AN ABSTRACT OF THE THESIS OF

Nathan Dodge for the degree of Master of Science in Exercise and Sport Sciences presented on May 23, 2011.

Title: Effects of Whole Body Vibration and Progressive Resistance Exercise on Balance and Lower Extremity Strength

Abstract approved:

Rod A. Harter

Whole body vibration (WBV) is widely used as a mechanical stimulus for neuromuscular training, and to a lesser extent, in the treatment of patients undergoing physical rehabilitation. **PURPOSE:** To quantify any beneficial and/or synergistic effects associated with the longitudinal administration of WBV and progressive resistance (PRE) exercise on lower extremity strength development and postural stability. **METHODS:** We recruited 30 physically-active men (age, 22.2±3.2 yrs; hgt, 178.9±6.1 cm; mass, 75.8±7.2 kg) who had not participated in resistance training activities during the past 3 months and had no history of lower extremity injury. Participants were randomly assigned to one of three groups: *WBV* = PRE squat exercises with WBV (n=10); *NO WBV* = PRE squat exercises without WBV (n=10), or *CONTROL* (n=10). For those in the *WBV* and *NO WBV* groups, the experimental treatment consisted of 24 sessions of progressively-loaded squat exercises (3 sessions per week x 8 weeks) using weighted vests. A computerized posturography device was used to administer the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) that quantified sway velocity. An isokinetic dynamometer was used to obtain concentric and eccentric peak torque values at 60°/sec, 120°/sec and 180°/sec during a unilateral, closed kinetic chain (CKC) leg press. All groups were tested at entry (Week 0), midpoint (Week 4), and upon conclusion of the study (Week 8). **RESULTS:** The mCTSIB scores (foam box/eyes open condition) were significantly better in the *WBV* group compared to *CONTROL* when measured at Week 4 (*WBV* = 0.46±0.01°/sec, *CONTROL* = 0.56±0.01°/sec; p=0.004) and at Week 8 (*WBV* = 0.49±0.01°/sec, *CONTROL* = 0.55±0.12°/sec; p=0.036). For the right limb, concentric leg press peak torques (normalized to Nm/kg body mass) increased at 60°/sec from 0.84±0.43 Nm/kg at Week 0 to 1.10±0.47 Nm/kg at Week 8 (p=0.03), and at 180°/sec from 0.82±0.37 Nm/kg at Week 0 to 1.03±0.36 Nm/kg at Week 8 (p=0.018). There were no significant Group differences observed for any of the CKC leg press measures ($p > 0.05$). **CONCLUSION:** While the 8-week training protocol was shown to be an effective means of improving both postural stability and isokinetic leg press strength, long-term exposure to WBV did not enhance lower extremity strength acquisition among the participants.

Effects of Whole Body Vibration and Progressive Resistance Exercise on Balance and Lower Extremity Strength

by
Nathan Dodge

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APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Nathan Dodge, Author

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CHAPTER 1

INTRODUCTION

Whole body vibration (WBV) exercise has recently gained attention as a means of mechanical training stimulus for enhancing muscular performance in various populations, including athletes [1-3], the physically active [3-8], non-athletic individuals,[9-12] and older adults[10, 13-15]. Both acute and chronic exposure to WBV have been associated with gains in strength[4, 7, 9-11, 15], jump height[3, 4, 6-12], power[14] and improved balance[7, 16]

Despite conflicting evidence regarding the use of WBV for neuromuscular enhancement in short term[5, 17] and long term[2, 13, 18] studies, it has been argued that the adaptations following strength training are due to neural potentiation mechanisms that resemble those found after power training[8]. Mechanical vibrations applied to tendons and muscles in the range of 10-200 Hz have been shown cause a contractile reflex response known as the "tonic vibration reflex" [19]. The tonic vibration reflex is thought to be dependent upon the excitation primary muscle spindle (Ia) fibers, which leads to a reflex activation of the α-motor neuron[20]. This vibration-induced reflex is capable of causing increased recruitment of motor units via this a-motor neuron activation and polysynaptic pathways[21].

A 30 Hz vibration stimulus applied during elbow flexion has been shown to improve short term contractile power, but the beneficial effects disappeared shortly after the removal of the vibration[22]. This improvement in acute contractile power is thought to result from the excitation of Ia afferents that innervate previously inactive motor units[22], creating a more rapid build-up of force at the start of a contraction[23]. The tonic vibration reflex is thought to occur in low frequency whole body vibration (< 30 Hz)[24], though lower frequencies may cause sensory conflict in the muscle spindle and decrease the response of the stretch reflex[24].

Structured resistance training programs using vibration have been combined with maximal and submaximal resistance training with mixed results. The first study to combine vibration and resistance training reported significant gains in maximal force production during isotonic elbow flexion after only 9 training sessions[25], although subsequent studies have not shown significant differences in strength generation between resistance exercise with and without applied vibration[6, 26]. Schlumberger et al[27] compared single leg squats using an external load, with participants training one leg with vibration and using the other as a control, a condition which may have transferred some of the strength gains to the contralateral limb. More recently, Ronnestad[6] evaluated two groups of resistance trained men using squats on a Smith Machine performed with and without WBV. He reported significant increases in maximal strength for both groups, with a tendency toward greater gains in the WBV group, but the improvements were not statistically significant[6] ($p > 0.05$). Since proprioception training has the ability to bring about improvements in explosive force[28], the lack of significant group differences in the

Ronnestad study may be due to the use of the guided Smith Machine as a balance aid while moving the load, therefore decreasing the proprioceptive need. This study was also limited by a small sample size (n=14), which increases the chances of a Type II error. Thus, there remains a need to quantify the individual and combined effects of longitudinal WBV and PRE programs upon strength development and balance.

Balance has been identified as "the single most important factor underlying movement strategies within the closed kinetic chain"[29]. Nashner and McCollum[30] identified three different operational definitions to describe postural stability: static, dynamic and functional balance. Static balance has been defined as the ability to limit the movement of the center of gravity (COG) within a fixed base of support, dynamic balance is defined as the ability to move and control the COG within a fixed base of support, and functional balance is defined as the ability to move and control the COG within a moving base of support[30].

There are three main sensory inputs that contribute to balance: somatosensory, visual and vestibular. Somatosensory input provides information about the orientation of body parts to one another and to the support surface, and integration of visual and somatosensory inputs plays a large role in the maintenance of balance[31]. The central nervous system (CNS) is responsible for organizing sensory inputs as well as the generation and execution of coordinated muscular activity[29] to maintain the body's center of gravity over its base of support[31]. Mechanoreceptors located within muscles and tendons provide the CNS with continuous, almost instantaneous feedback about the amount of stretch and tension on the muscle[32]. The information transmitted from the peripheral mechanoreceptors to the CNS has been suggested as having the ability to compensate for eye closure and vestibular deficiency[33-35]. As mentioned previously, WBV is thought to elicit its effects through the excitation of the α-motor neuron that results from neurogenic adaptation in response to vibration[7], in that WBV may have the ability to enhance balance through increased feedback from the somatosensory system.

The effects of chronic exposure to WBV on postural stability are not well established. In 2002, Torvinen et al showed that a single, 4 minute bout of vibration significantly improved body balance in young healthy men and women an average of 16%, but the WBV treatment effect lasted for only a short period of time, disappearing within an hour[7]. In contrast, a 4-month WBV study by Torvinen et al resulted in no significant changes in static or dynamic balance[11]. Participants in both of these studies followed similar exercise protocols, but neither study attempted to add an external load to the exercises used.

However, WBV has been shown to improve balance and postural control in older adults[16, 36]. In 2007, Cheung et al reported that 3 months of WBV exercise significantly improved directional control ($p< 0.05$) and enhanced movement velocity ($p < 0.01$) and endpoint excursion ($p<0.01$) in comparison to a group of sedentary age-matched elderly women[16]. These improvements in dynamic balance suggest that WBV exposure improved the ability to control the movement of the center of gravity over the base of support, a skill that has been shown to be critical for normal balance[37]. In a related study, Bogaerts et al demonstrated that 6 months of WBV exercise significantly decreased postural sway in older men and women when compared to a group of subjects who performed fitness exercises[36]. However, these groups used strikingly different exercise programs that did not directly compare the effects of WBV, as the WBV group performed light exercise on the plate only, while the fitness group performed strength training, cardiovascular exercise, and balance training. The very few studies that have quantified the effects of WBV on postural stability have reported mixed results, suggesting the need for further investigation of this research question.

A scientific abstract of the results of this study was submitted for peer-review on November 1, 2010, and has been accepted for a poster presentation at the 58th Annual Meeting of the American College of Sports Medicine on Saturday, June 4, 2011 in Denver, Colorado. The primary manuscript from this study, found in Chapter 2, will be submitted for peer-review and publication in the *Journal of Strength and Conditioning Research* in July 2011.

REFERENCES

1. Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol.* Mar 1999;79(4):306-311.
2. Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *Int J Sports Med.* Oct 2005;26(8):662-668.
3. Cochrane DJ, Stannard SR. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *Br J Sports Med.* Nov 2005;39(11):860-865.
4. Bosco C, Iacovelli M, Tsarpela O, et al. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol.* Apr 2000;81(6):449-454.
5. Cochrane DJ, Legg SJ, Hooker MJ. The short-term effect of whole-body vibration training on vertical jump, sprint, and agility performance. *J Strength Cond Res.* Nov 2004;18(4):828-832.
6. Ronnestad BR. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J Strength Cond Res.* Nov 2004;18(4):839-845.
7. Torvinen S, Kannu P, Sievanen H, et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging.* Mar 2002;22(2):145-152.
8. Bosco C, et al. The influence of whole body vibration on jumping performance. *Biol Sport.* 1998;15:157-164.
9. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc.* Jun 2003;35(6):1033-1041.
10. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med.* Jan 2004;25(1):1-5.
11. Torvinen S, Kannus P, Sievanen H, et al. Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc.* Sep 2002;34(9):1523-1528.
12. Torvinen S, Kannus P, Sievanen H, et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res.* May 2003;18(5):876-884.
13. Bautmans I, Van Hees E, Lemper JC, Mets T. The feasibility of Whole Body Vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial [ISRCTN62535013]. *BMC Geriatr.* 2005;5:17.

14. Russo CR, Lauretani F, Bandinelli S, et al. High-frequency vibration training increases muscle power in postmenopausal women. *Arch Phys Med Rehabil.* Dec 2003;84(12):1854-1857.
15. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res.* Mar 2004;19(3):352-359.
16. Cheung WH, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil.* Jul 2007;88(7):852-857.
17. Torvinen S, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Kannus P. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. *Int J Sports Med.* Jul 2002;23(5):374-379.
18. de Ruiter 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.* Nov 2003;90(5-6):595-600.
19. Eklund G, Hagbarth KE. Vibratory induced motor effects in normal man and in patients with spastic paralysis. *Electroencephalogr Clin Neurophysiol.* Oct 1967;23(4):393.
20. Roll JP, Vedel JP, Ribot E. Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Exp Brain Res.* 1989;76(1):213-222.
21. De Gail P, Lance JW, Neilson PD. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J Neurol Neurosurg Psychiatry.* Feb 1966;29(1):1-11.
22. Issurin VB, Tenenbaum G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci.* Mar 1999;17(3):177-182.
23. Bongiovanni LG, Hagbarth KE, Stjernberg L. Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *J Physiol.* Apr 1990;423:15-26.
24. Seidel H. Myoelectric reactions to ultra-low frequency and low-frequency whole body vibration. *Eur J Appl Physiol Occup Physiol.* 1988;57(5):558-562.
25. Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. *J Sports Sci.* Dec 1994;12(6):561-566.
26. Schlumberger A, Salin D, Schmidtbleicher D. [Strength training with superimposed vibrations]. *Sportverletz Sportschaden.* Vol 15. 2001/05/08 ed; 2001:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11338657. Accessed Mar.

27. Munn J, Herbert RD, Hancock MJ, Gandevia SC. Training with unilateral resistance exercise increases contralateral strength. *J Appl Physiol.* Nov 2005;99(5):1880-1884.
28. Gollhofer A, Schopp A, Rapp W, Stroinik V. Changes in reflex excitability following isometric contraction in humans. *Eur J Appl Physiol Occup Physiol.* 1998;77(1-2):89-97.
29. Riemann BL, Guskiewicz, K.M. Contribution of the Peripheral Somatosensory System to Balance and Postural Equilibrium. In: Lephart SM, Fu, F.H., ed. *Proprioception and Neuromuscular Control in Joint Stability*. Champaign, IL: Human Kinetics; 2000:37-51.
30. Nashner L, McCollum, G. The organization of human postural movements: a formal basis and experimental synthesis. *Behav Brain Sci.* 1985;8:135-172.
31. Nashner L. Computerized dynamic posturography. In: Jacobsen G, Newman, C., Kartush, J., ed. *Handbook of Balance Function and Testing*. St. Louis: Mosby Year Book; 1993:280-307.
32. Guyton A, Hall, J. Motor Functions of the Spinal Cord: the Cord Reflexes. *Textbook of Medical Physiology*. Philadelphia: Saunders; 2006:673-684.
33. Diener HC, Dichgans J, Guschlbauer B, Mau H. The significance of proprioception on postural stabilization as assessed by ischemia. *Brain Res.* Mar 26 1984;296(1):103-109.
34. Horak FB, Nashner LM, Diener HC. Postural strategies associated with somatosensory and vestibular loss. *Exp Brain Res.* 1990;82(1):167-177.
35. Nashner LM, Black FO, Wall C, 3rd. Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. *J Neurosci.* May 1982;2(5):536-544.
36. Bogaerts A, Verschueren S, Delecluse C, Claessens AL, Boonen S. Effects of whole body vibration training on postural control in older individuals: a 1 year randomized controlled trial. *Gait Posture.* Jul 2007;26(2):309-316.
37. Thomas M, Jankovic J, Suteerawattananon M, et al. Clinical gait and balance scale (GABS): validation and utilization. *J Neurol Sci.* Jan 15 2004;217(1):89-99.

CHAPTER 2

Effects of Whole Body Vibration and Progressive Resistance Exercise on Balance and Lower Extremity Strength

ABSTRACT

Effects of Whole Body Vibration and Progressive Resistance Exercise on Balance and Lower Extremity Strength

The purpose of this study was to quantify the effects associated with the longitudinal administration of whole body vibration (WBV) and progressive resistance exercise (PRE) on balance and lower extremity strength development. We recruited 30 physically-active men (age, 22.2±3.2 yrs; hgt, 178.9±6.1 cm; mass, 75.8±7.2 kg) who had not participated in resistance training activities during the past 3 months and had no history of lower extremity injury. Participants were randomly assigned to one of three groups: *WBV* = squat exercises with WBV (n=10); *NO WBV* = squat exercises without WBV (n=10), or *CONTROL* (n=10). The experimental treatment for the *WBV* and *NO WBV* groups consisted of 24 sessions of progressively-loaded squat exercises over 8 weeks using weighted vests. The modified Clinical Test of Sensory Interaction on Balance (mCTSIB) was used to quantify sway velocity. An isokinetic dynamometer was used to obtain concentric and eccentric peak torque values at 3 velocities during a unilateral closed kinetic chain (CKC) leg press. All groups were tested at entry (Week 0), midpoint (Week 4), and upon conclusion of the study (Week 8). The mCTSIB scores (foam box/eyes open condition) were significantly better in the *WBV* group compared to *CONTROL* when measured at Week 4 (*WBV* = 0.46±0.01°/sec, *CONTROL* = 0.56±0.01°/sec; p=0.004) and at Week 8 (*WBV* = 0.49±0.01°/sec, *CONTROL* = 0.55±0.12°/sec; p=0.036). For the right limb, concentric leg press peak torques (normalized to Nm/kg body mass) increased at 60°/sec from 0.84±0.43 Nm/kg at Week 0 to 1.10±0.47 Nm/kg at Week 8 (p=0.03), and at 180°/sec from 0.82±0.37 Nm/kg at Week 0 to 1.03±0.36 Nm/kg at Week 8 (p=0.018). While our 8-week training protocol was shown to be an effective means of improving both postural stability and isokinetic leg press strength, long-term exposure to WBV did not enhance lower extremity strength acquisition among our subjects.

Key Words: randomized controlled trial, resistance training, tonic vibration reflex

INTRODUCTION

Whole body vibration (WBV) exercise has recently gained attention as a means of mechanical training stimulus for enhancing muscular performance in various populations, including athletes [1-3], the physically active [3-8], non-athletic individuals,[9-12] and older adults[10, 13-15]. Both acute and chronic exposure to WBV have been associated with gains in strength[4, 7, 9-11, 15], jump height[3, 4, 6-12], power[14] and improved balance[7, 16]

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The purpose of this study was to identify the individual and combined effects of progressive resistance exercise and WBV on lower extremity strength development, and to investigate the role of WBV training in improving balance.

METHODS

Subjects

Participants consisted of 30 healthy males between the ages of 18 to 35 years who were considered physically active, weighed 200 pounds (91 kg) or less, and had not performed resistance training exercise within 3 months of initiation of the study. A weight limitation was imposed due to the maximum loading capacity of our vibration plates. All participants were recruited at our institution through physical activity classes and flyers posted around campus. Volunteers were screened through a questionnaire for medical contraindications to vibration and/or resistance exercise (see Table 2.1), and were provided documentation of informed consent. Volunteers who were accepted into the study were randomly assigned to one of three groups: Group 1 = progressive resistance exercise program (PRE) of squats with whole body vibration (*WBV*, n = 10); Group 2 = PRE squats without WBV (*NO WBV*, n = 10); or Group 3 = a control group (*CONTROL*, n = 10).

Experimental Protocol

All experimental testing and participant training sessions took place at the Oregon State University Sports Medicine/Disabilities Research Laboratory, and were performed by the same individual (ND). Outcome measures were taken at baseline, and participants were randomly assigned into 3 groups (*WBV, NO WBV* or *CONTROL*). Randomization to groups occurred *a priori* using a table of random numbers, and was performed by an individual who was not directly involved in the testing and training. The control group was asked to refrain from initiating a resistance-training program for the duration of the study. All subjects were asked to keep a journal recording the type and duration of any exercise that may occur outside of the study.

Each training session lasted approximately 15 minutes, and consisted of a 5-minute warm-up followed by squatting exercises. This warm-up consisted of 3 minutes of light cycling on a stationary bike followed by 2 minutes of light stretching of the involved muscle groups. The treatment groups trained 3 times per week for a total of 24 training sessions, with at least 48 hours in between training sessions. A midpoint testing session occurred after 12 training sessions.

All participants in the treatment groups were weighed prior to each training session to determine the load for the day, which was expressed as a predetermined percentage of body weight. Participants in both groups performed their squats without shoes to control for differences in footwear and possible damping of the WBV[38]. All participants began the training period with unloaded exercise before advancing to progressively higher external loads. Weighted vests have been used previously as a means of increasing intensity of resistance exercise[39], and were used to load the participants in the *WBV* and *NO WBV* experimental groups in the manner described in Table 2.2. All training sessions for all exercise participants were logged, and contained the following information: body weight, training load, number of repetitions, number of sets, and the duration of vibration exposure.

