F	10	6	126.4	51.4
8	58	M	4	2.5	131.1	50.5
9	69	F	22	6	72.5	24.0
10	43	F	3	1.5	65.2	26.8
11	47	F	9	2	88.1	42.6
12	66	F	13	4	85.6	31.5
13	57	F	11	6	103.3	66.8
14	47	M	20	6.5	88.1	41.6
15	59	F	19	6	107.5	24.9
Mean(±SD)	54.6 (9.6)	12F/3M	10.6 (6.2)	4.2 (2.3)	107.5 (39.4)	40.6 (14.0)

Abbreviations: EDSS, Expanded Disability Status Scale; Quad, Quadriceps; Ham, Hamstrings; N·m, newton meter.

*Time since diagnosis of MS

† Baseline isometric torque values for quadriceps and hamstrings as measured on second visit

After an explanation of the protocol, subjects signed an informed consent that had been approved by the University of Dayton's Human Subjects Review Board. Inclusion criteria included the following: a confirmed diagnosis of MS, the ability to ambulate 10 meters with or

without assistive device with no more than contact guard assistance, the ability to stand a minimum of 5 minutes with upper extremity support. Exclusion criteria included: thrombosis, acute inflammation, acute tendinopathy, recent (<6 months) fractures, gallstones, implants, surgery, wound/scar, hernia or discopathy, diabetic retinopathy, epilepsy, pacemaker, pregnancy, total joint replacement or the presence of any other neurological condition. For safety, blood pressure and heart rate were monitored before and after all testing.

During the initial visit, demographic and anthropometric information were recorded and a neurological examination was performed by a physical therapist with extensive experience in neurological rehabilitation. Using findings from the neurological exam, subjects were scored on the Kurtzke Expanded Disability Status Scale (EDSS), to characterize disease severity.²⁴ EDSS scores can range for 0-10, with a higher score indicating greater disability. The mean EDSS score was 4.2 ± 2.3 , range 0-6.5 (Table 1). This means that our subjects' level of disability varied considerably, from no overt symptoms to walking only limited distances with a cane or walker. While the EDSS was used for general descriptive purposes, it was not considered an important factor in the data analysis because of its questionable reliability and validity.²⁵

Study Design and Protocol

Using blocked randomization, subjects were assigned to receive either a low frequency 2 Hz WBV exposure or a higher frequency 26 Hz stimulus on their first visit. Subjects then received the alternate WBV frequency on their second visit in this repeated measures cross-over study. At the initial visit, subjects were familiarized with the testing procedures and baseline performance of the quadriceps and hamstrings on the subject's most impaired leg were

assessed using the Biodex System-3 dynamometer (Biodex Medical Systems, Shirley, New York). Average isometric peak torque (N·m) was calculated over three repetitions with the knee held at 60° of flexion. After a 15-minute rest period subjects then received either the 2 Hz WBV (6 mm amplitude, 30 seconds) or the 26 Hz WBV (6 mm amplitude, 30 seconds). Isometric torque was assessed again at 1, 10 and 20 min after the vibration stimulus. These time frames were chosen because they are similar to previous WBV research protocols.¹³⁻¹⁵ Subjects returned one week later at the same time of day, which was initially determined by each subject to optimize performance. Subjects then repeated the same protocol, receiving a second baseline assessment of muscle performance and then either the 2 or 26 Hz WBV depending on group assignment. The investigator responsible for performing the muscle testing was blinded to the type of treatment given by remaining in separate room until immediately after the vibration exposure. This researcher also used a consistent phrase of encouragement during the isokinetic testing.

