

WHOLE-BODY VIBRATION AND ITS EFFECTS ON
ELECTROMECHANICAL DELAY AND VERTICAL
JUMP PERFORMANCE

by

Deja L. Stevenson

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Exercise Sciences

Brigham Young University

August 2005

Copyright © 2005 Deja L. Stevenson

All Rights Reserved

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Deja L. Stevenson

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

Date

J. Brent Feland, Chair

Date

Ty Hopkins

Date

Iain Hunter

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Deja L. Stevenson in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

Date

J. Brent Feland
Chair, Graduate Committee

Accepted for the Department

Ruel M. Barker
Chair, Department of Exercise Sciences

Accepted for the College

Gordon B. Lindsay, Associate Dean
College of Health and Human Performance

ABSTRACT

WHOLE-BODY VIBRATION AND ITS EFFECTS ON ELECTROMECHANICAL DELAY AND VERTICAL JUMP PERFORMANCE

Deja L. Stevenson

Department of Exercise Sciences

Master of Science

The purpose of this study was to determine the effects of whole-body vibration on electromechanical delay and vertical jump performance. Twenty college aged subjects participated in 10 intervals of whole-body vibration (WBV) at a frequency of 26 Hz and amplitude of 5 mm. Each interval consisted of 60 s of WBV in a half-squat followed by 60 s of rest. After 5 intervals, subjects had 6 min of rest before the final 5 intervals. Each subject also participated in the control which included the same 10 intervals in a half-squat without the WBV. Tests were conducted to assess electromechanical delay (EMD) and vertical jump at baseline, during the 6 min rest period and immediately after the treatment and control. EMD was measured using tibial nerve stimulation and a force plate. EMD was recorded as the lag time between the initiation of gastrocnemius

stimulation and plantar flexion force production. Vertical jump was measured using a force plate and subjects' flight time. The factorial ANOVA results showed no differences between groups, the control and WBV treatment, for both EMD ($F(2, 38) = 1.385, p = 0.263$) and vertical jump ($F(2, 38) = 0.040, p < 0.96$). The WBV treatment protocol chosen had no effect on vertical jump. These results suggest that WBV, using this protocol, is not effective for acute vertical jump or EMD enhancement. Also, since there was no effect on EMD, this suggests that the WBV treatment did not enhance muscle spindle sensitivity.

Key Words: Muscle spindle sensitivity

ACKNOWLEDGMENTS

First and foremost I would like to thank my husband, Mark Stevenson, and all of my family for their tremendous love, support, and encouragement. Without them behind me, cheering me on, this thesis would never have been completed. I would also like to thank all the members on my thesis committee, Dr. Brent Feland, Dr. Ty Hopkins, and Dr. Iain Hunter, for their continual assistance with the research design, methodology, and writing of my thesis. All three were completely willing to help in any way possible and I am very grateful of their thoughtfulness.

Table of Contents

List of Tables	ix
List of Figures	x
Whole-body vibration and its effects on electromechanical delay and vertical jump performance	
Abstract	2
Introduction	3
Methods	5
Results	9
Discussion	10
References	16
Appendix A Prospectus	25
Introduction	26
Review of Literature	31
Methods	45
References	51

List of Tables

Table	Page
1 Normalized EMD Data	21
2 Normalized Vertical Jump Data.....	22

List of Figures

Figures	Page
1 Normalized EMD Graph.....	23
2 Normalized Vertical Jump Graph.....	24

WHOLE-BODY VIBRATION AND ITS EFFECTS ON ELECTROMECHANICAL
DELAY AND VERTICAL JUMP PERFORMANCE

Deja L. Stevenson, MS

J. Brent Feland, PhD, P.T.

Ty Hopkins, PhD, A.T.C.

Iain Hunter, PhD

Brigham Young University

Address Correspondence to:

J. Brent Feland, PhD, P.T.

120A RB

Brigham Young University

Provo, UT 84602

Telephone: (801) 422-1182

E-mail: brent_feland@byu.edu

Abstract

The purpose of this study was to determine the effects of whole-body vibration on electromechanical delay and vertical jump performance. Twenty college-aged subjects participated in 10 intervals of whole-body vibration (WBV) at a frequency of 26 Hz and amplitude of 5 mm. Each interval consisted of 60 s of WBV in a half-squat followed by 60 s of rest. After 5 intervals, subjects had 6 min of rest before the final 5 intervals. Each subject also participated in the control which included the same 10 intervals in a half-squat without the WBV. Tests were conducted to assess electromechanical delay (EMD) and vertical jump at baseline, during the 6 min rest period and immediately after the treatment and control. EMD was measured using tibial nerve stimulation and a force plate. EMD was recorded as the lag time between the initiation of gastrocnemius activation and plantar flexion force production. Vertical jump was measured using a force plate and subjects' flight time. The factorial ANOVA results showed no differences between groups, for both EMD ($F(2, 38) = 1.385, p = 0.263$) and vertical jump ($F(2, 38) = 0.040, p < 0.96$). The WBV treatment protocol chosen had no effect on vertical jump. These results suggest that WBV, using this protocol, is not effective for acute vertical jump or EMD enhancement. Also, since there was no effect on EMD, this suggests that the WBV treatment did not enhance muscle spindle sensitivity.