The following is a description of the experimental procedures administered to each of the three treatment groups:

Group 1: PRE Squats with WBV (*WBV*). Whole body vibration was applied using a Turbosonic Deluxe TT2590 (Turbosonic, USA) device with a maximal weight capacity of 300 pounds. A vertical sinusoidal vibratory stimulus was consistently applied at 25 Hz at an amplitude of 5 mm, and was not varied for the duration of the study. Participants in the *WBV* group performed three sets of dynamic squats to 90˚ knee flexion three days per week with at least one day of rest between sessions. The amplitude and frequency of the vibration stimulus were chosen to mimic studies that have had success in improving dynamic leg press[4] and countermovement vertical jump[3] performance. The dynamic squats were performed at a rate of 4 seconds per repetition for 3 sets of 8-12 repetitions. The vibration exposure time was limited to a maximum of 1 minute per set for each of the 3 sets, totaling a maximum of 9 minutes per week of vibration exposure. Duration of vibration exposure was documented for each training session. In the event the target repetitions for a given set were not completed within the time limit, the number of repetitions accomplished was logged in the participant's training journal. A 90 second seated rest period was provided between sets

Group 2: PRE Squats without WBV (*NO WBV*). Participants in the *NO WBV* group performed squatting exercises identical to the *WBV* group, consisting of 3 sets of squats to 90˚ knee flexion 3 days per week with at least 1 day of rest between sessions. Members in the *NO WBV* group performed the same squat exercises while wearing the same weighted vests while standing on the identical vibration platform that was not turned on, i.e., not actively vibrating. In the event the target repetitions for a given set were not completed, the number of repetitions accomplished was logged in the participant's training journal. As previously noted, the dynamic squat was performed at a rate of 4 seconds per repetition with a 90 second seated rest period provided in between sets.

Group 3: Control (*CONTROL*). Participants assigned to the *CONTROL* group did not participate in any PRE or WBV training sessions during the 8-week study period. They were instructed specifically not to initiate a resistance-training program and otherwise maintain their current lifestyles. The *CONTROL* group only participated in testing at baseline, midpoint, and the end of the study**.** A *CONTROL* group was included in effort to identify the treatment effects of WBV and resistance exercise, but also to detect any learning effects that might have occurred with the outcome measures in this study.

Outcome Measures

Strength Testing. Muscular strength was tested using a Biodex System 3™ (Biodex Medical, Shirley, NY) isokinetic dynamometer according to the manufacturer's instructions at baseline, and after 12 and 24 training sessions. All participants were tested bilaterally in a concentric/eccentric fashion using an attachment that allows for closed chain extension of the knee (see Figure 2.1). Participants were tested in the seated position with the knee and hip flexed to 90°, and the initial positioning during baseline was recorded to ensure consistency during repeated measures. At each data collection session, subjects were given 2 practice trials before the testing began and encouraged verbally to exert maximal effort during the concentric and eccentric phases of the leg press. Measurements of peak force for closed kinetic chain leg press were taken for 1 repetition at 60˚/sec, 120˚/sec, and 180˚/sec, and this sequence was repeated 3 times for a total of 9 trials.

A 30-second rest interval was provided between each trial. Peak force values were recorded for each participant and used to determine any gains in strength.

Balance Testing. Static balance was assessed using a SMART Balance Master™ system (NeuroCom, a division of Natus Medical, Inc., Clackamas, OR) according to the manufacturer's instructions. The modified Clinical Test of Sensory Interaction on Balance (mCTSIB) was performed using a 1.83 m long force plate to analyze the participant's balance control[40]. The test consists of 3 trials in each of 4 conditions: (1) eyes open on a firm surface, (2) eyes closed on a firm surface, (3) eyes open on an unstable surface, and (4) eyes closed on an unstable surface (see Figure 2.2 and Figure 2.3). Participants were instructed to stand as motionless as possible during each trial and maintain a parallel stance foot position. In the event that a subject had to take a step or open his eyes during an eyes-closed trial, that trial was marked as a "fall" and indicated as such in our analysis. Foot position was checked after each trial and repositioned as necessary. All participants were tested in stocking feet to control for differences in types of shoes.

Experimental Design and Statistical Analysis

A two-way Group (3) x Time (3) mixed repeated measures ANOVA model, with Time as the repeated factor, was used to determine the existence of differences among treatment groups and the presence of changes over time (a = 0.05). In the presence of significant main effects for Group or Time, Bonferroni *post hoc* testing was performed to determine the existence of any simple main effects ($p < 0.05$). All data were analyzed using SPSS software version 18.0 (SPSS, An IBM Company, Chicago, IL).

With our randomized assignment of subjects to groups, we expected a homogenous distribution of variance and did not anticipate significant pretest between-group differences on any of the outcome measures. However, we conducted a series of 1-way ANOVAs to analyze the pretest values for each of the outcome measures for differences between groups at entry into the study.

RESULTS

Analysis of Anthropometric Data

As shown in Table 2.3, one-way ANOVA analyses of the anthropometric data for all three groups at entry into the study revealed no significant differences ($p > 0.05$), thus subject randomization rendered the three experimental groups to be statistically equivalent.

Balance Measures

Of the five outcome measures obtained from the modified Clinical Test of Sensory Interaction on Balance (mCTSIB), only the results of the mCTSIB foam box/eyes open condition were significantly different among the experimental groups ($F_{2,27} = 3.59$, $p = 0.042$). An analysis of simple main effects using Bonferroni post-hoc testing indicated that the WBV group demonstrated significantly less postural sway velocity (0.48 ± 0. 12^{o}/sec) than the CONTROL group (0.59 ± 0. 11^{o}/sec) (p = 0.048).

In addition, the mCTSIB scores (foam box/eyes open condition) were significantly better in the WBV group compared to CONTROL when measured at Week 4 (WBV = 0.46 ± 0.01^{o}/sec, CONTROL = 0.56 ± 0.01^{o}/sec; p = 0.004) and at Week 8 (WBV = 0.49 ± 0.01^{o}/sec, CONTROL = 0.55 ± 0.12^{o}/sec; p = 0.036).

There were no significant Group x Time interactions, nor any additional significant differences between Groups with regard to the mCTSIB outcome measures (p > 0.05).

We also observed a significant main effect for Time on the postural sway velocity variable, with Bonferroni post-hoc analyses revealing that postural sway velocity was significantly lower at the conclusion of the 8-week intervention for the mCTSIB foam box/eyes closed condition (0.50 ± 0.11^{o}/sec) compared to baseline (Week 0) measures (0.57 ± 0.15^{o}/sec) (p = 0.021) [Table 2.4].

Isokinetic Leg Press

There were no statistically significant Group main effects or Group x Time interactions observed for any of the six isokinetic outcome measures for either limb at any velocity (p > 0.05). Isokinetic leg press peak torque values were found to increase from the beginning of the study to its conclusion in the WBV and NO WBV exercise groups, but these between group changes were not statistically significant.

For the right limb, concentric leg press peak torques measured at 60°/sec (normalized to Nm/kg body mass) increased from 0.84 ± 0.43 Nm/kg at Week 0 to 1.10 ± 0.47 Nm/kg at Week 8 ($p = 0.03$), and also when measured at 180°/sec, from 0.82 ± 0.37 Nm/kg at Week 0 to 1.03 ± 0.36 Nm/kg at Week 8 ($p = 0.018$). There were no significant Group differences observed for any of the closed kinetic chain leg press measures ($p > 0.05$) (Table 2.5).

DISCUSSION

Anthropometric Characteristics

Our randomization procedures were successful in that no significant differences were found among the three key anthropometric variables at the outset of the study, e.g., age, height, mass. It is important to note that all participants were screened before the study to ensure that they weighed less than 91 kg due to the maximum weight capacity on the vibration plate. The 136 kg maximum capacity of the vibration plate we used required us to exclude heavier participants from entering the study, and influenced the loads that we could add to the weighted vests.

No statistically significant changes were observed in body mass or body fat percentage in any of the experimental or control groups over the duration of the study.

Balance Measures

In our randomized controlled trial, the WBV group average amount of sway velocity (deg/sec) for the mCTSIB Foam-Eyes Open condition (p= 0.048) was 18.7% less than the CONTROL group following completion of the 8-week training protocol. This finding contradicts that of Torvinen et al [11], as they did not observe significant reductions in postural sway after 4 months of WBV training in 52 healthy, non-athletic male and female participants between the ages of 19 and 38 years. Participants in their WBV group (25-40 Hz, 2mm, 2.5-6.4g) trained 3 to 5 times per week each day for 10 seconds in each of 6 different unloaded positions (light squatting, standing erect, standing with slightly flexed knees, light jumping, weight shifting, and standing on the heels) repeated 4 times for a total of 4 minutes of vibration exposure each session. While their WBV group was compared to a control group, Torvinen et al did not indicate what, if any, activity was being performed by the control group. In comparison, we involved 30 physically-active males between the ages of 18 and 30 years who trained 3 times per week for a total of 3 minutes per session with or without WBV (25 Hz, 5 mm), but used a singular exercise (dynamic squat) and a progressive loading scheme rather than a series of unloaded positions in 10 second intervals.

In a related randomized, cross-over study also published in 2002, Torvinen et al [7] investigated the acute effects of WBV on muscular performance and balance in 16 healthy male and female participants aged 24 to 33 years. Each participant received the WBV treatment and the sham treatment, which consisted of performing all of the exercises on the vibration platform while the platform was turned off. The performance measures for each experimental condition were spread over 2 days, with a 1-2 week period between each condition. Torvinen's WBV protocol was applied for 1 minute at 15 Hz, and then was increased 5 Hz every minute thereafter for a total of 4 minutes, and corresponded with accelerations of 3.5g at 15 Hz, 6.5g at 20 Hz, 10g at 25 Hz, and 14g at 30 Hz [7]. The exercise protocol consisted of 10 seconds in each of 6 different unloaded positions (light squatting, standing erect, standing with slightly flexed knees, light jumping, weight shifting, and standing on the heels) repeated 4 times for a total of 4 minutes of vibration exposure. Balance data were collected before, 2 minutes after, and 60 minutes after either WBV or sham condition, and consisted of 4 successive 10-second intervals on an increasingly labile postural sway platform. Their WBV group showed a net benefit of 15.7% (p=0.049) improvement in the numerical stability index provided by the Biodex Stability System when compared to the sham treatment at the 2 minute post test, but this effect was transient, as the benefit disappeared by the 60 minute post test [7]. Similar transient improvements were noted in isometric extension strength of the lower extremity (3.2% net benefit at 2 minute post test, p=0.02) and jump height (2.5% net benefit at 2 minute post test, p=0.019). Based on these results, the authors suggested that the immediate effects of short bouts of vibration were beneficial for physical performance [7].

Although we also used a non-vibrating plate as an experimental condition, we would not go as far as to call it a “sham” condition, as our participants were fully aware of the fact that the plate was not vibrating. However, the current study was a randomized controlled trial in which the participants were not exposed to multiple conditions, thereby eliminating the need to attempt to create a placebo for a mechanical stimulus that provides both auditory and somatosensory stimuli that would be very difficult to replicate without compromising the validity of a study.

In their study of the acute effects of WBV, Torvinen et al [7] observed transient improvements in postural sway after only 4 minutes of vibration exposure, but this protocol did not translate into a chronic training effect in a subsequent study by the same authors [11]. Their participants in the acute study (33 women, 19 men) were randomized separately by sex to ensure equal representation in both the vibration and control groups, and then asked to train 3 to 5 times per week over a 4 month period, with performance tests at baseline and after 2 and 4 months. They observed no significant effects on postural sway at either 2 or 4 months, though vertical jump height improved 10.2% and 8.5% in the vibration group after 2 and 4 months, respectively [11].

This lack of effect on postural sway after training is in contrast with the current study, where the average amount of postural sway in our WBV group was about 19% less than the CONTROL group for the mCTSIB Foam-Eyes Open condition following completion of the 8-week training protocol. This difference may be due to variations in training protocols used in both studies. Torvinen et al [11] did not specifically mention any information regarding footwear during the vibration sessions, while all of our exercise participants (WBV and NO WBV groups) performed squats in stocking feet. This increased tactile contact with the vibration plate may have had some influence on the improved postural stability we observed, as pressure and vibration have been shown to affect posture in relationship to the anatomical location of application [41]. Kavounoudias et al [42] have shown that mechanical vibration stimulus applied to the sole of the foot can cause either plantar flexion or dorsiflexion ankle torques based on stimulus location and subsequent postural tilt.

Leg movements such as balance and gait require a large amount of motor control for efficient function during daily life activities. There are three main sensory inputs that contribute to balance: somatosensory, visual and vestibular. Somatosensory input provides information about the orientation of body parts to one another and to the support surface, and integration of visual and somatosensory inputs plays a large role in the maintenance of balance [43]. The central nervous system (CNS) is responsible for organizing sensory inputs as well as the generation and execution of coordinated muscular activity [29] to maintain the body's center of gravity over its base of support [43]. Mechanoreceptors located within muscles and tendons provide the CNS with continuous, instantaneous feedback about the amount of stretch and tension on the muscle [44]. Gains in force generating capacity after WBV training have been attributed to neural factors, namely an increased sensitivity of the stretch reflex that is responsible for initiating involuntary muscular contractions [10, 45]. Bongiovanni et al anesthetized the peroneal nerve, switching off γ-motor fibers, and then had subjects perform a 60 second maximal isometric contraction. The anesthetized condition produced a greater decrease in force and electromyographic (EMG) activity than normal contraction due to the nerve block. As a result of the block, the involved motor units were not capable of firing at a high frequency or generating force due to the lack of feedback from the 1a-afferents [23]. Stimulation of the 1a-afferent via the muscle spindle results in the facilitation of the associated α-motor neurons [45]. This 1a-afferent feedback has been shown to have an important effect on development of force [23].

Strength Measures

The improvement in balance in the WBV group was observed without an accompanying significant improvement in peak torque when compared to the CONTROL group. Our findings are similar to those reported by Fernandez-Rio et al [46] in their study of the long term effects of WBV training on force production in 31 female basketball players. All participants were randomly assigned to either the vibration group or a control group for the duration of the 14-week in-season training program. All participants followed the same strength-training program, but the vibration group (30-35 Hz, 4 mm) performed 3 extra vibration exercises (half squat, half squat with weight on toes, calf raise) twice weekly for 30-60 seconds. After 14 weeks the assessed values for squat jump, countermovement jump, 15-second jump test, and squat leg power had increased significantly from baseline to endpoint, but no additional effect from the WBV was seen for any of the performance measures [46] The authors noted that all the participants in the vibration group had the same vibration loading, unlike conventional strength training programs where the workload is individualized for each athlete. Due to this, they propose that perhaps WBV training should also be prescribed in a similar fashion in order to induce optimal effects [46].

Similar to the Fernandez-Rio study, all of the participants in the current study followed the same strength-training program for 8 weeks (not 14 weeks); the only exception being varied external load applied that was based on the participant's body weight. In the event that WBV training should be prescribed in an individual fashion, there exists the potential that the WBV as used in our study may not have been a large enough stimulus for some or all of the participants. This hypothesis is supported by the work of Bazett-Jones et al [47] who evaluated the acute effects of various accelerations during WBV on countermovement jump performance in 44 participants (33 male, 11 female). The goal of Bazett-Jones' study was to compare the effects of 5 different accelerations on countermovement jump height, duration of effect, and gender differences. All participants performed a 5-minute warm up on a cycle ergometer followed by two practice jumps. After 1 minute of rest, they performed 3 maximal countermovement jumps, resting another minute before vibration exposure. Vibration was applied at 1g (CONTROL), 2.18g (30 Hz, 2-4 mm), 2.8g (40 Hz, 2-4 mm), 4.87g (35 Hz, 4-6 mm), and 5.83g (50 Hz, 4-6 mm) while the participants performed 1 squat every 5 seconds for 45 seconds. The participants performed 3 maximal countermovement jumps immediately after vibration, and again at 5 and 10 minutes after vibration. The women demonstrated an 8.9% performance enhancement relative to the control for the 2.8g (40 Hz, 2-4 mm) WBV and an 8.3% improvement relative to the control for the 5.83g (50 Hz, 4-6 mm) WBV stimulus, while no performance effects were noted in the men for any of the experimental conditions. The authors noted that a linear trend in performance was not observed as acceleration increased, instead noting a relationship between higher frequencies and performance gains. The authors also postulated that the reason the women experienced enhanced performance was due to postactivation potentiation due to less muscle stiffness, creating a need for greater neuromuscular activation to dampen the stimulus [47]. The authors also mentioned that the women in their study were untrained and exhibited much greater variability than the men; however, one potential factor in the gender difference that was not directly discussed was the significant difference in body mass between men (74.5 ± 11.8 kg) and women (58.7 ±7.3 kg).

Bazett-Jones et al [47] originally set out to determine if different accelerations would alter the performance effects. However, due to statistically significant differences in mass, there may have been a dampening of the acceleration provided by the plate, as the force required to accelerate the participants upwards would have been larger in men (730.9 ± 115.8 N) than women (575.8 ± 71.6 N). While the Power Plate® Next Generation WBV platform used in their study does have the ability to adjust for body mass, these authors did not specifically mention whether this feature was utilized.

One possible reason why we did not observe additional strength gains associated with WBV in the current study is that our loading protocol may have altered the preset, intended frequency and/or amplitude of vibration stimulus experienced by the participants, especially as we got closer to the maximal loading capacity of the plate. Our WBV platform did not have the capacity to be adjusted for increased mass of the system, e.g., the subject and his weighted vest, so as the load in the vest increased the vibration stimulus delivered to the subject may have diminished due to increasing gravitational force from the system to the plate.

Lamont et al [48] evaluated the effects of a 6-week periodized squat training program with and without WBV on jump height and power output. Thirty resistance-trained male participants between the ages of 18 and 30 years were randomly assigned to 1 of 3 groups: squat training with vibration, squat training, or control. The squat training and squat training with vibration groups performed 12 workouts of 3 to 5 sets of back squats at 50-90% 1-RM. Testing was performed at baseline (week 1, mid-training (week 3), and post-training (week 7), and included 1-RM Smith machine back squat, 30-cm depth jumps, and 20 kg squat jumps. Jump height was calculated from flight time using a switch mat for all jumps and power during the upward, concentric phase of the depth and squat jumps was recorded using a linear accelerometer. Lamont et al administered their periodized training program of back squat exercises with a Smith machine twice per week, each separated by 72 hours of rest. The first 3 weeks of their protocol were intended to develop strength, with loads ranging from 55-90% of the participants' 1-RM for 3-4 sets of 3-5 repetitions, while the final 3 weeks were designed to develop power, using loads from 55-85% of 1-RM for 3-4 sets of 5-6 repetitions. The WBV group was exposed to vibration (50 Hz, 2-4 mm) for 30 seconds prior to the first set of squat exercises, with a 3-minute rest between vibration and the first set of squats. Ten second bouts of vibration (50 Hz, 4-6 mm) were then applied intermittently at 60, 120, and 180 seconds into the rest periods between sets, while the squat training group sat down for the entire 4-minute inter-set rest period. After 6 weeks of training, Lamont et al observed no significant changes in isometric force production after 7 weeks, though an increase of 1944.22 N/s for initial peak force during isometric contraction was observed in the squat with vibration group when compared to the squat group, indicating improvement in the ability to recruit and maximize firing frequency of high threshold motor units during the initial explosive drive.