Equipment

Subjects received whole-body vibration using the Maxuvibe[®] platform (Fitgroup BV, Hoogstrat, Holland) (Figure 1). The Maxuvibe[®] unit provides a rotational form of vibration. With rotational vibration, the platform rotates in a sinusoidal manner about an anterior-posterior axis so that positioning the feet further apart results in increased amplitude of movement and applies force asynchronously to the left and right foot, similar to standing near the middle of a “teeter-totter” (Figure 1). We chose to use a unit that provided rotational vibration instead of vertical vibration because it is easier to dampen the mechanical energy that is transferred to the spine and head by alternately flexing and extending the lower



FIGURE 1. Maxuvibe[®] vibration platform (Fitgroup BV, Hoogstrat, Holland)

extremities.²⁶ This type of vibration has also been shown to elicit a significantly great response of the knee extensors than vertical vibration.¹⁰ Vibration frequencies of 2 and 26 Hz with a 6 mm peak to peak amplitude were used because these parameters are consistent with previous WBV research demonstrating increased muscle activity and muscle performance during and following WBV exposure.^{10,23} Subjects were asked to wear thin-soled shoes and to use the same shoes on

each visit. Foot position was standardized at a width of 13 cm. This foot position ensured that

each patient experienced the same amplitude of movement (6 mm peak to peak) which is determined by foot width when using a rotational vibration unit. A knee flexion angle of approximately 25° was maintained and subjects were asked to shift their weight slightly towards the balls of the feet without lifting their heels. This position was chosen because it has been shown minimizes head vibration during WBV.²⁶ All subjects were asked to hold on to the vibration unit for safety but there arms were positioned to minimize any upper extremity weight bearing (Figure 1).

Isometric torque of the knee flexors and extensors was assessed using the Biodex System-3 dynamometer. Subjects were positioned sitting in the dynamometer with their most involved lower extremity held at 60° of flexion. For all testing, the trunk was stabilized with a

seat belt and shoulder harness and the thigh was also held in place with a belt. Subjects performed 3 maximal isometric contractions of both the knee flexors and extensors that were held for 5 seconds each. Isometric muscle testing in persons with MS using dynamometry has previously demonstrated excellent test-retest reliability (ICC = .97)²⁷

Statistical Analyses

A power test was not performed prior to data collection due to novelty of this pilot study and the lack of previous data with this patient population. However, a subsequent power test revealed that, to detect a relatively modest effect size of 0.5, given an alpha of 0.05 and power of 0.80 using the repeated measures design of our study, the minimum sample size would be 15. Therefore, we felt our study likely had sufficient power to minimize the risk of a Type II error.

A repeated measures analysis of variance was used to determine mean quadriceps and hamstring torque value differences between the 2 and 26 Hz conditions as well as differences between the baseline values and those measured at 1, 10 and 20 minutes post vibration. The statistical design was a 4 x 2 with repeated measures across both independent variables: treatment (2 Hz vs. 26 Hz) by time (baseline, 1, 10, and 20 min. post-treatment). Therefore, each subject was measured in every condition. In the repeated measures design, the presence of main effects and interaction terms (time x treatment) were evaluated. A main effect for time, for example, would indicate that, regardless of treatment, torque values tended to change with time. A significant interaction term would indicate that the effect of time on torque would depend on the treatment or the effect of treatment on time on torque would depend on time. Dependent variables were peak isometric quadriceps and hamstring torque.

Only the baseline values obtained on the second visit were used in the analyses because the baseline testing during the first visit was considered primarily a familiarization procedure to reduce possible early learning effects of the isometric testing. A priori statistical significance was set at an alpha level of 0.05. Despite the psychometric limitations of the EDDS, an exploratory Pearson product-moment correlation was used to determine if there were any relationships between the EDSS scores and the change in torque values from baseline for both vibration conditions.

Results

Table 2 and Figures 2 and 3 show torque values at 1, 10 and 20 minutes post WBV for the 2 and 26 Hz conditions for the quadriceps and hamstrings, respectively. For the quadriceps, only the main effect for time was statistically significant ($P < 0.05$) suggesting that, regardless of treatment, torque values tended to change with time. For the hamstrings, there were no statistically significant main effects or interaction term. Post-hoc analyses indicated that quadriceps torque increased significantly from the 1st to the 10th minute for both the 2 and 26 Hz conditions ($P < 0.05$). However, there was no significant difference between the baseline values and those measured at 1, 10, and 20 minutes post vibration for either WBV condition or muscle group. The visual trends shown in Figures 2 and 3 suggest that the 26 Hz condition elicited higher torque responses than the 2 Hz condition at all time points, though the analyses indicate that this trend did not achieve statistical significance. Effect sizes were calculated for the differences between the baseline torque values and those measured at 1, 10 and 20 minutes post vibration for both the 2 and 26 Hz conditions. Average effect sizes were small for both the quadriceps (2 Hz = 0.24, 26 Hz = 0.06) and hamstrings (2 Hz = 0.13, 26 Hz = 0.21).