Key Words: Muscle spindle sensitivity

Introduction

Vibration was initially researched at high-frequencies as a means to study the actions of muscle spindles (de Gail, et al. 1966; Desmedt and Godaux 1978; Marsden, et al. 1969). Previous research also focused on vibration as a possible occupational hazard (Cardinale 2003; Seroussi, et al. 1989), as an occurrence which could negatively affect athletic performance in certain sport activities (Thompson and Belanger 2002), and also as a means of rehabilitation for musculoskeletal injuries and conditions (Rittweger, et al. 2002; Verschueren, et al. 2004). Recently the literature has moved to studying vibration at lower frequencies in areas of muscular performance, such as improving the explosive arm movements utilized by boxers (Bosco, et al. 1999; Issurin and Tenenbaum 1999).

The recent positive findings in low-frequency vibration research specific to muscle adaptation has led to studies focused on using vibration as an exercise method. This exercise method is referred to as whole-body vibration (WBV) and involves a vibration platform. The idea of WBV is to utilize the isolated positive effects, such as muscle spindle activation (Bongiovanni, et al. 1990; Brooks, et al. 2000; de Gail, et al. 1966; Marsden, et al. 1969; Torvinen, et al. 2002b) and muscular performance (Bosco, et al. 1998a; Bosco, et al. 1998b; Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003; Verschueren, et al. 2004), and apply them to exercise and training for the entire body.

Theoretically, positive results due to WBV are a product of muscle activation (Cardinale and Lim 2003a; Delecluse, et al. 2003; Torvinen, et al. 2002a; Torvinen, et al.

2002b). WBV is based on the concept of muscle spindle activation and the resulting position feedback and muscle stretch provided by the vibration stimulation (Brooks, et al. 2000). An increase in muscle spindle sensitivity could potentially improve the neuromuscular response. The difficulty with WBV and the theory of muscle activation is how to narrow down and measure these adaptations.

One possibility of measuring muscle spindle sensitivity is to measure electromechanical delay (EMD). EMD is the lag time between muscle activation and force production. Increased muscle spindle sensitivity due to vibration increases spindle feedback which affects impulse firing to the muscle fiber (Brooks, et al. 2000), essentially priming the fibers for contraction (Marsden, et al. 1969). In other words, enhanced spindle sensitivity results in an increased number of cross bridges, taking up a portion of the slack in the series elastic component (SEC) and ultimately decreasing EMD. Therefore, a decrease in EMD would provide evidence for enhanced muscle spindle sensitivity.

Many studies have utilized the theory of increased muscle activation to explain the strength and power responses of muscles due to WBV. Acute responses to WBV have shown significant increases in isometric lower limb extension strength (Torvinen, et al. 2002a), leg press average force, velocity, and power (Bosco, et al. 1998b), and leg extensor mechanical power (Bosco, et al. 2000). Directly following application, WBV has also provided evidence of significant improvements in vertical jump performance (Bosco, et al. 2000; Torvinen, et al. 2002a). Other studies have shown that WBV training for longer durations (10 days – 8 months), also has positive influences on muscular

performance (Bosco, et al. 1998a; Delecluse, et al. 2003; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002b; Torvinen, et al. 2003). The majority of studies show that WBV can have a positive influence on strength and power responses, although a few studies have found WBV to have no effect on lower limb muscular performance (de Ruitter, et al. 2003; Torvinen, et al. 2002c) and an increase of fatigue due to WBV, decreased performance (Rittweger, et al. 2000).

The literature has shown that WBV exercise has potential benefits for neuromuscular performance. More research however, is needed to help explain the recent positive WBV findings. Therefore, the purpose of this study was to determine the effect of ten minutes of WBV exercise on EMD and vertical jump performance.

Methods

Participants

Twenty volunteer college-aged students (22.9 ± 2.2), 13 males and 7 females participated in this study. Each subject was recreationally active, not currently involved in any rigorous athletic training program, and had not suffered from any lower limb injuries within the last year. This study was approved by the University IRB.

All subjects were familiarized with the methods and procedures prior to testing. Each subject was assigned a treatment order using a counterbalance design. At least 2 days following the first treatment and testing, all subjects performed the second condition.