Similar to our study, Lamont et al did not observe significantly increased force production during isometric squats after chronic WBV training; however, these authors attributed the observed 8% improvement in the rate of force development to the WBV stimulus (50 Hz, 2-4 mm, 30 sec). WBV training is known to cause skeletal muscle to undergo small changes in length, which in turn induces a response known as the tonic vibration reflex [23, 24]. This reflex causes activation of muscle spindles, mediation of neural signals by 1a afferents, and activation of muscle fibers by large α-motor neurons [49]. This 1a afferent feedback has been shown to have an important effect on force development, as the tonic vibration reflex can briefly intensify EMG activity and force of random isometric contractions [23]. While rate of force development was not directly measured in the current study, it is possible that the reduction of postural sway observed in the current study is the result of an improved ability to respond to perturbations by enhanced motor unit recruitment.

Other than the loading paradigm, there are several key differences that existed between Lamont et al and our study. First, we used 30 physically active, non-resistance trained males because of the limitation imposed by the 136 kg maximum capacity of the vibration plate. The protocol that Lamont et al used was performed by 30 "recreationally resistance trained" male participants (22.8± 0.9 yrs, 87.2± 5.8 kg), operationally defined as having at least 6 months of resistance training experience while not performing more than 3 workouts per week. The training status of the participants in the Lamont et al study combined with the vibration protocol allowed them to use larger loads during their training study. Unlike our study, Lamont and associates applied the vibration stimulus between bouts of squats rather than during the squatting exercises, thereby avoiding the limitation of loading capacity on the vibration plate.

Ronnestad [6] examined the performance enhancing effects of squatting exercises with and without vibration by combining conventional resistance training with WBV to examine the additive effect that the synergy between the two may have. Fourteen recreationally resistance trained men (age, 21 to 40 yrs) were randomly assigned to one of two groups that performed squatting exercises on a Smith machine either with or without WBV. Participants performed 13 training sessions on nonconsecutive days over a 5-week period, and assessments of 1 repetition maximum (1-RM) and jump height were measured at baseline and after training. Both groups increased the 1-RM of the squat, and there was a trend towards greater relative strength increase in the WBV group compared to the non-WBV group, but this trend did not reach statistical significance. Similar trends were seen in jump height, as the WBV squat group were the only ones who significantly improved ($p<0.01$), though there was no significant difference between groups in relative jump height increase ($p=0.088$) [6] Training loads for this study were between 6-RM and 10-RM, and the pre-training 1-RM measures were 165± 34.5 kg and 150 ± 15.3 kg for the vibration and non-vibration groups, respectively. Based on this information, our assigned maximal training load of 36.4 kg fell short of the weight required to induce a large enough neuromuscular stimulus to develop strength. Neither exercise group demonstrated significantly greater gains in strength after 8 weeks of training when compared to the CONTROL group, indicating that the program itself did not generate strength gains due to sub-maximal loading, and WBV did not significantly augment the low-level progressive resistance training provided by this protocol.

CONCLUSION

As hypothesized, subjects in the WBV group demonstrated reduced postural sway in the mCTSIB Foam-Eyes Open condition after 8 weeks of training when compared to the CONTROL group, though these effects were not observed for any of the other conditions in the mCTSIB. However, no significant differences were observed between subjects in the WBV and NO WBV groups, meaning that our study was unable to identify any positive effect solely due to the WBV stimulus. No significant differences in peak isokinetic leg press torque were observed between groups after either 4 or 8 weeks of training.

Given the limited maximal load capacity of the vibration plate employed in this randomized controlled trial, more research needs to be performed to determine the potential additive effects of progressive resistance exercise programs incorporating WBV. These future studies should focus on determining appropriate combinations of WBV stimulus and externally loaded dynamic exercises to elicit performance enhancements in balance and strength.

REFERENCES

1. Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol.* Mar 1999;79(4):306-311.
2. Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *Int J Sports Med.* Oct 2005;26(8):662-668.
3. Cochrane DJ, Stannard SR. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *Br J Sports Med.* Nov 2005;39(11):860-865.
4. Bosco C, Iacovelli M, Tsarpela O, et al. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol.* Apr 2000;81(6):449-454.
5. Cochrane DJ, Legg SJ, Hooker MJ. The short-term effect of whole-body vibration training on vertical jump, sprint, and agility performance. *J Strength Cond Res.* Nov 2004;18(4):828-832.
6. Ronnestad BR. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J Strength Cond Res.* Nov 2004;18(4):839-845.
7. Torvinen S, Kannu P, Sievanen H, et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging.* Mar 2002;22(2):145-152.
8. Bosco C, et al. The influence of whole body vibration on jumping performance. *Biol Sport.* 1998;15:157-164.
9. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc.* Jun 2003;35(6):1033-1041.
10. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med.* Jan 2004;25(1):1-5.
11. Torvinen S, Kannus P, Sievanen H, et al. Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc.* Sep 2002;34(9):1523-1528.
12. Torvinen S, Kannus P, Sievanen H, et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res.* May 2003;18(5):876-884.
13. Bautmans I, Van Hees E, Lemper JC, Mets T. The feasibility of Whole Body Vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial [ISRCTN62535013]. *BMC Geriatr.* 2005;5:17.

14. Russo CR, Lauretani F, Bandinelli S, et al. High-frequency vibration training increases muscle power in postmenopausal women. *Arch Phys Med Rehabil.* Dec 2003;84(12):1854-1857.
15. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res.* Mar 2004;19(3):352-359.
16. Cheung WH, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil.* Jul 2007;88(7):852-857.
17. Torvinen S, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Kannus P. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. *Int J Sports Med.* Jul 2002;23(5):374-379.
18. de Ruiter 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.* Nov 2003;90(5-6):595-600.
19. Eklund G, Hagbarth KE. Vibratory induced motor effects in normal man and in patients with spastic paralysis. *Electroencephalogr Clin Neurophysiol.* Oct 1967;23(4):393.
20. Roll JP, Vedel JP, Ribot E. Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Exp Brain Res.* 1989;76(1):213-222.
21. De Gail P, Lance JW, Neilson PD. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J Neurol Neurosurg Psychiatry.* Feb 1966;29(1):1-11.
22. Issurin VB, Tenenbaum G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci.* Mar 1999;17(3):177-182.
23. Bongiovanni LG, Hagbarth KE, Stjernberg L. Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *J Physiol.* Apr 1990;423:15-26.
24. Seidel H. Myoelectric reactions to ultra-low frequency and low-frequency whole body vibration. *Eur J Appl Physiol Occup Physiol.* 1988;57(5):558-562.
25. Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. *J Sports Sci.* Dec 1994;12(6):561-566.
26. Schlumberger A, Salin D, Schmidtbleicher D. [Strength training with superimposed vibrations]. *Sportverletz Sportschaden.* Vol 15. 2001/05/08 ed; 2001:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11338657. Accessed Mar.

27. Munn J, Herbert RD, Hancock MJ, Gandevia SC. Training with unilateral resistance exercise increases contralateral strength. *J Appl Physiol.* Nov 2005;99(5):1880-1884.
28. Gollhofer A, Schopp A, Rapp W, Stroinik V. Changes in reflex excitability following isometric contraction in humans. *Eur J Appl Physiol Occup Physiol.* 1998;77(1-2):89-97.
29. Riemann BL, Guskiewicz, K.M. Contribution of the Peripheral Somatosensory System to Balance and Postural Equilibrium. In: Lephart SM, Fu, F.H., ed. *Proprioception and Neuromuscular Control in Joint Stability*. Champaign, IL: Human Kinetics; 2000:37-51.
30. Nashner L, McCollum, G. The organization of human postural movements: a formal basis and experimental synthesis. *Behav Brain Sci.* 1985;8:135-172.
31. Nashner L. Computerized dynamic posturography. In: Jacobsen G, Newman, C., Kartush, J., ed. *Handbook of Balance Function and Testing*. St. Louis: Mosby Year Book; 1993:280-307.
32. Guyton A, Hall, J. Motor Functions of the Spinal Cord: the Cord Reflexes. *Textbook of Medical Physiology*. Philadelphia: Saunders; 2006:673-684.
33. Diener HC, Dichgans J, Guschlbauer B, Mau H. The significance of proprioception on postural stabilization as assessed by ischemia. *Brain Res.* Mar 26 1984;296(1):103-109.
34. Horak FB, Nashner LM, Diener HC. Postural strategies associated with somatosensory and vestibular loss. *Exp Brain Res.* 1990;82(1):167-177.
35. Nashner LM, Black FO, Wall C, 3rd. Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. *J Neurosci.* May 1982;2(5):536-544.
36. Bogaerts A, Verschueren S, Delecluse C, Claessens AL, Boonen S. Effects of whole body vibration training on postural control in older individuals: a 1 year randomized controlled trial. *Gait Posture.* Jul 2007;26(2):309-316.
37. Thomas M, Jankovic J, Suteerawattananon M, et al. Clinical gait and balance scale (GABS): validation and utilization. *J Neurol Sci.* Jan 15 2004;217(1):89-99.
38. Rehn B, Lidstrom J, Skoglund J, Lindstrom B. Effects on leg muscular performance from whole-body vibration exercise: a systematic review. *Scand J Med Sci Sports.* Feb 2007;17(1):2-11.
39. Winters-Stone KM, Snow CM. Site-specific response of bone to exercise in premenopausal women. *Bone.* Dec 2006;39(6):1203-1209.
40. NeuroCom. Modified Clinical Test of Sensory Interaction on Balance Protocol - Source on Internet. http://www.onbalance.com/neurocom/protocols/sensoryImpairment/mCTSIB.aspx. Accessed March 10, 2008.

41. Kavounoudias A, Roll R, Roll JP. The plantar sole is a 'dynamometric map' for human balance control. *Neuroreport.* Oct 5 1998;9(14):3247-3252.
42. Kavounoudias A, Roll R, Roll JP. Foot sole and ankle muscle inputs contribute jointly to human erect posture regulation. *J Physiol.* May 1 2001;532(Pt 3):869-878.
43. Nashner L. Computerized dynamic posturography. In: Jacobsen G, Newman C, Kartush J, eds. *Handbook of Balance Function and Testing*. St. Louis: Mosby Year Book; 1993:280-307.
44. Guyton A, Hall, J. Motor Functions of the Spinal Cord: the Cord Reflexes. *Textbook of Medical Physiology*. Philadelphia: Saunders; 2006:673-684.
45. Cardinale M, Bosco C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev.* Jan 2003;31(1):3-7.
46. Fernandez-Rio J, Terrados N, Fernandez-Garcia B, Suman OE. Effects of vibration training on force production in female basketball players. *J Strength Cond Res.* May 2010;24(5):1373-1380.
47. Bazett-Jones DM, Finch HW, Dugan EL. Comparing the effects of various whole-body vibration accelerations on counter-movement jump performance. *J Sports Sci and Med.* 2008;7:144-150.
48. Lamont HS, Cramer JT, Bemben DA, Shehab RL, Anderson MA, Bemben MG. Effects of adding whole body vibration to squat training on isometric force/time characteristics. *J Strength Cond Res.* Jan 2010;24(1):171-183.
49. Hagbarth KE, ed. *The effect of muscle variation in normal man and in patients with motor disease*. Basel: Karger; 1973.

Table 2.1— Subject Inclusion and Exclusion Criteria.

Inclusion Criteria:	Exclusion Criteria:
1. Males between the ages of 18 and 35.	1. No regular resistance training program within the last 3 months
2. Physically-active as defined by planned or recreational physical activity 3 or more times per week for at least 30 minutes.	2. Medical condition for which whole body vibration is contraindicated, including: cardiovascular, respiratory, neurological, musculoskeletal disease, and prostheses
	3. Previous injury to ankle, knee or hip within the past 12 months
	4. History of concussion, otitis media (inner ear infection) or other medical condition that would affect postural stability and balance.
	5. Body weight greater than 200 pounds. *(Note: For persons over 200 lbs, the combination of subject body weight and our weighted vest loading protocol will exceed the 300 lb. capacity of our vibration plates).*

Table 2.2 – Subject data collection and PRE training timeline.

Week	Training Session 1	Training Session 2	Training Session 3
Week 0	Initial Screening/Obtain Informed Consent	Initial Screening/Obtain Informed Consent	Conduct Pre-Test
Week 1	BW (3 sets x 8 reps)	BW (3 sets x 10 reps)	BW (3 sets x 12 reps)
Week 2	110% BW (3 sets x 8 reps)	110% BW (3 sets x 10 reps)	110% BW (3 sets x 12 reps)
Week 3	115% BW (3 sets x 8 reps)	115% BW (3 sets x 10 reps)	115% BW (3 sets x 12 reps)
Week 4	120% BW (3 sets x 8 reps)	120% BW (3 sets x 10 reps)	120% BW (3 sets x 12 reps)
Week 5	Conduct Midpoint Test	125% BW (3 sets x 8 reps)	125% BW (3 sets x 10 reps)
Week 6	125% BW (3 sets x 12 reps)	130% BW (3 sets x 8 reps)	130% BW (3 sets x 10 reps)
Week 7	130% BW (3 sets x 12 reps)	135% BW (3 sets x 8 reps)	135% BW (3 sets x 10 reps)
Week 8	135% BW (3 sets x 12 reps)	140% BW (3 sets x 8 reps)	140% BW (3 sets x 10 reps)
Week 9	140% BW (3 sets x 12 reps)	Conduct Post-Test	

BW = baseline body weight, then percentage increase by weighted vest

Table 2.3. Summary of ANOVA Results for Anthropometric Data at Entry into the Study (mean values ± SD)

Variable	**WBV**	**No WBV**	**CONTROL**	**F ratio**	***P***
Age (yrs)	23.0 ± 3.8	22.1 ± 3.1	21.5 ± 2.9	<1	0.528
Height (cm)	180.0 ± 4.4	177.6 ± 4.4	178.9 ± 8.9	<1	0.704
Mass (kg)	77.6 ± 5.0	73.5 ± 7.4	76.3 ± 8.9	<1	0.448

Table 2.4. Summary of ANOVA Results for Group and Time Means from the modified Clinical Test of Sensory Interaction on Balance (mCTSIB). Lower scores are indicative of a reduction in postural sway.

	Pre-Test			**Mid-Test**			**Post-Test**				
	WBV	**NO WBV**	**CON**	**WBV**	**NO WBV**	**CON**	**WBV**	**NO WBV**	**CON**	**Group Effects**	**Time Effects**
mCTSIB Firm-Eyes Open (deg/s)	0.22 ±.079	0.24 ±.108	0.32 ±.123	0.20 ±.082	0.22 ±.063	0.25 ±.097	0.20 ±.067	0.21 ±.057	0.27 ±.082	0.067	0.048♦
mCTSIB Firm-Eyes Closed (deg/s)	0.26 ±.084	0.26 ±.084	0.32 ±.114	0.25 ±.071	0.28 ±.079	0.35 ±.118	0.23 ±.067	0.28 ±.114	0.29 ±.074	0.114	0.249
mCTSIB Foam-Eyes Open (deg/s)	0.50 ±.170	0.56 ±.117	0.66 ±.126	0.46 ±.097	0.50 ±.082	0.56 ±.097	0.49 ±.099	0.47 ±.116	0.55 ±.118	0.042✷	0.003♣
mCTSIB Foam-Eyes Closed (deg/s)	1.53 ±.295	1.38 ±.316	1.52 ±.447	1.34 ±.280	1.34 ±.344	1.42 ±.452	1.28± .257	1.18 ±.280	1.41 ±.325	0.49	0.014♠
mCTSIB Composite Score (deg/s)	0.64 ±.126	0.61 ±.120	0.71 ±.179	0.57 ±.106	0.58 ±.114	0.66 ±.171	0.55 ±.071	0.54 ±.135	0.64 ±.135	0.147	0.003♥

♦ - Significant main effect for TIME, p= .048

✷- Significant simple main effect for GROUP (CONTROL vs. WBV, p= .042)

♣ - Significant simple main effect for TIME (Post-test >Pre-test , p= .036; Mid-test > Pre-Test, p=.004)

♠ - Significant simple main effect for TIME (Post-test >Pre-test, p= .021)

♥ - Significant simple main effect for TIME (Post-test >Pre-test, p= .009; Mid-test > Pre-test, p= .048)

Table 2.5. Summary of ANOVA Results for Group and Time Means from the Biodex Isokinetic Leg Press Peak Torque (Normalized to Nm/kg).