Additionally, no significant relationships were identified between the EDSS scores and the change in torque values for either the quadriceps ($r = 0.07 - 0.30, P > 0.05$) or hamstrings ($r = 0.01 - 0.42, P > 0.05$). There were no adverse events (pain, anxiety, loss of balance, cardiovascular or neurological changes) encountered during testing and all subjects completed the study.

TABLE 2. Mean(\pm SD) isometric peak torque(N·m) values for quadriceps and hamstrings at baseline, 1, 10 and 20 minutes post-vibration.

	Quadriceps		Hamstrings	
	2Hz	26Hz	2Hz	26HZ
Baseline ^a	107.5 (39.4)		40.6 (14.0)	
1 min	102.5 (37.2)	107.3 (34.4)	39.6 (13.7)	40.9 (13.9)
10 min	108.5 (34.4)	111.5 (36.5)	40.7 (12.6)	41.5 (12.1)
20 min	107.9 (29.6)	111.8 (34.8)	39.4 (12.1)	42.0 (14.2)

^aBaseline values as measured on the second visit.

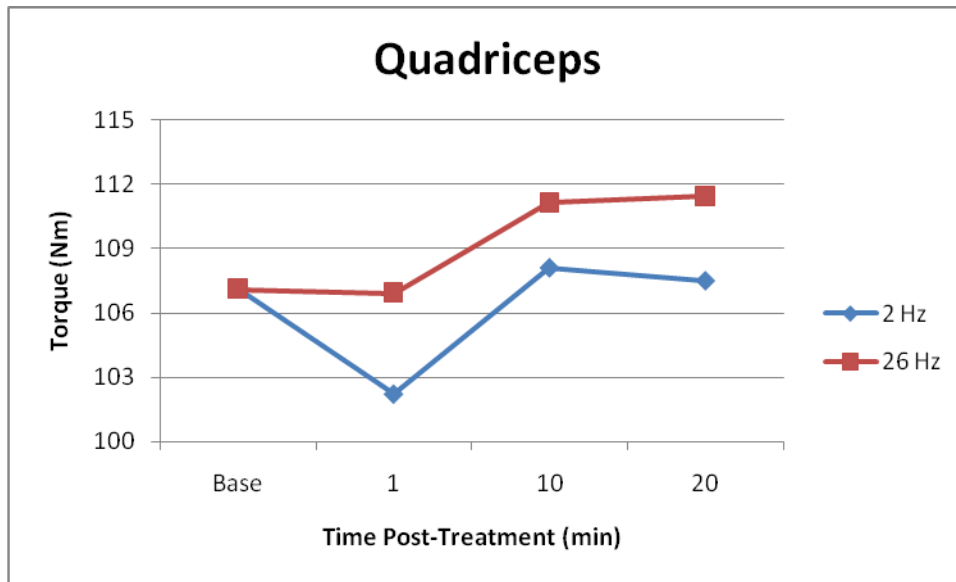


FIGURE 2. Quadriceps torque between 2 and 26 Hz whole body vibration conditions as measured 1, 10 and 20 minutes post-treatment. Note: Values on the x-axis are not proportional to actual time.