Measurement Methods

The two variables tested in this study were involuntary EMD and vertical jump height. Both variables were tested and measured at baseline (pretreatment), halfway through treatment (following 5 sessions), and posttreatment for each subject.

Subject Preparation. The skin of each subject's right leg around the medial head of the gastrocnemius, medial malleolus, and the posterior aspect of the knee was shaved if needed and cleaned with isopropyl alcohol. Two pre-gelled Ag-AgCl electrodes (Type Blue Sensor P00S, Medicotest, Ølstykke, Denmark) were placed on the medial head of the gastroc, parallel to the muscle fibers and 2 cm superior the distal end. The ground electrode was placed on the medial malleolus.

Involuntary EMD. Involuntary EMD was assessed using a supramaximal percutaneous electrical muscle stimulation (ISOC, BIOPAC Systems Inc., Santa Barbara, CA) of the tibial nerve, similar to the peroneal method used by Mora (Mora, et al. 2003). A water-based gel was used on the stimulator bar and the stimulation electrode was placed over the tibial nerve, at the posterior aspect of the knee, in the popliteal space. To ensure proper positioning over the tibial nerve, the stimulator was tested and moved until a supramaximal stimulation (maximum m-wave) of the gastroc was detected. Once the correct stimulator position was found, it was secured to the leg using elastic athletic tape.

Each subject then stood with the right foot on a force plate (AMTI Measurements Group, Watertown, MA) with the heel on a marked position. The left foot was positioned on the floor, to the side of the force plate over a marked spot. Subjects then placed hands on a support stand located 30.5 cm in front of toes and at the level of the naval and were

instructed not to lean on it, but use only to maintain balance. Subjects were then instructed to relax with weight equally distributed to both legs, with knees extended. Three stimuli were then administered with 30 s of rest between each stimulation.

During stimulation, muscle activation from the gastroc was measured using surface electromyography (EMG) (MP150, BIOPAC Systems, Inc., Santa Barbara, CA). The signals were amplified (DA100B, BIOPAC Systems, Inc., Santa Barbara, CA) from the disposable surface electrodes. The plantar flexion moment was measured using the force plate. Vertical ground reaction force, detected on the force plate, represented the force induced by stimulation and timing of the movement. A specifically designed software program on Microsoft Visual Basic (Microsoft, Portland, Oregon) was then used to identify the onset of muscle activity and force in order to calculate EMD. EMD was calculated from the time EMG first detected stimulation to the time a moment/force was observed (± 2 SD).

Vertical Jump. During each testing, subjects performed 3 maximal vertical counter-movement jumps (CMJ) with their hands on their hips. Each CMJ was performed on a force plate (AMTI Measurements Group, Watertown, MA) and the force was collected at 1000 Hz during each jump. An analog to digital conversion card (Keithley 3100, Keithley Instruments Inc., Cleveland, OH) combined with Microsoft Visual Basic (Microsoft, Portland, Oregon) provided the vertical force. Flight time was calculated using the time when force was below 20 N. Jump height was estimated using the following equation:

$$\text{VJ height} = 0.5g * [\text{Tair} / 2]^2 \quad (1)$$

Where g is the gravitational acceleration for the site of data collection, estimated at 9.797 m/s^2 (Jursa 1985).

For every 3 test jumps the maximal height was used for comparisons. This method of determining vertical jump has been found to be both very reliable and valid (Aragon-Vargas 2000).

Experimental Procedures

At baseline, each subject was tested for involuntary EMD and maximal vertical jump height. After baseline measurements, each subject was either given the ten-minute WBV treatment or the control. At no less than 2 d following the first treatment, each subject received the alternate treatment.

The WBV treatment involved exercise on a vibration platform (Power Plate North America, Inc., Northbrook, IL) at a frequency of 26 Hz and amplitude of 5 mm. Each exercise session consisted of WBV for 60 s intervals, with 60 s of rest between each interval. After 5 WBV exercise intervals subjects received 6 min of rest, which included the second session of testing for EMD and vertical jump. Another 5 WBV exercise intervals were then performed, for a total of 10 min of vibration. Posttesting for EMD and vertical jump measurements were then administered. The subjects stood on the vibration platform with their weight distributed on the balls of their feet, in a half-squat (45° knee flexion set by a goniometer), with hands placed on the machine's railing for balance. An elastic band apparatus was positioned under subjects' gluteal region, and subjects were instructed to stay in contact with the elastic band once the knee angle was set. This treatment procedure was modeled after a study by Bosco (Bosco, et al. 2000).

However, one change that was made for this study was knee angle during the half-squat. Bosco et al. reported using a knee flexion angle of 100°. When piloting our testing protocol, we found that subjects could not maintain that amount of knee flexion without excessive fatigue.