	Pre-Test			**Mid-Test**			**Post-Test**				
Isokinetic Speed (deg/sec)	**WBV**	**NO WBV**	**CON**	**WBV**	**NO WBV**	**CON**	**WBV**	**NO WBV**	**CON**	**Group Effects**	**Time Effects**
L CON 60	0.844 ±.340	0.785 ±.336	0.707 ±.251	1.000 ±.291	0.972 ±.263	0.797 ±.372	1.064 ±.323	1.012 ±.434	0.818 ±.364	p= 0.303	p= 0.003♦
L ECC 60	1.405 ±.512	1.327 ±.514	1.250 ±.385	1.508 ±.476	1.616 ±.568	1.319 ±.596	1.608 ±.609	1.629 ±.699	1.225 ±.509	p= 0.384	p= 0.164
L CON 120	0.875 ±.322	0.937 ±.323	0.743 ±.158	0.998 ±.245	0.932 ±.252	0.824 ±.329	1.163 ±.551	0.964 ±.290	0.838 ±.351	p= 0.214	p= 0.111
L ECC 120	1.604 ±.447	1.657 ±.817	1.341 ±.432	1.692 ±.474	1.74 ±.582	1.406 ±.519	1.609 ±.440	1.738 ±.668	1.420 ±.551	p= 0.302	p= 0.690
L CON 180	0.881 ±.369	0.933 ±.376	0.719 ±.144	1.125 ±.480	1.009 ±.240	0.861 ±.333	1.037 ±.327	1.003 ±.336	0.871 ±.405	p= 0.247	p= 0.069
L ECC 180	1.689 ±.530	1.794 ±1.036	1.613 ±.528	1.798 ±.430	1.859 ±.599	1.556 ±.627	1.609 ±.440	1.738 ±.668	1.420 ±.551	p= 0.532	p= 0.333
R CON 60	0.930 ±.416	0.735 ±.347	0.862 ±.540	1.047 ±.368	0.995 ±.297	0.857 ±.575	1.183 ±.463	1.093 ±.378	1.033 ±.551	p= 0.698	p= 0.006♣
R ECC 60	1.365 ±.428	1.441 ±.639	1.441 ±.909	1.630 ±.425	1.721 ±.567	1.444 ±.782	1.816 ±.667	1.909 ±.807	1.576 ±.588	p= 0.773	p= 0.015♠
RCON 120	0.906 ±.358	0.840 ±.462	0.878 ±.433	1.046 ±.185	1.038 ±.310	0.847 ±.437	1.178 ±.387	1.117 ±.345	0.909 ±.380	p= 0.438	p= 0.054
R ECC 120	1.638 ±.424	1.783 ±.931	1.606 ±.979	1.747 ±.328	1.813 ±.478	1.505 ±.912	1.925 ±.528	1.951 ±.801	1.651 ±.948	p= 0.673	p= 0.209
R CON 180	0.864 ±.408	0.795 ±.338	0.815 ±.391	1.06 ±.221	0.995 ±.385	0.822 ±.455	1.082 ±.292	1.155 ±.352	0.867 ±.410	p= 0.445	p= 0.005♥
R ECC 180	1.619 ±.358	1.836 ±1.082	1.725 ±.871	1.848 ±.402	2.001 ±.821	1.669 ±.965	1.900 ±.406	2.159 ±.882	1.639 ±.824	p= 0.612	p= 0.134

♦ - Significant simple main effect for TIME (Post Test >Pre-Test, p=0.003)
♣ - Significant simple main effect for TIME (Post Test >Pre-Test, p=0.03)
♠ - Significant simple main effect for TIME (Post Test >Pre-Test, p=0.043)
♥ - Significant simple main effect for TIME (Post Test >Pre-Test, p= 0.018)

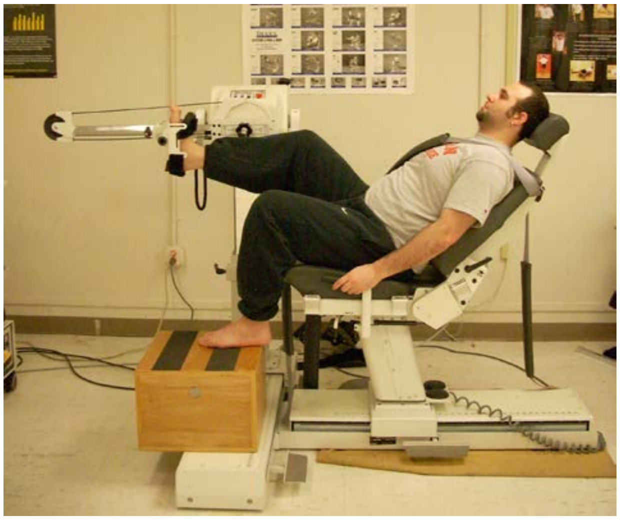

Figure 2.1— Biodex™ System 3 closed kinetic chain leg press experimental set-up. (Please note the foot plate attachment.)

Figure 2.2 – NeuroCom™ modified Clinical Test of Sensory Interaction on Balance (mCTSIB) experimental set-up.

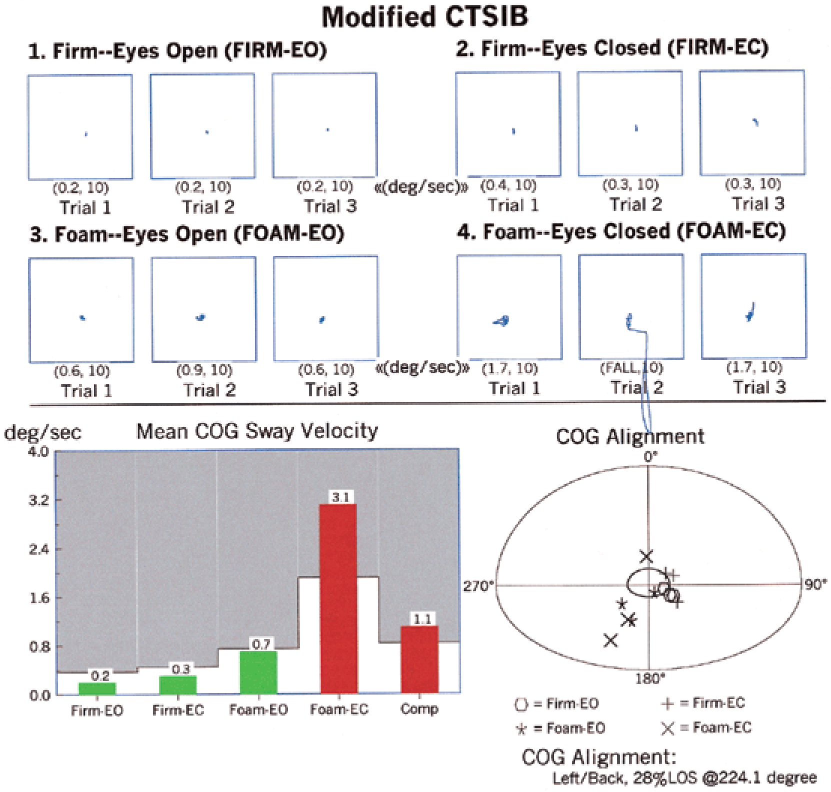

Figure 2.3 – Representative output from the NeuroCom™ modified Clinical Test of Sensory Interaction on Balance (mCTSIB). *(Source: NeuroCom, a division of Natus Medical Incorporated, accessed May 13, 2011)*

Chapter 3

Summary and Recommendations for Future Research

Chapter 3

Recommendations for Future Research

In retrospect, there are several aspects of this study that could have been improved in order to better answer my original research question. One of the major limitations of this study was the available load capacity of the commercially-available vibration plate (TurboSonic) that we utilized. Since the total load was capped at 136 kg (300 pounds) for the combination of the participant and the ultimate training load, we were not able to employ training loads that would most commonly be used to generate strength gains. Due to this limitation, our training loads were capped at 40% of the participant's body weight, which for example, equated to a maximum of 36.4 kg of added resistance via weighted vest for a 91 kg participant.

Ideally we would have been able to test each participant before entry into the study to gather information about his predicted single repetition maximum (1-RM) and assigned training loads based on these values. Our maximal training load of 36.4 kg is likely far below any of the training loads that would have been predicted during 1-RM assessment, which could have been part of the reason for the lack of significant strength gains. A larger load capacity on the vibration plate would have allowed us to use a more traditional strength development program using predicted 1-RM as a basis for training load rather than a percentage of body weight, which may have resulted in larger strength gains and identification of any possible beneficial synergistic effects on muscular strength.

First, the load capacity of the weighted vests that we employed was 54.5 kg, so the limitation enforced by the plate meant that we were unable to use the maximal load capacity of the vests, which may or may not have been in the range of the predicted 1-RM values. If not faced with the limitation of weight on the vibration plate, a more appropriate strength program would have involved testing predicted 1-RM upon entry to the study, then designing individual training protocols for each of the participants based on this prediction. A more appropriate load for strength development would have been 6 or less repetitions at greater than 85% of the predicted 1-RM, as recommended by the National Strength and Conditioning Association [1]. In our defense, we were aware of the limitation imposed by the vibration plate, and this was the driving factor behind recruiting untrained individuals as participants in this study. This was done in an attempt to maximize the effect of the submaximal training loads used in our progressive loading paradigm.

The second alteration that could have been made in the presence of a vibration plate with a larger load capacity is the ability to load the participants in a more traditional fashion using a bar and weight plates instead of the weighted vest. The reason for choosing a weighted vest as the loading method is a result of the limited load capacity of the plate and the chosen population. Since the maximal training load for the heaviest possible participant (91 kg) was 36.4 kg, using a standard Olympic bar (20.5 kg) would have severely limited our ability to increase the load in small increments for progression. Also, due to the light load, we recruited non-resistance trained participants, some of whom needed to be taught how to squat properly. Using the weighted vest eliminated some of the safety risks associated with attempting to teach novice lifters to squat with an Olympic bar as it kept the load centralized and balanced. A greater load capacity on the vibration plate could have allowed us to expand our population to include resistance trained individuals and move towards a more traditional loading pattern, i.e., Olympic bar and percentage of 1-RM, due to increased familiarity with resistance training.

Another experimental design change that might have improved the results of this study would have been to measure power through maximum vertical jump height rather than strength using isokinetic leg press. The Biodex dynamometer setup was somewhat counterintuitive to some of the participants, in spite of the unlimited practice repetitions and efforts to familiarize them with the device. This complication alone could have resulted in the lack of observed changes in strength. Another potential issue with this method of evaluating strength was that the squatting exercises were performed bilaterally, but the evaluation of isokinetic leg strength was performed unilaterally. Due to the complicated process of isokinetic testing and the fact that it was not a bilateral performance test, jump height may have been a more appropriate evaluation of human performance than the unilateral isokinetic leg press, especially given the training status of the participants we recruited.

Lastly, the vibration stimulus itself may have been insufficient to generate a neuromuscular challenge that would bring about strength gains, especially when using a submaximal loading paradigm. According to Marin and Rhea [2, 3], a positive linear relationship in treatment effect exists between frequency and strength improvements with vibration, as frequencies between 40 to 50 Hz are associated with the largest strength gains while power is optimally developed at frequencies between 35 and 40 Hz.

Similarly, larger amplitudes are also associated with greater improvements in strength and power after vibration training. Vibration plate deflection amplitudes below 6 mm do not result in large treatment effects for power development [2] and small amplitudes (2-6 mm) showed smaller treatment effects for strength than do larger amplitudes (8 to 10 mm) [3]. In the current study, the vibration stimulus was configured at a frequency of 25 Hz and plate deflection amplitude of 5 mm, both of which are below the recommended stimulus for observing large treatment effects for either muscular strength or power [2, 3].

As described by Cohen [4], the power of a statistical test is the probability that it will lead to the rejection of the null hypothesis, or the probability that the test will yield statistically significant results. In order to avoid making a Type II error, the failure to reject a false null hypothesis, the advised minimum statistical power for any outcome measure is 0.80, or an 80% chance of making a correct decision[4]. Many of the analyses of the outcome measures in the current study had observed power less than 0.80, particularly the isokinetic strength data. Effect size is also described by Cohen [4] as the degree to which the null hypothesis is false. Three categories of effect sizes have been identified, and are defined in Table 3.1, while Table 3.2 lists the observed power ($1 - \beta$) and effect sizes (partial eta squared) for all outcome measures analyzed with the SPSS software in the current study.

Table 3.1 – Categories of Effect Size, as proposed by Cohen [4]

Small	η^2 = .01 to .08
Medium	η^2 = .09 to .24
Large	$\eta^2 = \geq .25$

Table 3.2 **–** Observed Statistical Power and Effect Sizes of Outcome Measures

Outcome Measure	**Observed Power (1-β)**	**Effect Size (η2)**
mCTSIB Firm-Eyes Open (deg/s)	0.591	0.107
mCTSIB Firm-Eyes Closed (deg/s)	0.254	0.050
mCTSIB Foam-Eyes Open (deg/s)	0.885	0.191
mCTSIB Foam-Eyes Closed (deg/s)	0.758	0.146
mCTSIB Composite Score (deg/s)	0.885	0.191
L CON 60 deg/sec	0.898	0.198
L ECC 60 deg/sec	0.372	0.065
L CON 120 deg/sec	0.402	0.084
L ECC 120 deg/sec	0.107	0.014
L CON 180 deg/sec	0.500	0.102
L ECC 180 deg/sec	0.238	0.040
R CON 60 deg/sec	0.766	0.173
R ECC 60 deg/sec	0.729	0.162
RCON 120 deg/sec	0.535	0.113
R ECC 120 deg/sec	0.327	0.056
R CON 180 deg/sec	0.840	0.194
R ECC 180 deg/sec	0.411	0.072

Of the 17 analysis of variance (ANOVA) calculations performed in our study, only 4 (24%) had the minimum level of observed statistical power recommended by Cohen. The low observed statistical power associated with many of our outcome measures could likely have been improved by increasing our sample size.

While none of the results of the 17 ANOVAs revealed a “large” effect size, we did observe a “medium” treatment effect for 10 of the 17 analyses (59%). This was a highly encouraging finding, confirming the neurophysiological relevance of the majority of our selected outcome measures.

Summary

There has been a recent expansion of interest in WBV as a training modality for improved athletic performance and rehabilitation purposes, and while the results of this randomized controlled study did not provide much insight in terms of statistically significant results, it does bring forward several interesting questions for future considerations. First, would a more traditional progressive loading paradigm for strength using greater loads be helpful in finding evidence in favor of my original hypothesis. The second question that I would like to answer is whether or not a different vibration stimulus, either increased frequency or amplitude, or both, could create a large enough neuromuscular stimulus to overcome a submaximal loading protocol.

REFERENCES

1. Baechle TR, Earle RW, ed. *Essentials of Strength Training and Conditioning.* 3rd ed. Champaign: Human Kinetics; 2008.
2. Marin PJ, Rhea MR. Effects of vibration training on muscle power: a meta-analysis. *J Strength Cond Res.* Mar 2010;24(3):871-878.
3. Marin PJ, Rhea MR. Effects of vibration training on muscle strength: a meta-analysis. *J Strength Cond Res.* Feb 2010;24(2):548-556.
4. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates, Inc.; 1988.

APPENDICES

IRB Application #4059

Appendix A

IRB Application

1. Brief Description

This project is significant because it will provide important new information regarding the use of whole body vibration (WBV) as a means of enhancing the results of resistance exercise training programs. There are three specific aims of this research project. First, we will determine the extent to which a progressive resistance training program using squat exercises combined with WBV affects lower extremity muscular strength gains. Second, we will quantify the effects of whole body vibration training on standing balance. Lastly, we will measure the longitudinal effects of WBV training across an 8-week period. We hypothesize that the combination of resistance training and whole body vibration will result in significantly greater gains in force as measured by a leg press exercise. We also hypothesize that the group who performed squat exercises while undergoing WBV will have better standing balance than subjects who performed squat exercises without WBV, and a control group of subjects who performed no exercises during the 8-week study period.

Figure 1 - TurboSonic Deluxe TT2590 Vibration Plate

2. Background and Significance

Whole body vibration (WBV) devices have been utilized as a mechanical stimulus for the improvement of muscular strength and power by sport and recreational activity participants, as well as patients undergoing orthopedic rehabilitation. The current literature contains conflicting evidence regarding the magnitude of the influence of WBV on strength development and balance in humans. To date, very little is known about the combined effects of WBV and progressive resistance exercise (PRE) in enhancing strength development and balance. Whole body vibration is thought to generate muscular contractions by placing the muscle in a stretched position, causing a subsequent contraction of the stretched muscle, a protective mechanism known as the stretch reflex. Since near-maximal muscular contractions are necessary to build strength, WBV may be a more efficient means of developing strength, especially in a sedentary or mobility-limited population. We anticipate that the results of this study will provide evidence of positive longitudinal effects of WBV on progressive resistance exercise training programs, which may have significant implications for sport, general fitness and orthopedic rehabilitation activities.

3. Methods and Procedures

Balance deficits occur as a normal part of the aging process, as older adults are known to have increased displacement of the center of pressure (more postural sway) during standing compared to younger adults [1]. These changes may be due to deterioration of the visual (eyes), vestibular (inner ear balance mechanism), and somatosensory systems (motion sensors in joints and muscles), as well as the way these three systems are integrated during postural balance [2]. Measures of sensory input**,** such as visual, neuromuscular, and vestibular, have been shown to be good predictors of center of pressure displacement during bipedal stance (see Figure 3) [3].

There is long-established evidence of age-related declines in proprioception and joint position sense ($r = 0.57$, $p < 0.001$) in older adults [4, 5]. Older individuals made more errors (7 ± 1) when compared to younger individuals (4 ± 1, $p < 0.05$), indicating a decline in joint motion sense over time [4]. For these reasons, we believe that working with an older population may introduce a degree of variability into our data that may mask treatment effects.

Additionally, the American College of Sports Medicine's exercise prescription guidelines state that "asymptomatic, apparently healthy men under the age of 40 do not require medical evaluation by a physician before initiating a program of vigorous exercise training" (ACSM, 2002). Recruiting an older subject population in our proposed study would require medical clearance for participation, creating additional risk and requiring extra costs and time on the subject's behalf.

Adult women and men are known to have very different physiological responses to resistance exercise. Previous studies have shown that men exhibit significant (range, 25% to 35%; $p \leq 0.05$) increases in serum testosterone after 6 weeks of resistance training exercise [6], a response that has not been observed in women [7, 8]. This difference originates in adolescence and has been implicated in anaerobic performance differences between the sexes [9] due to a greater rise above

resting levels of growth hormone and testosterone in men [10]. On average, women have 5% of the circulating
testosterone levels that men possess [6], making it more difficult for them to gain strength and muscle mass relative to men.

The resistance training protocol in our study is intended to develop muscle hypertrophy (increased muscle cross-sectional area), a physiological response that has been shown to activate the endocrine system more effectively than workouts designed for strength or power (range, 26% to 89%; $p = 0.000\text{-}0.0015$) [11]. This activation occurs in response to a high volume load, which causes release of the anabolic hormones testosterone and growth hormone [11]. Since women demonstrate a lower relative testosterone response to resistance exercise, female subjects would require longer than the 8-week study period to demonstrate similar changes in muscle mass that would be observed in male subjects.

Strength testing will be performed at all 3 time points using a Biodex System 3™ isokinetic dynamometer (Figure 2) using the manufacturer's instructions. Participants will be asked to sit in the device's chair and place their stocking foot into the leg press attachment. The chair back will be set to a 45° angle with the subject's hip and knee placed at a 90° angle. Participants will be strapped into the seat using seat belt-like straps to prevent unwanted movement during testing. The exact position of the equipment will be noted for each participant at baseline testing to maximize the repeatability of the measurements obtained at the midpoint and conclusion of this study. Once the starting position is established, the test will be described verbally as “pushing as hard as possible” with the leg for both the extension and flexion phases of the leg press. Participants will be given 2 practice trials for familiarization before data is collected. The test will consist of 9 single repetitions, using 3 repetitions each for 3 dynamometer speeds, 60°/sec, 120°/sec and 180°/sec. The individual repetitions will be administered in an order from slow to fast, then repeated 3 times for a total of 9 repetitions. A 30-second rest period will be provided between each trial, and the same protocol will be used to test each leg, beginning with the right. This portion of the testing session is expected to last approximately 15 minutes.