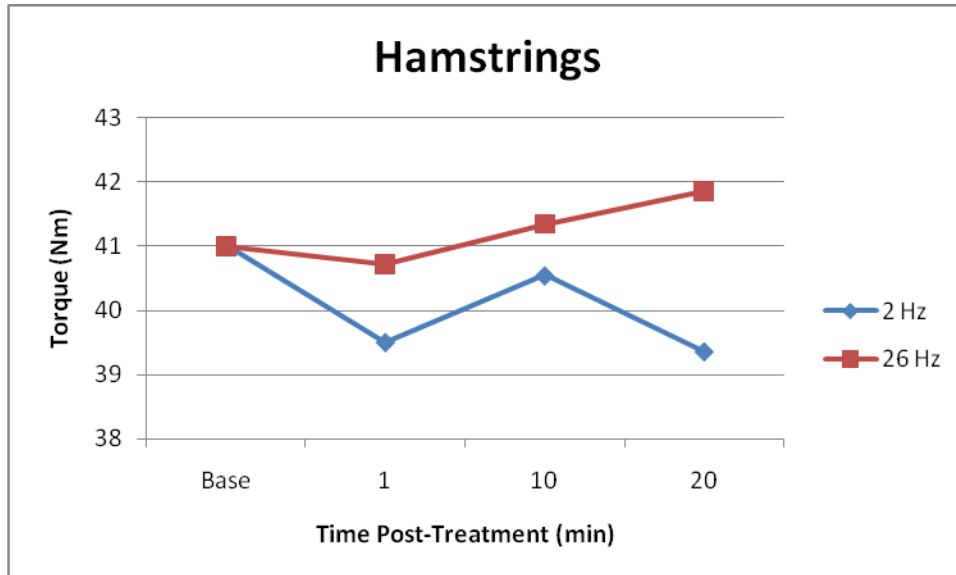


FIGURE 3. Hamstrings torque between 2 and 26 Hz whole body vibration conditions as measured 1, 10 and 20 minutes post-treatment. Note: Values on the x-axis are not proportional to actual time.

Discussion

This is the first study we are aware of that has evaluated the effects of WBV on muscle performance in persons with MS. The main finding of our study, although not statistically significant, was that mean quadriceps and hamstring torque values were consistently greater following 30 seconds of WBV at 26 vs. 2 Hz. Additionally, quadriceps and hamstring torque values continued to show a trend for improvement at 20 minutes following the 26 Hz vibration while performance began to decline by the 20 minute mark after the 2Hz stimulus. The only previous WBV study involving persons with MS evaluated the effects of a lower frequency (2 - 4.4 Hz) multidirectional type of vibration on postural control (dynamic posturography, functional reach), and functional performance (Timed Up and Go).¹⁹ Although there were temporary improvements in postural control and functional performance following a brief (5 X 1 min) vibration exposure, changes were small and the clinical importance of the findings may be questionable. Due the profound differences in vibration parameters and outcome measures between this study and ours, it was difficult to make any direct comparisons.

However, a recent study²³ involving subjects with sub-acute strokes, used WBV parameters (20 Hz, 5mm amplitude) and outcome measures (isometric/eccentric torque) that were similar to the present study. In this investigation the authors reported significant improvements in isometric and eccentric knee extensor torque, 36.6% and 22.2% ($P < .05$) respectively, immediately following WBV. They also reported a post-vibratory increase in EMG activity of the knee extensors with a corresponding decrease in EMG activity of the knee flexors. We did not find similar improvements in our study, but several important differences must be pointed out. First, and most importantly, is the difference in patient populations. While both MS and stroke can cause upper motor neuron lesions the pathology is quite

different. It is possible that the loss of myelin in the cerebrum and spinal cord associated with MS and the potential for impaired nerve conduction could limit the motor response to vibration as well as afferent transmission of the vibration stimulus to multilevel polysynaptic spinal reflexes and supra-spinal centers involved in the vibratory reflex.⁹ Second, the subjects with stroke were exposed to four consecutive one-minute bouts of WBV while our subjects received a single 30-second exposure. It is conceivable, that in our attempt to ensure that we provided a “non-fatiguing” stimulus, we did not use an optimal or even adequate vibration dosage to see significant effects.