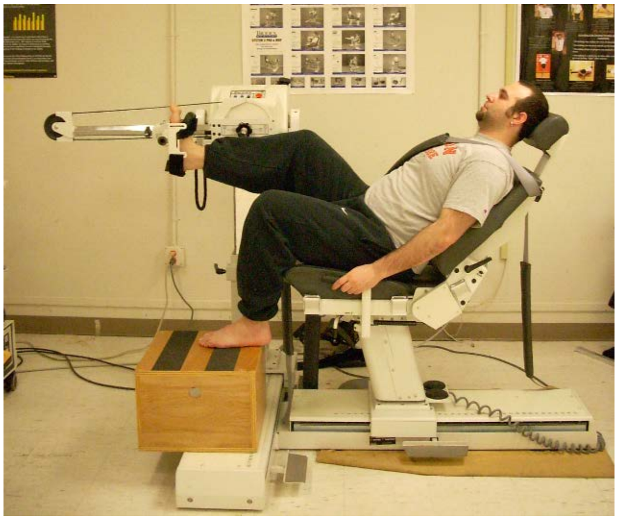

Figure 2- Biodex System 3™ Isokinetic Dynamometer

Balance will be assessed using the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) on a Neurocom SMART Balance Master™ device (Figure 3). This test will be performed in stocking feet and consists of 3 trials in each of 4 different conditions: 1) eyes open on a firm surface, 2) eyes closed on a firm surface, 3) eyes open on a foam surface, and 4) eyes closed on a foam surface. Before this test, we will measure the height of each participant as height is required data for the device's software calculations of postural stability. Participants will be instructed to stand as motionless as possible during each trial while maintaining a parallel foot position. This portion of the testing is expected to last approximately 5 minutes.

Methods and Procedures—continued:

Figure 3 – NeuroCom modified Clinical Test of Sensory Interaction on Balance™ (mCTSIB), Test Condition #4: Eyes closed on a foam surface.

Participants who are assigned to the control group will not participate in any training sessions for this study. The only requirements of this group will be to refrain from beginning any new resistance exercise training programs and to otherwise maintain their current lifestyles over the 8-week study period. This group's only involvement in this study will be to participate in strength and balance testing during Week 1, Week 4 and Week 9.

Participants who are assigned to the two treatment groups will perform 24 training sessions lasting approximately 20 minutes each. These sessions will begin with a warm-up period consisting of 5 minutes of light jogging on a treadmill followed by light stretching of the involved muscle groups. Once the 10-minute warm-up period is finished, participants will perform 3 sets of 8 to 12 repetitions of squatting exercises with a 90-second rest period between the sets. The number of repetitions performed increases from low to high within the week while maintaining a constant training load to achieve the progression of the weighted squat exercises. This protocol is described in detail in Table 1. Subjects in the treatment groups will begin the study with “body weight only” squat exercises for familiarization before addition of external loads using weighted vests. The weighting will be assigned based on a percentage of body weight, beginning with an additional 10% and progressing towards 40% at the end of the 8-week training period.

Participants who are assigned to the WBV group will perform these squat exercises while standing on a WBV platform vibrating at 25 Hz (25 times per second) and while deflecting 5 mm up and down with each cycle. The subject’s vibration exposure will be controlled and limited to no more than 1 minute of WBV per set for each of the 3 sets per exercise session, for a maximum of 9 minutes per week of vibration exposure.

4. Risks/Benefit Assessment

Risks – Potential risks in this study are muscle soreness due to exertion during strength training procedures. We will minimize the risk of soreness by providing an appropriate warm-up and stretching period before every training session. As with most exercise, the risk of injury does exist, but will be minimized by having a qualified individual present during all testing and training sessions to ensure the participants use biomechanically-correct movement patterns.

Benefits – Participants in the treatment groups may benefit from the training protocol through enhanced muscular strength and improved balance. All participants will also be financially compensated for their time.

Although the risks associated with the performance of resistance exercises are present, appropriate means of injury prevention are in place to minimize these risks.

5. Participant Population

The participant population will consist of 48 healthy males between the ages of 18 and 35 years who are considered physically active, weigh 200 pounds or less, and have not performed resistance training exercise within 3 months of the initiation of the study. We have selected males to eliminate the potential confounding factor of sex of the subject. The 200 pound subject weight limit is necessary because the combination of body weight and the weighted vests worn by the subjects during the squat exercises must not exceed the 300 pound limit of our WBV devices.

Participants will be selected for participation in this study by meeting the criteria mentioned above and not having any of the following contraindications: cardiovascular, respiratory, neurological, musculoskeletal disease, prostheses, previous injury to ankles, knees or hips within the past 12 months, or history of concussion, otitis media (inner ear infection), or other medical condition that would affect postural stability and balance.

6. Subject Identification and Recruitment

All participants will be recruited through physical activity classes at Oregon State University, as well as through flyers posted around the campus area to allow for a representative sample of the population.

7. Compensation

Participants in this study will be compensated up to $40 for taking part in this research study. Compensation will be pro-rated in the following manner: participants who withdraw after baseline testing will receive $5, participants who withdraw after midpoint testing will receive $15, and participants who complete all aspects of the 8-week study will receive payment of the full $40.

8. Informed Consent Process

Informed consent will be obtained through signature of an informed consent document detailing the rights of the participants. Any questions or concerns about involvement in the study will be addressed at the time of signing.

9. Anonymity or Confidentiality

To ensure anonymity and confidentiality all participants will be assigned a subject number that will be used during data processing. All data will be kept in a secure filing cabinet in a locked office within the OSU Sports Medicine and Disabilities Research Laboratory.

REFERENCES

1. Onambele, G.L., M.V. Narici, and C.N. Maganaris, *Calf muscle-tendon properties and postural balance in old age.* J Appl Physiol, 2006. **100**(6): p. 2048-56.
2. Horak, F.B., C.L. Shupert, and A. Mirka, *Components of postural dyscontrol in the elderly: a review.* Neurobiol Aging, 1989. **10**(6): p. 727-38.
3. Fitzpatrick, R. and D.I. McCloskey, *Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans.* J Physiol, 1994. **478 (Pt 1)**: p. 173-86.
4. Kaplan, F.S., et al., *Age-related changes in proprioception and sensation of joint position.* Acta Orthop Scand, 1985. **56**(1): p. 72-4.
5. Skinner, H.B., R.L. Barrack, and S.D. Cook, *Age-related decline in proprioception.* Clin Orthop Relat Res, 1984(184): p. 208-11.
6. Kraemer, W.J., et al., *The effects of short-term resistance training on endocrine function in men and women.* Eur J Appl Physiol Occup Physiol, 1998. **78**(1): p. 69-76.
7. Kraemer, W.J., et al., *Changes in hormonal concentrations after different heavy-resistance exercise protocols in women.* J Appl Physiol, 1993. **75**(2): p. 594-604.

8. Kraemer, W.J., et al., *Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females.* Int J Sports Med, 1991. **12**(2): p. 228-35.

9. Nindl, B.C., et al., *Lower and upper body anaerobic performance in male and female adolescent athletes.* Med Sci Sports Exerc, 1995. **27**(2): p. 235-41.

10. Hakkinen, K. and A. Pakarinen, *Acute hormonal responses to heavy resistance exercise in men and women at different ages.* Int J Sports Med, 1995. **16**(8): p. 507-13.

11. Crewther, B., et al., *The salivary testosterone and cortisol response to three loading schemes.* J Strength Cond Res, 2008. **22**(1): p. 250-5.

Table 1 – Subject data collection and PRE training timeline.

Week	Training Session 1	Training Session 2	Training Session 3
Week 0	Initial Screening/Obtain Informed Consent	Initial Screening/Obtain Informed Consent	Conduct Pre-Test
Week 1	BW (3 sets x 8 reps)	BW (3 sets x 10 reps)	BW (3 sets x 12 reps)
Week 2	110% BW (3 sets x 8 reps)	110% BW (3 sets x 10 reps)	110% BW (3 sets x 12 reps)
Week 3	115% BW (3 sets x 8 reps)	115% BW (3 sets x 10 reps)	115% BW (3 sets x 12 reps)
Week 4	120% BW (3 sets x 8 reps)	120% BW (3 sets x 10 reps)	120% BW (3 sets x 12 reps)
Week 5	Conduct Midpoint Test	125% BW (3 sets x 8 reps)	125% BW (3 sets x 10 reps)
Week 6	125% BW (3 sets x 12 reps)	130% BW (3 sets x 8 reps)	130% BW (3 sets x 10 reps)
Week 7	130% BW (3 sets x 12 reps)	135% BW (3 sets x 8 reps)	135% BW (3 sets x 10 reps)
Week 8	135% BW (3 sets x 12 reps)	140% BW (3 sets x 8 reps)	140% BW (3 sets x 10 reps)
Week 9	140% BW (3 sets x 12 reps)	Conduct Post-Test	

BW = body weight

APPENDIX B

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INFORMED CONSENT DOCUMENT

Project Title:	**The Longitudinal Effects of Progressive Resistance Exercise With and Without Whole Body Vibration on Lower Extremity Strength and Static Balance**
Principal Investigator:	Rod A. Harter, Ph.D., ATC, Department of Nutrition and Exercise Sciences
Co-Investigator(s):	Nathan Dodge, C.S.C.S., Department of Nutrition and Exercise Sciences

WHAT IS THE PURPOSE OF THIS STUDY?

You are being invited to take part in a research study designed to investigate the long term effects of whole body vibration on strength and balance over an 8-week period. Some previous studies have reported that whole body vibration has improved strength and balance while other studies have found no significant differences in strength and balance after exposure to whole body vibration. In this study we will test your leg strength as well as your ability to balance on three separate occasions: at the beginning, at the midpoint and at the end of the study. The results of this project will be used as part of a graduate student's master's thesis, and will likely be presented at a strength and conditioning conference and submitted for publication in a peer-reviewed exercise science journal. We are studying this because it helps us understand how whole body vibration affects the human nervous and muscular systems.

WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a man who is between the age of 18 and 35 years, weighs less than 200 pounds, and is physically-active as defined by planned or recreational physical activity 3 or more times per week for at least 30 minutes. You have not participated in regular resistance training program within the last 3 months, do not have cardiovascular, respiratory, neurological, musculoskeletal disease, prostheses, previous injury to ankles, knees or hips within the past 12 months, or history of concussion, otitis media (inner ear infection), or other medical condition that would affect postural stability and balance.

WHAT WILL HAPPEN DURING THIS STUDY AND HOW LONG WILL IT TAKE?

If you agree to take part in this study, your total time commitment will be approximately 8 hours over a total of 27 visits (3 testing, 24 training). All testing and training will be performed in the Sports Medicine Laboratory at Oregon State University. Each of the 3 data collection sessions will be expected to last approximately 40 minutes and will consist of the following activities:

- Balance assessment (~15 minutes) – You will be asked to stand on a 6' long force plate with your feet parallel and your arms at your sides during 3 trials each of 4 different conditions:
    - Eyes open on a firm surface
    - Eyes closed on a firm surface
    - Eyes open on a foam surface
    - Eyes closed on a foam surface

- Strength assessment (~25 minutes) – You will be asked to perform leg press exercises on an isokinetic dynamometer with one leg at a time. You will be required to rest for 1 minute between sets of three repetitions. The strength testing protocol consists of 9 trials total for each leg in the following manner:
    - 3 repetitions at 60°/second
    - 3 repetitions at 120°/second
    - 3 repetitions at 180°/second

In the event you are assigned to one of the exercise groups, you will be asked to attend training sessions 3 days per week for 8 weeks. All training sessions will consist of the following:

- Weigh-in (~1 minute) – You will be weighed before each training session
- Cycling warm-up (3 minutes) – You will be asked to pedal a stationary bike at a comfortable pace
- Light Stretching (~2 minutes) – You will be asked to perform light static stretching of the lower extremity for the following muscle groups:
    - Quadriceps
    - Hamstrings
    - Calves
    - Gluteal muscles
    - Hip flexors

- Squatting Exercises (~5 minutes) – You will be asked to perform 3 sets of 10-12 repetitions of squats with a gradually increasing load. You will be provided a 90 second seated rest period in between sets. The load will be predetermined based on a percentage of your body weight obtained during weigh-in. The loading pattern is as follows:
    - Week 1 – Body weight
    - Week 2 – 110% Body weight
    - Week 3 – 115% Body weight
    - Week 4 – 120% Body weight
    - Week 5 – 125% Body weight
    - Week 6 – 130% Body weight
    - Week 7 – 135% Body weight
    - Week 8 – 140% Body weight

WHAT ARE THE RISKS OF THIS STUDY?

The possible risks and/or discomforts associated with the procedures described in this study are minimal, but include lower extremity muscular fatigue and soreness from physical exertion associated with strength testing and resistance training exercise. You may also experience slight discomfort from whole body vibration which usually fades quickly. To prevent injury and soreness, a warm-up period consisting of light jogging and stretching will be performed before each training session.

WHAT ARE THE BENEFITS OF THIS STUDY?

We do not know if you will benefit from being in this study. However, we hope that, in the future, other people might benefit from this study through a better understanding of how whole body vibration affects the human muscular system.

WILL I BE PAID FOR PARTICIPATING?

You will be paid up to $40 for being in this research study. Compensation will be pro-rated in the following manner: If you withdraw from the study after completing baseline testing, you will be paid $5. If you withdraw from the study after completing midpoint testing, you will be paid $15. If you complete all aspects of the 8-week study, you will receive a payment of $40.

WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, we will assign you a participant number, and will only use that participant number during the collection and analysis of your data.

If the results of this project are published your identity will not be made public.

DO I HAVE A CHOICE TO BE IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

WHO IS PAYING FOR THIS STUDY?

This study will be funded by the student researcher.

WHAT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: Nathan Dodge (dodgen@onid.orst.edu, 541-737-6899) or Dr. Rod A. Harter (rod.harter@oregonstate.edu, 541-737-6801).

If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-4933 or by email at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed):

____

____ __________________________
(Signature of Participant) (Date)

Appendix C

Medical Screening Questionnaire

1) Demographic Information

Name: ___________________

Age: ______

Height (in inches): _____

Weight (in pounds): _____

2) Are you physically active for 30 minutes 3 or more days out of the week?

Yes ____ No ____

3) Does this physical activity include resistance training (weight training)?

Yes ____ No ____

4) Do you have any of the following medical conditions?

Cardiovascular disease	Yes ____	No ____
Respiratory disease	Yes ____	No ____
Neurological disease	Yes ____	No ____
Musculoskeletal disease	Yes ____	No ____

5) Have you had an injury to any of the following joints in the past 12 months? If so, please describe the nature of the injury.

Ankle Yes _____ No _____

Description ____

Knee Yes ____ No ____

Description ____

Hip Yes ____ No ____

Description ____

6) Have you ever experienced any of the following?

Concussion	Yes ____	No ____
Recurrent inner ear infection	Yes ____	No ____

The Seattle RAPA:

Vigorous activities

-your heart rate increases a lot

-you can't talk or your talking is broken up by large breaths

Moderate activities

-your heart beats faster than normal

-you can talk but not sing

Light activities

-Your heart beats slightly faster than normal

-You can talk and sing

Physical Activities are activities where you move and increase your heart rate above its resting rate, whether you do them for pleasure, work, or transportation.

The following questions ask about the amount and intensity of physical activity you usually do.

The intensity of the activity is related to the amount of energy you use to do these activities

	Yes	No
1. I rarely do any physical activity		
2. I do some **light** or **moderate** physical activities, but not every week.		
3. I do some **light** physical activity every week.		
4. I do **moderate** physical activities every week, but less than 30 minutes per day, 5 days per week.		
5. I do **vigorou**s physical activities every week, but less than 20 minutes per day, 3 days per week.		
6. I do 30 minutes or more per day of **moderate** physical activities, 5 or more days per week.		
7. I do 20 minutes or more per day of **vigorous** physical activities, 3 or more days per week.		
8. I do activities to increase muscle **strength**, such as lifting weights or calisthenics, once a week or more.		
9. I do activities to improve **flexibility**, such as stretching or yoga, once a week or more.		

APPENDIX D

REVIEW OF LITERATURE

Whole body vibration (WBV) exercise has recently gained attention as a means of mechanical training stimulus for enhancing muscular performance in various populations, including competitive athletes [1-4], the physically active [3, 5-10], sedentary individuals [11-14], and older adults [12, 15-17]. Both acute and chronic exposure to WBV have been associated with gains in strength [6, 9, 11-13, 17], jump height [3, 5, 6, 8, 9, 11-14, 18, 19], power [16], and balance [9, 20]. The purpose of this literature review is to summarize and evaluate the current evidence regarding WBV and its potential to enhance resistance training. Specific topics of focus in this review include the theorized neural mechanisms that underlie vibration training, as well as the existing experimental and clinical evidence associated with WBV and the facilitated development of neuromuscular strength and power, and balance.

Neural Mechanisms

There are several theories on how WBV elicits an effect on muscular performance. Gains in force generating capacity in the first few months of training have been attributed to neural factors, namely an increased sensitivity of the stretch reflex that is responsible for initiating involuntary muscular contractions [12, 21]. Bongiovanni et al anesthetized the peroneal nerve, switching off γ-motor fibers, and then had subjects perform a 60 second maximal isometric contraction. The anesthetized condition produced a decrease in force and electromyographic (EMG) activity when compared to a normal contraction. Due to the nerve block, the involved motor units were not capable of firing at a high frequency or generating force due to the lack of feedback from the 1a-afferents [22]. Stimulation of the 1a-afferent via the muscle spindle results the facilitation of the associated α-motor neurons [21]. This 1a-afferent feedback has been shown to have an important effect on development of force [22].

Whole body vibration has been hypothesized to enhance the efficiency of the stretch reflex by lowering the excitation threshold of the muscle spindles [23]. Vibration is also thought to stimulate 1a afferents through the muscle spindle as well, resulting in a facilitation of the associated motor neurons [21] through the stretch reflex. This stretch reflex is thought to be an important contributor to the generation of explosive force through a mechanism known as the stretch-shortening-cycle (SSC) [24]. This model assumes that a short stretching phase takes place in activities such as walking, jumping and running. The elastic properties of muscle and tendon combine with the reflexive facilitation of α-motor neurons caused by 1a-afferents to produce a concentric contraction of the muscle that immediately follows the stretch [25]. The ability to generate power during the SSC is dependent on a precise interaction of several mechanisms. Pre-activation of the muscle is initiated by the central nervous system before ground contact [26], increasing the stiffness of the muscle and decreasing the amount of lengthening in the muscle upon contact [27]. Simultaneous stretch reflex activity serves to enhance the actual force production by the muscle, releasing the elastic energy that has been stored in the tendons of the active muscle [28, 29].

The tonic vibration reflex (TVR) is a sustained contraction of a muscle that is subjected to vibration, and is thought to involve the muscle spindles that detect stretch. Bongiovanni and Hagbarth [30] established that the TVR can briefly intensify EMG activity and force of a random isometric contraction, but this effect disappears soon after the contraction reaches maximal levels. The TVR may play a role in muscular fatigue, as the excitatory effect of vibration disappears and becomes strongly inhibitory under prolonged vibration of the tendon of the ankle dorsiflexors [30]. According to these findings, the facilitating effects of vibration are only present when there are few repetitions because vibration has a larger inhibitory effect with a greater number of repetitions.

Clinical and Experimental Applications of Vibration

Modes of Vibration Training

Vibration training constitutes a mechanical stimulus that enters the human body in a number of different ways. Vibration can be applied through the hands by gripping a dumbbell, bar, or pulley system; through the feet while standing on a vibrating platform; or directly applied to the belly or tendon of the target muscle. Platforms are the most common form of vibration exercise, and they come in two varieties. Vertical platforms vibrate in a vertical direction and oscillating platforms vibrate via rotation about a horizontal axis such that distances that lie further from the fulcrum result in larger vibration amplitudes [31]. Two recent meta-analyses [32, 33] determined that oscillating platforms elicited a greater effect size (ES) for acute strength (ES =.24) when compared to vertical platforms (ES = -.07). However, vertical vibration platforms compare favorably to conventional resistance training regarding chronic strength improvements. This difference may be due to prescription of lower frequency vibrations, lower exercise volumes, and shorter training durations in studies in which oscillating platforms were used [33]. Vertical platforms have the ability to operate in higher frequency ranges (30 Hz to 50 Hz) and apply the vibration stimulus in a symmetrical fashion to both legs. In contrast, oscillating platforms operate in lower frequency ranges (5 Hz to 30 Hz) and apply an asymmetrical perturbation of the legs. According to Abercromby et al [31], vertical vibration platforms transmitted between 71% to 189% more mechanical energy to the upper body and head during squatting exercises when compared to oscillating platforms.

Vibration stimulus is often characterized by frequency and amplitude, which can be applied in different combinations. A linear increase in treatment effect exists between frequency and strength improvements with vibration, as frequencies between 40 to 50 Hz are associated with the largest strength gains [33]. In contrast, power development capabilities of vibration did not increase linearly with increased vibration frequency; rather, the optimal range was between 35 to 40 Hz, as frequencies above and below this range were shown to be less effective [32]. Larger amplitudes are also associated with greater improvements in strength and power after vibration training. Amplitudes below 6 mm do not result in large treatment effects for power development [32], and small amplitudes (2-6 mm) showed smaller treatment effects than larger amplitudes (8 to 10 mm) [33].

Short Term (Acute) Effects of Whole Body Vibration

Rehn et al [34] defined short term vibration exercise as an assessment of muscular performance immediately after of a single bout of vibration stimuli, usually 1-5 minutes long [3, 6, 9, 35-39]. Bouts of acute exposure to vibration training have been shown to increase muscle strength and power [1, 2, 5, 9, 40-44], flexibility [3, 42, 45], neural activity [2, 5, 10, 46-48], as well as plasma concentrations of growth hormone and testosterone [6]. Brief periods of WBV have also been shown to improve vertical jump performance [3, 6, 9, 18, 19] and body balance [9, 49].

Acute Whole Body Vibration and Power

One of the earliest inquiries into the performance enhancing effects of vibration was conducted by Bosco et al in 1999 [1]. In this study, 12 boxers received 5 sessions of vibration training (30 Hz, 6 mm, 34 m/s^2) that lasted 1 minute each on one of their arms, while their other arm was not vibrated. The vibrated arm was in a semi-flexed position while a 2.8-kilogram weight was lifted during the vibration training. The power generation in the vibrated arm increased approximately 12%, while the non-vibration trained arm did not show an increase in power [1]. This difference was speculated to be the result of lowering the excitation threshold of the reflexes, thus producing increased efficiency in movement as evidenced by an improvement in the EMG/power ratio that was only observed in the vibrated arm ($p<0.01$) [1].

Further confirmation of increased neuromuscular efficiency occurred in a subsequent study involving 14 female volleyball players who had one leg exposed to vibration (26 Hz, 10 mm, 54 m/s^2) for 10 sessions of 1 minute with a 1 minute rest period between bouts of vibration [2]. The vibration treatment was administered with the participants standing in a plantar-flexed position with the knee flexed to 100 degrees. Significant acute increases in average power per kilogram of body weight, average velocity, and average force were observed in the experimental leg compared to the control. The researchers argued that vibration training caused the same improvements in neuromuscular efficiency that occur during explosive weight training due to similarities in the training stimulus [2]. Increases in the power of gravity are used as a stimulus for neuromuscular enhancement of power during explosive training, namely activities such as continuous jumping or jumping from height. Similarly, vibration training creates large amounts of acceleration on the body, thereby increasing the amount of force on the body and causing a rapid adaptation through training.

In 2009, Rhea and Kenn [44] examined the effect of acute WBV on lower body power output in male college athletes (n= 16) performing body-weight squats. Participants were randomly assigned to groups had their lower body power during the back squat exercise measured before and after the treatment, either passive rest for 3 minutes in a seated position or 2 minutes rest followed by 30 seconds of dynamic, body-weight squats on a WBV platform (35 Hz, 4 mm) followed by 30 seconds of seated rest. The WBV significantly increased post-test squat power ($p < 0.05$, 5.2%) compared to the passive rest condition (.55%). The authors hypothesized that increased activation and synchronization of the muscle tissue due to vibration may have accounted for the increased power output [44]. This increase may potentially occur due to interactions with the stretch reflex, in which a heightened sensitivity of the reflex is thought to enhance power output [50].

Acute WBV and Muscular Strength

In 2002, Torvinen et al investigated the acute effects of WBV on muscle performance and body balance [9, 35]. Sixteen volunteers (8 men, 8 women) aged 18 to 35 years underwent both vibration (15-30 Hz, 2 mm) and sham treatments (standing on a WBV platform that was not vibrating) in a randomized order on different days. Six measures of physical performance—stability platform, grip strength, isometric extension strength of the leg extensors, tandem walk, vertical jump, and shuttle run—were obtained at baseline and again at 2 minutes and 60 minutes post-intervention. The vibration treatment induced a 3.2% benefit in isometric leg extension strength (p= 0.02) after 2 minutes, but these improvements disappeared 60 minutes after vibration exposure [9].

Ronnestad [40] recently quantified the acute effects of different vertical vibration frequencies on one repetition maximum (1-RM) for the half squat in 16 men (n=13) and women (n=3) between the ages of 19 to 33. These subjects were then divided into two groups based on training status, an untrained group (n=8, 5 male, 3 female) and a trained group (n=8, all male). All subjects performed 1-RM tests while being randomly exposed to three different WBV frequencies (20 Hz, 35 Hz, or 50 Hz, 3 mm), or no vibration. All half squats were performed on a Smith machine to avoid balance problems, in similar fashion to earlier methods used by the author [8]. The high frequency 50 Hz condition produced higher gains in 1-RM than all others, with the untrained subjects displaying a larger gain in 1-RM than the recreationally trained subjects. In addition, the 20 and 35 Hz frequencies had no impact when compared to the no vibration condition [40]. Based on these results, the author concluded that if the main goal of WBV is to increase the amount of stimulus to the neuromuscular system, then larger frequencies must be used to create a larger amount of overload [40]. These findings were similar to those of Issurin et al [51], who found that heavy strength training was enhanced by vibration (44 Hz, 3 mm) in regard to maximal force development.

In 2010, McBride et al examined the effect of an acute bout of WBV on muscle force output and motor neuron excitability of the triceps surae complex in recreationally trained males between the ages of 18 and 27 [41]. The participants were randomly assigned to either WBV (30 Hz, 3.5 mm) or sham treatments and participated in 4 separate testing sessions separated by 24 to 72 hours. Sham treatments consisted of the same treatment protocol exercises on the same vibration platform, but did not receive the vibration treatment. The first session was a familiarization session in which all participants performed 3 maximal voluntary contractions (MVC) of the triceps surae complex and learned the treatment protocol exercises. The next 3 sessions tested motor neuron excitability, peak force, rate of force development, and average integrated electromyography during MVC. Data collections were taken before treatment, then immediately, 8 minutes, and 16 minutes after treatment. Significant increases ($p \leq .05$) in peak force during MVC were observed in the WBV group immediately after (9.4%) or 8 minutes after (10.4%) treatment. No significant changes were observed in rate of force development, motor neuron excitability, or muscle activity in either the WBV or sham group [41].

Acute Whole Body Vibration and Flexibility

A study of 18 elite female field hockey players (age 21.8 ± 5.9 years) by Cochrane and Stannard used 3 intervention periods of WBV (26 Hz, 6 mm), cycling, and control to quantify the effect of WBV on countermovement vertical jump and flexibility [3]. The WBV group performed a sequence of 6 positions (standing, isometric squat, kneeling with hands on the platform, squatting at a tempo of 2 seconds up and 2 seconds down, and lunge positions for with each leg on the platform), and the control group performed the same sequence without the vibration stimulus. The WBV group displayed an 8.2 ± 5.4% ($p < 0.05$) increase in flexibility when compared to the control (5.3 ± 5.1%) and cycling (5.3 ± 4.9%) groups [3]. The authors proposed that WBV may replicate a warm up effect by increasing pain threshold, blood flow, and muscle elasticity [3].

Gerodimos et al [45] investigated the effects of several different WBV protocols on flexibility and squat jump performance. The first portion of this study evaluated the effect of vibration amplitude using 25 female participants assigned to a control group or one of three vibration amplitudes: 4 mm, 6 mm, and 8mm. The frequency was set at 25 Hz for all vibration groups. Flexibility was improved ($p<0.01$) immediately after exercise and at 15 min post exercise in all amplitudes while remaining unchanged in the control group [45]. The second portion of the study evaluated the effect of manipulating vibration frequency in eighteen female participants. These participants were divided into a control group and 3 frequency groups: 15 Hz, 20 Hz, and 30 Hz at 6 mm deflection for each of the given frequencies. Flexibility was improved ($p<0.01$) for all three vibration frequencies immediately after and at 15 minutes post exercise; however, there were no significant changes for squat jump performance observed at any of the chosen amplitudes or frequencies [45].

Bunker et al [42] examined the efficacy of WBV to increase flexibility and power during an active golf warm up. Ten adult males (45 ± 15 yr) performed a dynamic WBV warm up between sessions of 7 golf drives. Each performed their own personal warm up followed by a functional movement squat test and sit and reach test before hitting the first set of balls. The golfers were then taken through a bout of WBV (50 Hz, 2 mm, 30 seconds per exercise x 8 exercises) stretching exercises, performed the functional movement squat test and sit and reach test again, then rested for 3 minutes before hitting 7 more balls with their driver. Significant changes ($p<.05$) were observed in the sit and reach (+8.00 ± 3.37 cm), ball speed (+1.53 ± 1.82 m/s), carry distance (+9.72 ± 11.86 m), and total distance (+10.05 ± 11.59 m) [42]. The authors concluded that WBV was a quick, efficient way to improve flexibility and power output in recreational golfers [42].

Jacobs and Burns [52] recently evaluated the acute effects of WBV on muscular strength, flexibility, and heart rate in 20 adults who had been previously untrained with WBV. An oscillating vibration treatment was performed with the participants standing upright on the vibration platform for a total of 6 minutes with the feet 16 cm to either side of the axis of rotation. The vibration frequency was increased from 0 to 26 Hz for the first minute, and the 26 Hz frequency was maintained for the remaining 5 minutes of the treatment protocol. The vibration was compared to 6 minutes of cycle ergometry where the power was increased gradually from 0 to 50 W over the first minute and maintained at 50 W for the remainder of the treatment period.

Jacobs and Burns monitored heart rate continuously over the exercise period and recorded immediately before and after each of the 6-minute exercise protocols [52]. The sit-and-reach box test was used to assess flexibility, and a Biodex System 2 isokinetic dynamometer was used to evaluate isokinetic torque produced by concentric actions of the knee extensors and flexors at 120°/sec. Heart rate increased significantly ($p < 0.05$) in the cycle condition (24.7 beats per minute, 29.5%) when compared to the WBV (15.8 beats per minute, 19.3%); however, significant gains in flexibility ($p < 0.05$) and isokinetic knee extension torque ($p < 0.05$) were observed in the WBV condition when compared to the cycle condition. Knee flexion torque increased in the both groups, and although a trend towards greater increased in peak torque were observed in the WBV group, it was not statistically significant ($p = 0.10$). The authors concluded that WBV was able to elicit simultaneous benefits in flexibility and muscular torque without the increased cardiovascular and respiratory stresses that accompany traditional warm up activities such as cycling. Therefore, WBV may potentially serve as a simple, effective preparatory activity as compared to traditional warm up strategies that may take longer to complete [52].

Acute Whole Body Vibration and Neural Activity

In an effort to quantify the amount of muscle activity generated by WBV training, Roelants et al analyzed leg muscle activity during standard, unloaded squatting exercises on a WBV platform [47]. Fifteen young male (age, 21.2 ± 0.1 yrs) physical education students exposed to vibration (35 Hz, 2.5 mm) in 3 different positions (high squat, low squat, and 1-legged squat) and EMG activity of the vastus lateralis, vastus medialis, and gastrocnemius was recorded using surface electrodes. This same protocol was also performed without vibration as a control condition. Muscle activity was recorded for a total of 30 seconds in both conditions over 4 sets of each type of exercise with a 1-minute rest provided between the sets. WBV resulted in significantly higher ($p < 0.05$) muscle activity in all muscle groups and all exercises when compared to the control, and the one-legged squat produced a significantly higher ($p < 0.05$) amount of muscle activity when compared to the high and low squat exercises [47].

In 2010, Marin et al [10] examined the effects of different WBV magnitudes on elbow extension performance. Recreationally active men (n=14) and women (n=6) performed one session per week for 5 weeks, the first being instruction to 1-RM testing for elbow extension on a cable pulley, the second to assess elbow extension 1-RM, followed by 3 testing sessions to assess the effects of different WBV conditions on the number of repetitions performed, mean velocity of repetitions, and perceived exertion during exercise. The conditions included: high magnitude (50 Hz, 2.51 mm, 95.55 m/s^2), low magnitude (30 Hz, 1.15 mm, 20.44 m/s^2), and a control session in which elbow extensions were performed without vibration. The total number of repetitions performed was significantly greater ($p \leq 0.05$) in both high (21.5%) and low magnitudes (18.1%) compared to the control, the average velocity of repetitions was significantly faster ($p \leq 0.05$) in the high magnitude condition in comparison to the low magnitude and control conditions [10]. The authors concluded that high magnitude vibration was more effective in generating neuromuscular facilitation than low magnitude vibration, and that WBV applied to the feet can result in improved performance of upper body musculature [10].

Another 2010 study by Eckhardt et al [46] evaluated the ability of WBV to enhance myofibril recruitment during exhaustive squatting exercises in recreationally active, non-resistance trained men (n=14). All subjects participated in 2 familiarization sessions to determine the load necessary to cause exhaustion after 10 repetitions and to acclimatize to squatting on the vibration plate. After 7-10 days without any knee extension exercise, participants performed one session of conventional squats and one session of WBV squats in randomized order, one week apart. Outcome measures were taken using three isometric leg press MVC's lasting 5 seconds each at 90° knee flexion and were recorded with a 5 minute rest interval between MVC's to determine maximal electromyographical (EMG) activity in the vastus lateralis during development of the MVC. In the training sessions, participants performed 5 sets of 10 squats with an additional barbell load equal to the participants' 10 RM. Each set was separated by a 3 -minute rest period, and the squats were performed rhythmically at 3 seconds per squat, controlled by metronome. The WBV was applied in an oscillating fashion (22 Hz, 4 mm) using the same protocol that was used for the conventional resistance exercise. EMG activity increased significantly ($p < 0.01$) for the WBV condition (approximately 11%) during each set of squats, but there were no significant differences in MVC between the WBV and conventional resistance exercise groups. The authors concluded that the results provided strong evidence that WBV added to conventional heavy resistance exercise enhanced muscle fiber recruitment, which is a proposed mechanism for improved muscular strength and power following WBV [21, 53, 54].

Hazell et al [48] examined the effect of the addition of a light external load on enhancing WBV induced increases in muscle activity during dynamic squatting. Recreationally active male students who had not participated in resistance training for 4 months prior to the study (n=13) had the EMG activity of the vastus lateralis, biceps femoris, tibialis anterior, and gastrocnemius recorded as they performed dynamic squats from 90° to 160°. The load provided was 30% of the participant's body weight applied through a standard Olympic lifting bar, and all WBV was applied at 4 mm amplitude. The WBV and load were manipulated to form 8 conditions that were randomized within and between subjects: No vibration with and without a load, and well as 25, 35, or 45 Hz vibration performed with and without a load. Seven squats were performed at a 2 second cadence, aided by the use of metronome to provide consistency, with a 5 minute rest period between conditions to prevent fatigue. The vastus lateralis displayed significant main effects for vibration ($p = 0.004$) and load ($p < 0.001$), but there was no significant interaction between vibration and load. The 45 Hz condition also significantly increased ($p = 0.017$) muscle activity in the vastus lateralis when compared to the 25 Hz condition. Similar results were observed in the biceps femoris, with the 45 Hz condition eliciting significantly higher muscle activity compared to the no vibration squats ($p < 0.001$), 25 Hz squats ($p < 0.001$), and 35 Hz squats ($p = 0.031$). The tibialis anterior demonstrated a significant 2-way interaction between vibration and load ($p = 0.03$), and a main effect for load resulting in a decrease in activity ($p = 0.008$), but not vibration ($p = 0.08$). The gastrocnemius showed no significant interaction between vibration and load ($p = 0.15$), though main effects were observed for vibration ($p < 0.001$) and load ($p = 0.01$). The 45 Hz condition significantly increased the amount of muscle activity compared to the no vibration ($p < 0.001$) and 25 Hz condition ($p = 0.042$), and all vibration conditions increased gastrocnemius muscle activity compared to the no WBV condition (45 Hz, $p < 0.001$; 35 Hz, $p = 0.03$; 25 Hz, $p = 0.03$). Based on the results, the authors concluded that WBV exposure results in a similar increase in muscle activity during both unloaded and loaded squats, and that the addition of a light external load to dynamic squats with WBV increases the intensity of the exercise being performed [48].

Acute Whole Body Vibration and Balance

The 2002 Torvinen study [9] also evaluated the effects of vibration (15-30 Hz, 2 mm) on balance. The vibration treatment induced 15.7% improvement in body balance ($p = 0.049$) after 2 minutes; however, like the gains in isometric leg extension strength, these improvements also disappeared 60 minutes after vibration exposure [9]. In contrast, a 2010 study by Carlucci et al [49] evaluated the acute effects of a single vibration session on balance control in 22 healthy elderly women. This study measured balance at baseline and immediately, 15 minutes, and 60 minutes after the vibration intervention. The interventions consisted of a series of static and dynamic knee extensor exercises lasting 60 seconds each with 30 seconds of rest in between. These exercises were performed in two different sessions, one with WBV and one without WBV, with the treatments administered in random order 3 days apart from each other. The authors found that there were no significant differences in the recorded postural parameters, which contradicts the findings of Torvinen et al [9]. Carlucci et al attributed these differences to the type and frequency of vibration chosen for the intervention (oscillating vs. vertical) [49].

Acute Whole Body Vibration and Jump Height

Several studies have found that WBV enhances jump height. In the aforementioned 2002 Torvinen study [9] the vibration treatment induced 2.5% net benefit in jump height ($p= 0.019$) that did not persist past 60 minutes after exposure.

Similarly, in Cochrane and Stannard's 2005 study [3] The WBV group displayed an 8.1 ± 5.8% increase in countermovement jump height ($p < 0.001$).