Several other factors also need to be considered when evaluating the results of our study. First, was our decision measure only the strength of knee flexors and extensors. Previous researchers have shown that during WBV the vibration stimulus is attenuated in a distal to proximal manner, with muscles such as the gastrocnemius, soleus and anterior tibialis showing greater activation and training responses than more proximal muscles of the knee and hip.^{10,28} Perhaps if we had measured ankle plantar flexion and dorsiflexion torque, changes in muscle performance would have been more apparent. The primary reason we chose to assess the knee flexors and extensors was because of its established test-retest reliability in persons with MS²⁷ and potential to compare our data with previous research demonstrating changes in knee muscle function following WBV.^{13,23} A second issue was our decision to position the knee at 60° of flexion for isometric testing. In hindsight, it may have been better to position the knee at the same joint angle (25°) that was maintained during the WBV exposure in accordance with principles of training specificity.

As mentioned previously, there is conflicting evidence for both the acute and long-term use of WBV in active younger adults. However, there is a growing body of evidence showing

potential benefits of longer-term WBV training (2-3 wk x 8-12 wks) in sedentary individuals and older adults.^{17,28,29} The results of these studies also show that it is important to perform some type of exercise activity (squats, lunges, calf raises) while using WBV and that distal musculature maybe preferentially affected.²⁸ Since many patients with MS are sedentary and have difficulty with voluntary activation of distal lower extremity muscles, studies involving longer-term WBV combined with simple exercises maybe warranted.

While this study demonstrated no significant changes in muscle performance after a single brief exposure to WBV, the information gained may help in the design of future research studies on both the acute and long-term effects of WBV in persons with MS. Another potentially useful finding of this research was that a single brief exposure to WBV was well tolerated by persons with MS who had a wide range of disability.

Conclusion

The main purpose of this study was to determine if a brief 30-second exposure to WBV transiently improves knee muscle performance in persons with MS. The results of this study showed no significant difference in isometric torque production following WBV at frequencies of 2 and 26 Hz. However, there was consistent trend for improved torque production in both the quadriceps and hamstrings following the 26 Hz stimulus that continued for at least 20 minutes that was not evident in the 2 Hz condition. Whether or not WBV presents a viable treatment option as either a neuromuscular “warm-up” activity or as a long-term exercise modality for persons with MS is yet to be determined. Future acute and long-term studies should include a wider variety of vibration parameters, the evaluation of additional muscle groups and the use of functional outcome measures.

References

1. Rowland LP, ed. Merrit's Textbook of Neurology, 10th Ed. Baltimore, MD: Lippincott Williams and Wilkins; 2000.
2. Lambert CP, Archer RL, Evans WJ. Muscle strength and fatigue during isokinetic exercise in individuals with multiple sclerosis. *Med Sci Sport Exerc.* 2001;33:1613-1619.
3. Ponichtera JA, Rodgers MM, Glaser RM, Mathews, T. Concentric and eccentric isokinetic lower extremity strength in persons with MS. *J Orthop Sport Phys Ther.* 1988;16:114–122.
4. Armstrong LE, Winant DM, Swasey PR, Seidle ME, Carter AL, Gehlsen GM. Using isokinetic dynamometry to test ambulatory patients with MS. *Phys Ther.* 1983;63:1274–1279.
5. White LJ, McCoy SC, Castellano V, Guiterrez G, Stevens JE, Walter GA, Vandeborne K. Resistance training improves strength and functional capacity in persons with multiple sclerosis. *Multiple Sclerosis.* 2004;10:668-674.
6. White LJ, Dressendorfer RH. Exercise and multiple sclerosis. *Sports Med.* 2004;34:1077-1100.
7. Jordan MJ, Norris SR, Smith DJ, Herzog W. Vibration training: an overview of the area, training consequences, and future considerations. *J Strength Cond Res.* 2005;19:459-466.
8. Cardinale M, Bosco C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev.* 2003;31:3-7.
9. Nishihira Y, Iwasaki T, Hatta A, et al. Effect of whole body vibration stimulus and voluntary contraction on motoneuron pool. *Adv Exerc Sports Physiol.* 2002;8:83-86.