Vibration training has also been linked to increases in the hormonal levels after a brief period of exposure. Circulating testosterone levels have been linked to increases the number or size of motor endplates that are responsive to acetylcholine in muscle [55]. Testosterone levels have also been positively correlated with improved countermovement jump height and average running speed [56]. Bosco et al evaluated acute responses of plasma concentrations of testosterone, growth hormone, and cortisol and neuromuscular performance in response to WBV in young men ($n = 14$, mean age 25 ± 4.6 years)[6]. WBV treatment (26 Hz, 4 mm, 17 m/s^2) was applied in 10 bouts lasting 60 seconds each, with a 60 second rest in between each treatment and a 6-minute rest after 5 treatments. This small amount of WBV stimulus was sufficient to increase leg power during maximal leg press exercise ($p=0.03$) concurrent with decreased EMG activity in the leg extensor muscles during the test ($p = 0.008$). An increase in countermovement jump height (36.2 ± 5.2 cm to 37.5 ± 5.1 cm, $p < 0.001$) was also observed following WBV. Blood concentrations of testosterone and growth hormone increased while cortisol levels decreased after treatment with WBV as well ($p = 0.026$ and $p = 0.014$, respectively), which may be responsible for influencing neural structures [55, 56] that allow for enhanced leg power and countermovement jump height [6].

In 2010, Lamont et al examined the effect of WBV on jump performance in college-aged, recreationally resistance trained men [19]. Testing sessions were done over two days with at least 48 hours in between, with two conditions per testing session divided by a 20-minute rest period. The WBV was applied at 30 Hz with a 2-4 mm amplitude or 50 Hz with a 4-6 mm amplitude, and either 30 continuous seconds or 3 exposures of 10 seconds with a minute between sets of vibration. Three countermovement jumps were performed before WBV, then again at 2 minutes, 7.5 minutes, and 17 minutes post WBV. There were no significant differences observed between condition or jump for countermovement jump height, but an analysis of percentage of change of countermovement jump height demonstrated a significant interaction (mean = 4.12%, p=0.009) between the high amplitude WBV applied at 50 Hz for 3 sets of 10 seconds and the low amplitude WBV applied at 30 Hz for 30 continuous seconds on the third jump [19]. The authors surmised that the higher frequency WBV condition may have caused higher 1a afferent discharge rates due to supercompensation within the stretch and H-reflexes. They also suggest that intermittent dosages may decrease the amount of fatigue relative to postactivation potentiation, and that repeated dosages of as little as five seconds may be enough to facilitation performance in the stretch-shortening cycle [19].

Long Term (Chronic) Effects of Whole Body Vibration

Long-term vibration exercise is defined as an assessment of muscular performance after regular vibration exercise [34]. Vibration studies that fall into this category have had a variety of durations, a range from 9 days to 18 months in the length of the intervention [57]. Training periods within this range have been shown to improve lower limb strength [8, 11-13, 17, 52, 58-60], power [5, 16, 61, 62], flexibility [52, 63], jump height [5, 8, 11, 13, 14, 18, 58, 60, 61], movement velocity[58], and balance [13, 20, 64, 65], although not all studies have produced significant changes in these outcome measures [4, 7, 15, 19].

Chronic Whole Body Vibration and Power

Bosco et al [5] conducted one of the first studies of chronic training adaptation due to vibratory stimulus. Fourteen physically active subjects volunteered to participate in a 10 day study in either one of two groups: experimental (age 20.4 ± 1.1) or control (age 19.9 ± 0.7). The experimental group was exposed to WBV (26 Hz, 10 mm, 54 m/s^2) for 5 series of vibrations lasting 90 seconds each every day for 10 consecutive days. Over this time, the duration of the vibration stimulus was increased by 5 seconds every day until a maximum of 2 minutes vibration exposure. Rest periods of 40 seconds were given in between each series of exercise. The control group was untreated and asked to maintain their typical activities. After the treatment period countermovement jump height and mean power output were significantly higher ($p< 0.05$) in the experimental group compared to the control group. The authors concluded that WBV elicited a biological adaptation that was similar to the effect produced by a power training regimen consisting of jumping and bouncing exercises [5].

In 2003, Russo et al [16] investigated the effects of WBV on muscle power and bone characteristics in a randomized clinical trial involving 29 postmenopausal women. The intervention group in this study stood on an oscillating WBV platform (28 Hz) for three 2-minute sessions, twice weekly for six months, while the control group did not receive any exercise intervention. Muscular power was shown to have increased by approximately 5% in the intervention group when compared to the control group (p=.004), leading to the conclusion that vibration exercise is a safe, feasible, and effective intervention for preventing a decline in muscle power in postmenopausal women [16].

A 2009 study by Lamont et al [61] evaluated the effects of a 6-week periodized squat training program with and without WBV on jump height and power output. Thirty resistance trained male participants between the ages of 18 and 30 years were randomly assigned to 1 of 3 groups: control, squat training with vibration, or squat training. The squat training and squat training with vibration groups performed 12 workouts of 3 to 5 sets of back squats at 50-90% 1-RM. Testing was performed at baseline (week 1) , mid-training (week 3), and post-training (week 7), and included 1-RM Smith machine back squat, 30-cm depth jumps, and 20 kg squat jumps. Jump height was calculated from flight time using a switch mat for all jumps and power during the upward, concentric phase of the depth and squat jumps was recorded using a linear accelerometer. The periodized training program of Smith machine back squat exercises was administered twice per week, each separated by 72 hours. The first 3 weeks were intended to develop strength, with loads ranging from 55-90% of the participants' 1-RM for 3-4 sets of 3-5 repetitions, while the final 3 weeks were designed to develop power, using loads from 55-85% of 1-RM for 3-4 sets of 5-6 repetitions. Four minutes of rest were allowed in between all sets of exercise. The WBV group was exposed to vibration (50 Hz, 2-4 mm) for 30 seconds prior to the first set of squat exercises, with a 3-minute rest between vibration and the first set of squats. Ten second bouts of vibration (50 Hz, 4-6 mm) were then applied intermittently at 60, 120, and 180 seconds into the rest periods between sets, while the squat training group sat down for the entire 4-minute inter-set rest period. After 6 weeks of training, significant differences (p=0.034) between maximal power output were observed between the squat and squat with vibration groups. Though significant group differences were not seen in squat jump height, there was an observed trend favoring squats with vibration over the squat and control groups, possibly due to high variability between participants [61]. The authors propose that the addition of WBV before and in between sets of resistance exercise may aid in the facilitation of neuromuscular adaptation, leading to improved performance [61].

Chronic Whole Body Vibration and Muscular Strength

In 2002, Torvinen, et al evaluated the effects of four months of vertical WBV on muscular performance and balance [13]. This randomized controlled study involved 56 young, healthy, non-athletic adults; half of whom were subjected to vibration training for four minutes per day, 3-5 times per week for a four-month period while the other half served as a control group. Performance measures were taken at baseline, two, and four months and included countermovement jumps, postural sway, grip strength, a shuttle run, and maximal isometric strength of the leg extensors. Lower limb extension strength increased by 3.7% after 2 months ($p=0.034$), but these gains diminished by the end of 4 months in the WBV condition. However, vertical jump height increased significantly after 2 months ($p = 0.001$) and after 4 months ($p=0.001$) in the vibration group when compared to the control group [13].

Similar training effects were seen in knee extensor strength after 12 weeks in a group of younger women (mean age 21.4 ± 1.8 years). Delecluse et al [11] compared unloaded WBV squatting exercises (35-40 Hz, 2.5-5 mm, 22.3-49.9 m/s^2) to resistance training, placebo vibration, and a control group. They found similar increases in both isometric and dynamic knee extensor torque after the training period, while the control and placebo groups did not improve in either measure. However, only the WBV trained group improved in the countermovement jump ($p<0.001$), which was used as a measure of explosive strength. These authors concluded that WBV provokes the stimulation of propriospinal pathways, resulting in a increase in muscle activity and a subsequent strength gains [11].

Longitudinal WBV training has been shown to be a safe, effective means of increasing strength in older women. Roelants et al demonstrated significant gains in isometric and dynamic knee extensor strength and speed of movement (n=89, $p<0.001$), countermovement jump height ($p<0.001$) in post-menopausal women who performed unloaded lower body exercises in combination with WBV after training 3 times per week for 24 weeks [58]. This study directly compared unloaded WBV exercise to traditional resistance training exercise and found that no significant difference existed between the WBV and resistance training groups. Most of the strength gains observed in the treatment groups happened in the first 12 weeks of training, which suggests that neural adaptation was responsible for the increase. Since early strength gains in traditional resistance training have been attributed to neural and intramuscular adaptations [66], the comparable increases in strength shown in the two treatment groups led the authors to conclude that the WBV training had an effect on the neuromuscular system similar to that of traditional resistance training [58].

Roelants et al investigated the effects of WBV training in young women, comparing static and dynamic exercises performed on a WBV platform (40 Hz, 2.5-5 mm) to a fitness group that followed a standard cardiovascular and resistance training program and a control group [12]. Both of the exercise groups trained 3 times per week for 24 weeks. Outcome measures for the study included isometric (0°/sec) and isokinetic knee extension strength (50°/sec, 100°/sec, 150°/sec), and after 24 weeks the WBV group and fitness group both experienced significant gains in isometric strength and all three isokinetic speeds tested. The authors concluded that strength gains due to WBV exercise were comparable to those elicited by the traditional fitness-training program [12].

The performance enhancing effects of squatting exercises with and without vibration were examined in a 2004 study by Ronnestad [8] that attempted to combine conventional resistance training with WBV to examine the additive effect that the synergy between the two may have. Fourteen recreationally resistance trained men (age, 21 to 40 yrs) were randomly assigned to two groups that performed squatting exercises on a Smith machine either with or without WBV. Participants performed 13 training sessions on non-consecutive days over a 5-week period, and assessments of 1 repetition maximum (1-RM) and jump height were measured at baseline and after training. Both groups increased the 1-RM of the squat, and there was a trend towards greater relative strength increase in the WBV group compared to the non-WBV group, but this trend did not reach statistical significance. Similar trends were seen in jump height, as the WBV squat group were the only ones who significantly improved ($p<0.01$), though there was no significant difference between groups in relative jump height increase ($p=.088$) [8].

Verschueren et al [17] evaluated the musculoskeletal effects of high frequency loading through WBV on 70 postmenopausal women. Volunteers were randomly assigned to one of 3 conditions: a control group, a WBV training group, or a resistance-training group, with the latter two training 3 times per week for 24 weeks. The WBV group performed static and dynamic exercises for the knee extensors on a vibration plate (35-40 Hz, 1.7-2.5 mm), while the resistance group performed dynamic leg press and leg extension exercises. Both exercise groups improved dynamic and isometric knee extensor strength after 6 months of training when compared to the control group, though the WBV group did not seem to improve to a greater extent than the resistance-training group. The authors concluded that their 24 week WBV program was feasible and able to modify muscular strength and balancing abilities in healthy, postmenopausal women [17].

Delecluse et al [4] examined the effect of adding WBV training to the conventional training of sprint-trained athletes. Twenty athletes were randomly assigned to either a WBV group or a control group for a 5-week experiment. All participants continued their normal training program, but the WBV group performed static and dynamic exercises on a vibration plate (35-40 Hz, 1.7-2.5 mm) 3 times per week in addition to their conventional training. Isometric and isokinetic (100°/s) strength of the knee flexors and extensors was assessed using a dynamometer, and vertical jump performance was measured using a contact mat. After 5 weeks, no changed were observed in any of the outcome measures, leading the authors to conclude that this specific vibration protocol had no added effect on the training program of sprint trained athletes [4].

In 2010, Fernandez-Rio et al [59] investigated the long term effects of WBV training on force production in female basketball players (n=31). All participants were randomly assigned to either the vibration group or a control group for the duration of the 14-week training in-season training program. All participants followed the same strength-training program, but the vibration group (30-35 Hz, 4 mm) performed 3 extra vibration exercises (half squat, half squat with weight on toes, calf raise) twice weekly for 30-60 seconds. After 14 weeks the assessed values for squat jump, countermovement jump, 15-second jump test, and squat leg power had increased significantly from baseline to endpoint, but no additional effect from the WBV was seen for any of the performance measures [59]. The authors do mention that all the participants in the vibration group had the same vibration loading, unlike conventional strength training programs where the workload is individualized for each athlete. Due to this, they propose that perhaps WBV training should also be prescribed in a similar fashion in order to induce optimal effects [59].

Colson et al [60] recently measured the effects of 4 weeks of WBV training added to the conventional training of 18 competitive basketball players during their preseason, randomly assigned to either the WBV group or a control group. All participants had been competing regularly in basketball for a minimum of 5 years, but none of them had participated in strength training or vibration exercise in the 3 months prior to beginning the experiment. The WBV training program consisted of twelve 20-minute sessions of unloaded static exercises on a vertical vibration platform (40 Hz, 4 mm), with 3 sessions performed each week. Each session was 30 seconds of WBV exposure for 2 exercises (high squat and high squat on toes) followed by 30 seconds of standing rest, totaling 10 minutes of vibration exposure per session. Outcome measures included: isometric bilateral MVC of the knee extensors, jump performance, and a 10-meter sprint. After 4 weeks, maximal bilateral isometric strength of the knee extensors increased significantly ($p < 0.001$) in the WBV group when compared to the control, as did squat jump performance ($p < 0.05$). Similar to the Fernandez-Rio study [59], the authors mention the large amount of variability in the squat jump performance, and attribute such variation to potential individual differences other than gender or training status [60].

Chronic Whole Body Vibration and Flexibility

In a 2010 randomized control trial, Feland et al [63] examined the relationship between hamstring stretching with WBV on effectiveness and retention of changes in flexibility. Recreationally-active college age subjects (n= 34) were randomly assigned to a control group, a static stretch group, or a vibration and static stretch group. All participants stretched 5 days per week for 4 weeks, followed by a 3-week cessation period after treatment to monitor retention. Significant differences were observed between treatment groups ($p < 0.0001$), time ($p < 0.0001$) and gender ($p = 0.0002$), as well as a Treatment x Time interaction ($p = 0.012$). The follow-up test 3 weeks later showed that the static stretching group had returned to baseline measures, but the vibration group was still approximately 11% more flexible than at baseline. The authors concluded that stretching concurrent with WBV was beneficial in enhancing stretch on the hamstrings with the potential for longer retention of flexibility gains when compared to static stretching [63].

Chronic Whole Body Vibration and Balance

In a randomized controlled study, Torvinen et al [13] investigated the effects of 4 months of WBV training on muscular performance and balance. Fifty-six subjects aged 19 to 38 years were randomized into either the vibration group or a control group. Subjects in the WBV (25-40 Hz, 2mm, 2.5-6.4g) group were asked to train 3 to 5 times per week each day for 10 seconds in each of 6 different unloaded positions (light squatting, standing erect, standing with slightly flexed knees, light jumping, weight shifting, and standing on the heels) for a total of 4 minutes of vibration exposure each session [13]. Performance measures were taken at baseline, 2 months and 4 months, and included a countermovement jump, postural sway assessment, a 30-meter shuttle run test, and maximal isometric strength of the leg extensors. Countermovement jump height improved 10.2% after 2 months ($p< 0.001$), and a net benefit of 8.5% ($p=0.001$) after 4 months when compared to the control group. Isometric lower limb strength improved 3.7% ($p=0.034$) over 2 months, but the net benefit diminished to 2.5% ($p= 0.25$) after 4 months when compared to the control group. No differences were observed in the shuttle run or postural sway at either the 2 or 4-month tests. Despite the lack of significant changes in balance over the treatment period, the authors suggested that muscular power and strength, both of which improved as a result of the intervention, play a role in functional performance; therefore, WBV exercise might be an efficient training stimulus for individuals prone to falling [13].

Similarly, Cheung et al [20] investigated the effect of WBV training on balancing ability in 69 elderly women aged 60 and older. Participants were randomized into: WBV and no-treatment control groups. Oscillating WBV (20 Hz) was administered to the exercise group for 3 minutes per day, 3 days per week for 3 months. WBV was shown to significantly enhance movement velocity ($p< 0.01$), maximum excursion ($p< 0.01$), and directional control ($p<0.05$). These authors concluded that WBV was an effective means to improve balancing ability in elderly women, and that at little as 3 minutes per day may be sufficient to aid in maintenance of balance and fall risk reduction [20].

Another study evaluating the efficacy of WBV in synergy with other muscle strengthening, balance, and walking exercises in the walking ability of the elderly was conducted by Kawanabe et al [65]. The 2-month intervention involved 67 elderly participants divided into a 2 groups: an exercise alone group and a WBV plus exercise group in which WBV was performed at 12-20 Hz for a duration of 4 minutes, once per week in addition to the exercise protocol. After 2 months of the exercise program, walking speed, step length, and maximum single leg stance times improved significantly for the WBV plus exercise group, while no significant changes were observed in the exercise alone group. These results led the authors to conclude that WBV exercise performed in conjunction with other exercises may be beneficial in providing a safe, tolerable means for improving walking ability and balance in the elderly [65].

WBV has also been examined as a means of improving balance and gait in individuals who have Parkinson's disease [64]. Ebersbach et al compared WBV with conventional physiotherapy in a randomized, controlled trial involving 27 Parkinson's patients on dopamine replacement medication. WBV participants received two 15-minute sessions per day, 5 days per week for a total of 3 weeks followed by a follow up test 4 weeks after the end of the exercise treatment. Oscillating WBV (25 Hz, 7-14 mm) was administered to the WBV group, while the non-WBV group performed standard balance training on a tilt board in addition to the standard therapy provided to all participants. Outcome measures included a Tinetti Balance Scale score, a stand-walk-sit test, walking velocity, a motor examination score, a pull test, and dynamic posturography. All measures but dynamic posturography improved from baseline to termination of treatment in both groups; however, the WBV group had a tendency ($p<0.093$) towards reduced sway at the end of the treatment and at follow up [64]. The authors concluded that the application of WBV in combination with conventional physiotherapy was not more effective at improving equilibrium and gait in Parkinson's patients than conventional physiotherapy alone, though dose effects may have obscured any potential differences [64].

Another study examining the effect of WBV on functional capacity and muscular performance was done by Bautmans et al [15] in 2005. Twenty-four nursing home residents were randomly assigned to either 6 weeks of static WBV exercise or a static exercise only control group. Both groups were similar at baseline, but the WBV group performed significantly better at the timed-up-and-go ($p= 0.029$) and Tinetti body balance test ($p= 0.001$). The authors concluded that 6 weeks of static WBV exercise is feasible due to high compliance rates as well as being beneficial for balance and mobility.

Chronic Whole Body Vibration and Jump Height

Many of the chronic studies that have evaluated the influence of WBV on improving muscular strength and power have also used jump height as an outcome measure [5, 8, 11, 13, 14, 18, 60, 61], as previously discussed. In a 2003 randomized controlled study, Torvinen et al [14] investigated the effect of an 8-month WBV intervention on bone, muscular performance, and body balance in 56 young adults. All participants were randomly assigned to either control or WBV (25-45 Hz, 2-8 g), and the experimental group performed WBV exercise for 4 minutes per day, 3 to 5 times per week. Performance tests (vertical jump, isometric leg extension, grip strength, shuttle run, and postural sway) were administered at baseline and again at the end of the 8-month intervention. The authors found that the WBV intervention increased vertical jump height in a significant manner (+7.8%, $p = 0.003$), but had no effect on any other neuromuscular performance measures or bone strength [14].

In 2004, Cochrane, Legg, and Hooker [7] evaluated the short term chronic effects of oscillating WBV on vertical jump, sprint speed, and agility. Twenty-four men and women who participated in team sports but had little experience in power, speed, or agility training were divided into two groups, WBV or control. The WBV (26 Hz, 11 mm) group performed 9 days of treatment consisting of 2-minute exposures during 5 body positions (standing upright, squat at 90° knee angle, squat at 90° knee angle with feet externally rotated, and single leg standing at 90° knee angle for both limbs) separated by 40 seconds rest between each position. These exercises were performed for 5 consecutive days before 2 days of recovery, followed by 4 more days of exercise performance. The control group performed the same body positions and temporal routine as the WBV group, but on the floor to the side of the vibration plate. Performance outcomes included countermovement and concentric squat jumps, sprints of 5, 10, and 20 meters, and an up-and-back agility test. The authors found no significant differences in performance measures between pre-training and post-training, and concluded that the WBV treatment failed to demonstrate any neuromuscular enhancement, potentially due to the chosen exposure duration and recovery times [7].

More recently, Wyon, Guinan, and Hawkey [18] examined the efficacy of WBV training in improving vertical jump height in dancers over a 6-week period. Female undergraduate dance majors (n=18) were randomly assigned to either the intervention or control group. The intervention group held 5 positions for 30 seconds twice each on a vibration plate (35 Hz, 4 mm) 2 times per week with 2 days rest between treatments. The control group performed the same static holds, but without the vibration stimulus. Vertical jump was assessed before and after the intervention using a contact mat to measure flight time, which can then be used to calculate jump height. After 6 weeks of training, the WBV group had increased jump height significantly ($p<0.001$) when compared to the control group. The authors concluded that a minimal amount of WBV training was a beneficial way to increase jump height in dancers without increasing the overall training load [18].

Relationship between Muscular Strength and Balance

Leg movements such as balance and gait require a large amount of motor control to for efficient function during daily life activities. Training interventions designed for both athletes and orthopedic rehabilitation patients seek to improve postural control and motor performance of the leg musculature[67]. In a recent study, Beck et al attempted to determine the sites and mechanisms of long-term plasticity following lower limb muscle training by comparing two different training interventions: postural stability training and ballistic ankle strength training. Twenty-seven men and women (age range, 20 to 38 years) were allotted to either of the two treatment groups or a control. Sixteen training sessions were performed over a 4-week period, with each session lasting approximately 60 minutes. Stability training consisted of unilateral postural stabilization tasks that included a wobble board, spinning top, soft mat, and a balance pad. The ballistic training group performed four sets of 10 ankle dorsiflexion and 10 plantar flexion movements, with the contractions performed at a maximum velocity against a load of 30-40% of 1-RM. The ballistic ankle strength training group showed an increase in the recruitment of motor evoked potentials during for trained tasks, while the size of the motor evoked potentials was decreased in the postural stability group [67].

Clinical Assessment of Balance

Balance has been identified as "the single most important factor underlying movement strategies within the closed kinetic chain"[68]. Nashner and McCollum [69] identified three different operational definitions to describe postural stability: static, dynamic and functional balance. Static balance has been defined as the ability to limit the movement of the center of gravity (COG) within a fixed base of support, dynamic balance is defined as the ability to move and control the COG within a fixed base of support, while functional balance is defined as the ability to move and control the COG within a moving base of support [69].

There are three main sensory inputs that contribute to balance: somatosensory, visual and vestibular. Somatosensory input provides information about the orientation of body parts to one another and to the support surface, and integration of visual and somatosensory inputs plays a large role in the maintenance of balance [70]. The central nervous system (CNS) is responsible for organizing sensory inputs as well as the generation and execution of coordinated muscular activity [68] to maintain the body's center of gravity over its base of support [70]. Mechanoreceptors located within muscles and tendons provide the CNS with continuous, instantaneous feedback about the amount of stretch and tension on the muscle[71]. The information transmitted from the peripheral mechanoreceptors to the CNS has been suggested as having the ability to compensate for eye closure and vestibular deficiency [72-74].

In 1986, Shumway-Cook suggested a new method of sensory interaction on postural stability in the standing position, known as the Clinical Test for Sensory Interaction in Balance (CTSIB). The CTSIB was administered using a medium density foam block and a Japanese lantern modified to fit over the head of the subject. Six different combinations of "Foam and Dome" assess postural sway during the maintenance of standing balance [75]. Sway referenced balance assessment assumes that healthy subjects should ignore functionally inaccurate sway referenced sensory inputs and maintain balance by using other sensory inputs[68].

Over the past two decades the CTSIB has subsequently been altered, and a modified Clinical Test for Sensory Interaction on Balance (mCTSIB) can be performed using a computerized postural stability system (SMART Balance Master™, NeuroCom, a division of Natus®, Clackamas, OR). The mCTSIB consists of 3 trials in each of 4 conditions: (1) eyes open on a firm surface, (2) eyes closed on a firm surface, (3) eyes open on an unstable surface, and (4) eyes closed on an unstable surface [76]. The system uses a force place and allows for the assessment of the center of gravity and calculates the degrees of sway during each 10-second test. This test is primarily used during rehabilitation, and while the cause of imbalance cannot be determined [77], the mCTSIB have been shown to be useful as a means of monitoring the progress of patients over the course of treatment [78, 79].

REFERENCES

1. Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol.* Mar 1999;79(4):306-311.

2. Bosco C, Colli R, Introini E, et al. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol.* Mar 1999;19(2):183-187.

3. Cochrane DJ, Stannard SR. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *Br J Sports Med.* Nov 2005;39(11):860-865.

4. Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *Int J Sports Med.* Oct 2005;26(8):662-668.

5. Bosco C, et al. The influence of whole body vibration on jumping performance. *Biol Sport.* 1998;15:157-164.

6. Bosco C, Iacovelli M, Tsarpela O, et al. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol.* Apr 2000;81(6):449-454.

7. Cochrane DJ, Legg SJ, Hooker MJ. The short-term effect of whole-body vibration training on vertical jump, sprint, and agility performance. *J Strength Cond Res.* Nov 2004;18(4):828-832.

8. Ronnestad BR. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J Strength Cond Res.* Nov 2004;18(4):839-845.

9. Torvinen S, Kannu P, Sievanen H, et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging.* Mar 2002;22(2):145-152.

10. Marin PJ, Herrero AJ, Sainz N, Rhea MR, Garcia-Lopez D. Effects of different magnitudes of whole-body vibration on arm muscular performance. *J Strength Cond Res.* Sep 2010;24(9):2506-2511.

11. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc.* Jun 2003;35(6):1033-1041.

12. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med.* Jan 2004;25(1):1-5.

13. Torvinen S, Kannus P, Sievanen H, et al. Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc.* Sep 2002;34(9):1523-1528.

14. Torvinen S, Kannus P, Sievanen H, et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res.* May 2003;18(5):876-884.

15. Bautmans I, Van Hees E, Lemper JC, Mets T. The feasibility of Whole Body Vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial [ISRCTN62535013]. *BMC Geriatr.* 2005;5:17.

16. Russo CR, Lauretani F, Bandinelli S, et al. High-frequency vibration training increases muscle power in postmenopausal women. *Arch Phys Med Rehabil.* Dec 2003;84(12):1854-1857.

17. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res.* Mar 2004;19(3):352-359.

18. Wyon M, Guinan D, Hawkey A. Whole-body vibration training increases vertical jump height in a dance population. *J Strength Cond Res.* Mar 2010;24(3):866-870.

19. Lamont HS, Cramer JT, Bemben DA, Shehab RL, Anderson MA, Bemben MG. The Acute Effect of Whole-Body Low-Frequency Vibration on Countermovement Vertical Jump Performance in College-Aged Men. *J Strength Cond Res.* Dec 2010;24(12):3433-3442.

20. Cheung WH, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil.* Jul 2007;88(7):852-857.

21. Cardinale M, Bosco C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev.* Jan 2003;31(1):3-7.

22. Bongiovanni LG, Hagbarth KE, Stjernberg L. Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *J Physiol.* Apr 1990;423:15-26.

23. Gollhofer A, Schopp A, Rapp W, Stroinik V. Changes in reflex excitability following isometric contraction in humans. *Eur J Appl Physiol Occup Physiol.* 1998;77(1-2):89-97.

24. Ross A, Leveritt M, Riek S. Neural influences on sprint running: training adaptations and acute responses. *Sports Med.* 2001;31(6):409-425.

25. Komi PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *J Biomech.* Oct 2000;33(10):1197-1206.

26. Dietz V, Noth J, Schmidtbleicher D. Interaction between pre-activity and stretch reflex in human triceps brachii during landing from forward falls. *J Physiol.* Feb 1981;311:113-125.

27. Flitney FW, Hirst DG. Cross-bridge detachment and sarcomere 'give' during stretch of active frog's muscle. *J Physiol.* Mar 1978;276:449-465.

28. Gollhofer A, Schmidtbleicher D, Dietz V. Regulation of muscle stiffness in human locomotion. *Int J Sports Med.* Feb 1984;5(1):19-22.

29. Nichols TR, Houk JC. Improvement in linearity and regulation of stiffness that results from actions of stretch reflex. *J Neurophysiol.* Jan 1976;39(1):119-142.

30. Bongiovanni LG, Hagbarth KE. Tonic vibration reflexes elicited during fatigue from maximal voluntary contractions in man. *J Physiol.* Apr 1990;423:1-14.

31. Abercromby AF, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Vibration exposure and biodynamic responses during whole-body vibration training. *Med Sci Sports Exerc.* Oct 2007;39(10):1794-1800.

32. Marin PJ, Rhea MR. Effects of vibration training on muscle power: a meta-analysis. *J Strength Cond Res.* Mar 2010;24(3):871-878.

33. Marin PJ, Rhea MR. Effects of vibration training on muscle strength: a meta-analysis. *J Strength Cond Res.* Feb 2010;24(2):548-556.

34. Rehn B, Lidstrom J, Skoglund J, Lindstrom B. Effects on leg muscular performance from whole-body vibration exercise: a systematic review. *Scand J Med Sci Sports.* Feb 2007;17(1):2-11.

35. Torvinen S, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Kannus P. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. *Int J Sports Med.* Jul 2002;23(5):374-379.

36. Kelly SB, Alvar BA, Black LE, Dodd DJ, Carothers KF, Brown LE. The effect of warm-up with whole-body vibration vs. cycle ergometry on isokinetic dynamometry. *J Strength Cond Res.* Nov 2010;24(11):3140-3143.

37. Dabbs NC, Brown LE, Coburn JW, Lynn SK, Biagini MS, Tran TT. Effect of whole-body vibration warm-up on bat speed in women softball players. *J Strength Cond Res.* Sep 2010;24(9):2296-2299.

38. Armstrong WJ, Grinnell DC, Warren GS. The acute effect of whole-body vibration on the vertical jump height. *J Strength Cond Res.* Oct 2010;24(10):2835-2839.

39. Nepocatych S, Bishop PA, Balilionis G, Richardson MT, Hubner PJ. Acute Effect of Upper-Body Vibration on Performance in Master Swimmers. *J Strength Cond Res.* Dec 2010;24(12):3396-3403.

40. Ronnestad BR. Acute effects of various whole body vibration frequencies on 1RM in trained and untrained subjects. *J Strength Cond Res.* Oct 2009;23(7):2068-2072.

41. McBride JM, Nuzzo JL, Dayne AM, Israetel MA, Nieman DC, Triplett NT. Effect of an acute bout of whole body vibration exercise on muscle force output and motor neuron excitability. *J Strength Cond Res.* Jan 2010;24(1):184-189.

42. Bunker DJ, Rhea MR, Simons T, Marin PJ. The Use of Whole-Body Vibration as a Golf Warm-Up. *J Strength Cond Res.* Mar 10 2010.

43. Ronnestad BR. Acute effects of various whole-body vibration frequencies on lower-body power in trained and untrained subjects. *J Strength Cond Res.* Jul 2009;23(4):1309-1315.

44. Rhea MR, Kenn JG. The effect of acute applications of whole-body vibration on the iTonic platform on subsequent lower-body power output during the back squat. *J Strength Cond Res.* Jan 2009;23(1):58-61.

45. Gerodimos V, Zafeiridis A, Karatrantou K, Vasilopoulou T, Chanou K, Pispirikou E. The acute effects of different whole-body vibration amplitudes and frequencies on flexibility and vertical jumping performance. *J Sci Med Sport.* Jul 2010;13(4):438-443.

46. Eckhardt H, Wollny R, Muller H, Bartsch P, Friedmann-Bette B. Enhanced Myofiber Recruitment During Exhaustive Squatting Performed as Whole-Body Vibration Exercise. *J Strength Cond Res.* Jul 17 2010.

47. Roelants M, Verschueren SM, Delecluse C, Levin O, Stijnen V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *J Strength Cond Res.* Feb 2006;20(1):124-129.

48. Hazell TJ, Kenno KA, Jakobi JM. Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. *J Strength Cond Res.* Jul 2010;24(7):1860-1865.

49. Carlucci F, Mazza C, Cappozzo A. Does Whole-Body Vibration Training Have Acute Residual Effects on Postural Control Ability of Elderly Women? *J Strength Cond Res.* Dec 2010;24(12):3363-3368.

50. Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. *Sports Med.* 2005;35(1):23-41.

51. Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. *J Sports Sci.* Dec 1994;12(6):561-566.

52. Jacobs PL, Burns P. Acute enhancement of lower-extremity dynamic strength and flexibility with whole-body vibration. *J Strength Cond Res.* Jan 2009;23(1):51-57.

53. Jordan MJ, Norris SR, Smith DJ, Herzog W. Vibration training: an overview of the area, training consequences, and future considerations. *J Strength Cond Res.* May 2005;19(2):459-466.

54. Nordlund MM, Thorstensson A. Strength training effects of whole-body vibration? *Scand J Med Sci Sports.* Feb 2007;17(1):12-17.

55. Bleisch W, Luine VN, Nottebohm F. Modification of synapses in androgen-sensitive muscle. I. Hormonal regulation of acetylcholine receptor number in the songbird syrinx. *J Neurosci.* Mar 1984;4(3):786-792.

56. Bosco C, Tihanyi J, Viru A. Relationships between field fitness test and basal serum testosterone and cortisol levels in soccer players. *Clin Physiol.* May 1996;16(3):317-322.

57. von Stengel S, Kemmler W, Engelke K, Kalender WA. Effects of whole body vibration on bone mineral density and falls: results of the randomized controlled ELVIS study with postmenopausal women. *Osteoporos Int.* Jan;22(1):317-325.

58. Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *J Am Geriatr Soc.* Jun 2004;52(6):901-908.

59. Fernandez-Rio J, Terrados N, Fernandez-Garcia B, Suman OE. Effects of vibration training on force production in female basketball players. *J Strength Cond Res.* May 2010;24(5):1373-1380.

60. Colson SS, Pensini M, Espinosa J, Garrandes F, Legros P. Whole-body vibration training effects on the physical performance of basketball players. *J Strength Cond Res.* Apr 2010;24(4):999-1006.

61. Lamont HS, Cramer JT, Bemben DA, Shehab RL, Anderson MA, Bemben MG. Effects of a 6-week periodized squat training program with or without whole-body vibration on jump height and power output following acute vibration exposure. *J Strength Cond Res.* Nov 2009;23(8):2317-2325.

62. Bedient AM, Adams JB, Edwards DA, et al. Displacement and frequency for maximizing power output resulting from a bout of whole-body vibration. *J Strength Cond Res.* Sep 2009;23(6):1683-1687.

63. Feland JB, Hawks M, Hopkins JT, Hunter I, Johnson AW, Eggett DL. Whole body vibration as an adjunct to static stretching. *Int J Sports Med.* Aug 2010;31(8):584-589.

64. Ebersbach G, Edler D, Kaufhold O, Wissel J. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson's disease. *Arch Phys Med Rehabil.* Mar 2008;89(3):399-403.

65. Kawanabe K, Kawashima A, Sashimoto I, Takeda T, Sato Y, Iwamoto J. Effect of whole-body vibration exercise and muscle strengthening, balance, and walking exercises on walking ability in the elderly. *Keio J Med.* Mar 2007;56(1):28-33.

66. Sale DG. Neural adaptation to resistance training. *Med Sci Sports Exerc.* Oct 1988;20(5 Suppl):S135-145.

67. Beck S, Taube W, Gruber M, Amtage F, Gollhofer A, Schubert M. Task-specific changes in motor evoked potentials of lower limb muscles after different training interventions. *Brain Res.* Nov 7 2007;1179:51-60.

68. Riemann BL, Guskiewicz, K.M. Contribution of the Peripheral Somatosensory System to Balance and Postural Equilibrium. In: Lephart SM, Fu, F.H., ed. *Proprioception and Neuromuscular Control in Joint Stability*. Champaign, IL: Human Kinetics; 2000:37-51.

69. Nashner L, McCollum, G. The organization of human postural movements: A formal basis and experimental synthesis. *Behav Brain Sci.* 1985;8:135-172.

70. Nashner L. Computerized dynamic posturography. In: Jacobsen G, Newman, C., Kartush, J., ed. *Handbook of Balance Function and Testing*. St. Louis: Mosby Year Book; 1993:280-307.

71. Guyton A, Hall, J. Motor Functions of the Spinal Cord: the Cord Reflexes. *Textbook of Medical Physiology*. Philadelphia: Saunders; 2006:673-684.

72. Diener HC, Dichgans J, Guschlbauer B, Mau H. The significance of proprioception on postural stabilization as assessed by ischemia. *Brain Res.* Mar 26 1984;296(1):103-109.

73. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: a review. *Neurobiol Aging.* Nov-Dec 1989;10(6):727-738.

74. Nashner LM, Black FO, Wall C, 3rd. Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. *J Neurosci.* May 1982;2(5):536-544.

75. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction of balance. Suggestion from the field. *Phys Ther.* Oct 1986;66(10):1548-1550.

76. International N. Modified Clinical Test of Sensory Interaction on Balance Protocol. http://www.onbalance.com/neurocom/protocols/sensoryImpairment/mCTSIB.aspx. Accessed March 10, 2008.

77. Nashner LM, Peters JF. Dynamic posturography in the diagnosis and management of dizziness and balance disorders. *Neurol Clin.* May 1990;8(2):331-349.

78. Black FO. What can posturography tell us about vestibular function? *Ann N Y Acad Sci.* Oct 2001;942:446-464.

79. Cohen HS, Kimball KT. Decreased ataxia and improved balance after vestibular rehabilitation. *Otolaryngol Head Neck Surg.* Apr 2004;130(4):418-425.