10. Abercromby AFJ, Amonette WE, Layne CS, et al. Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc.* 2007;39:1642-1650.
11. Bosco C, Cardinale M, Tsarpela O et al. The influence of whole-body vibration on jumping performance. *Biol Sport.* 1998;15:157-164.
12. Bosco C, Colli R, Intorini E et al. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol.* 1999;19:183-7.
13. Torvinen S, Kannus P, Sievanen H, et al. Effect of a vibration exposure on muscular performance and body balance. randomized cross-over study. *Clin Physiol & Func Im.* 2002;22:145-152.
14. Cormie P, Deane R, Triplett NT et al. Acute effects of whole-body vibration on muscle activity, strength, and power. *J Strength Cond Res.* 2006;20:257-61.
15. de Ruyter CJ, van der Linden RM, van der Zijden MJA, Hollander AP, de Haan A. Short-term effects of whole body vibration on maximal voluntary isometric extensor force and rate of force rise. *Eur J Appl Physiol.* 2003;88:472-475.
16. de Ruyter CJ, van Raak SM, Schilperoort JV, Hollander AP, de Haan A. The effects of 11 weeks whole body vibration training on jump height, contractile properties and activation of human knee extensors. *Eur J Appl Physiol.* 2003;90:595-600.
17. Delecluse C, Roelants M, Verschueren S. Strength Increases after whole-body vibration compared with resistance training. *Med Sci Sports Exerc.* 2003; 35:1033-41.

18. Haas CT, Turbanski S, Kessler K, Schmidbleicher D. The effects of random whole-body vibration on motor symptoms in Parkinson's disease. *Neuro Rehabil.* 2006; 21:29-36.
19. Schuhfried O, Mittermaier C, Jovanovic T *et al.* Effects of whole-body vibration in patients with multiple sclerosis: a pilot study. *Clin Rehab.* 2005;19:834-842.
20. Turbanski S, Haas CT, Schmidbleicher D. Effects of random whole body vibration on postural control in Parkinson's disease. *Res Sports Med.* 2005;13:243-256.
21. van Nes IJ, Geurts AC, Hendricks HT, Duysens J. Short-term effects of whole-body vibration on postural control in unilateral chronic stroke patients: preliminary evidence. *Am J Phys Med Rehabil.* 2004;83:867-873.
22. van Nes IJ, Latour H, Schils F, Meijer R, van Kuijk A, Geurts AC. Long-term effects of 6-week whole-body vibration on balance recovery and activities of daily living in the postacute phase of stroke: a randomized, controlled trial. *Stroke.* 2006;37:2331-2335.
23. Tihanyi TK, Monika H, Fazekas G, Hortobagyi T, Tihanyi J. One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke. *Clin Rehab.* 2007;21:782-793.
24. Kurtzke JF. Rating neurological impairment in multiple sclerosis: an expanded disability status scale (EDSS). *Neurology.* 1984; 33:1444-52.
25. Hobart J, Freeman J, Thompson A. Kurtzke scales revisited: the application of psychometric methods to clinical intuition. *Brain.* 2000;123:1027-40.

26. Abercromby AFJ, Amonette WE, Layne CS , et al. Vibration exposure and biodynamic responses during whole-body vibration training. *Med Sci Sports Exerc.* 2007;39:1794-1800.
27. Surakka J, Romberg A, Ruutiainen J, et al. Assessment of muscle strength and motor fatigue with a knee dynamometer in subjects with multiple sclerosis: a new fatigue index. *Clin Rehabil.* 2004;18:652-659.
28. Rees SS, Murphy AJ, Watsford ML. Effects of whole-body vibration exercise on lower-extremity muscle strength and power in an older population: a randomized clinical trial. *Phys Ther.* 2008;88:462-470.
29. Dolny DG, Reyes GC. Whole body vibration exercise: training and benefits. *Curr Sports Med Rep.* 2008;7:152-157.