After baseline testing, the control condition consisted of the exact same half-squat exercise on the vibration platform, only with no vibration. An in-between testing session after the first 5 exercise intervals was also administered, as well as after the final 5 exercise intervals. Each testing consisted of the involuntary EMD and vertical jump measurements.

Statistical Analysis

The average EMD and maximal vertical jump height from each testing session was used for data analysis. Descriptive statistics of group means and standard deviations were calculated for both the control and vibration groups' EMD and vertical jump results. Means were normalized to the pretest measure and reported as a percent change from baseline, seen in Table 1. A (2 groups x 3 trials) repeated measures factorial ANOVA was used to detect differences between groups over time for both EMD and vertical jump using the SPSS 11.5 system. The significance level was accepted at $p \leq 0.05$ for all tests.

Results

All normalized data are presented in Figures 1 and 2. No significant differences were detected in EMD between groups ($F(2, 38) = 1.385, p = 0.263$). We observed a non significant decrease in EMD of the second and third testing sessions from baseline measurements of 5.9% and 5.2% in the control group and a 0.4% and 0.1% decrease for

the WBV group. No significant differences were detected in vertical jump between groups ($F(2, 38) = 0.040, p < 0.96$). A non significant 4.0% and 3.6% decrease in vertical jump for the control and 4.2% and 3.5% decrease for the WBV treatment of the second and third testing session were observed from the baseline measurements.

Discussion

The purpose of this study was to expose the experimental group to 10 min of WBV and compare any changes with those of a control group. In addition, researchers wanted to see if reported increases in vertical jump could be explained by measuring EMD as an estimate of spindle sensitivity. The results of this study showed no significant difference in EMD between the control and WBV treatment. EMD was used as an estimate of the influence of WBV on muscle spindle sensitivity. In this study EMD is defined as the lag time between the beginning of gastrocnemius activation and the beginning of the plantar flexion moment, or the time between muscle activation and its mechanical contribution. This same method was used by Mora (Mora, et al. 2003). They concluded that peroneus longus EMD could be used as an indirect method for assessing muscle stiffness. Mora et al. reported that a decrease in EMD was a product of spindle sensitivity and resulted in greater stiffness around the joint. Simply put, a decrease in EMD would indicate an increase in muscle spindle sensitivity and muscle activation. When muscles are vibrated, it is said that spindle sensitivity is enhanced and muscle stiffness increases to dampen the vibration (Cardinale and Bosco 2003; Lephart and Fu 2000). The increased stiffness and change in muscle spindle sensitivity, increases the muscle's α -motoneuron activity and the number of actin-myosin cross-bridges.

Therefore, since cross bridges have already been formed the time necessary to take up slack in the series elastic component may be significantly reduced, decreasing the overall time between activation and force development (Riemann and Lephart 2002). If all variables of movement and posture are held constant, it is possible then that EMD would be a good method for measuring muscle spindle sensitivity and providing further evidence for the theories of muscle activation due to vibration.

In the current study, EMD was found to have no change due to WBV, therefore, no increased muscle spindle sensitivity. These results do not conform to the current ideas explaining WBV literature. Several studies have attributed improvements in muscle performance due to WBV, to increased muscle spindle sensitivity and the feedback system (Delecluse, et al. 2003; Torvinen, et al. 2002a; Torvinen, et al. 2002b). Therefore, it was expected to see decreases in EMD due to a WBV treatment.

The unexpected EMD response, no change in EMD due to WBV, found in this study could mostly be due to the WBV treatment protocol. The duration of the current WBV treatment may have been a factor. In previous studies, EMG recordings were highest during a WBV treatment of only 60 s, at a frequency of 30 Hz and amplitude of 10 mm (Cardinale and Lim 2003b) and following a 4 min WBV exposure at a progressive frequency of 20 – 30 Hz and amplitude of 10 mm (Torvinen, et al. 2002a). This might suggest that the 10 min total of WBV exposure in this study may have been too long to get the intended EMD response, because the duration went beyond what was previously suggested as optimal for muscle activation. Also, the frequency of 26 Hz and amplitude of 5 mm may not have given the desired intensity to observe changes in EMD.

However, increases in vertical jump were observed using these same parameters (Bosco, et al. 2000), with spindle sensitivity as an explanation for the improvement in performance. Our results show that this WBV treatment has no effect on EMD, indirectly indicating that the spindle system is not enhanced by means of WBV.

The long duration in the current study may have brought about the issue of fatigue, mainly in the control group. The majority of the subjects reported the WBV treatment to have a relaxing effect while the control group provided feedback that fatigue started to set in during the static half-squat. While not significant, the control group exhibited, at the second and third testing sessions, a 5.9% and 5.2% decrease in EMD from baseline measurements, while the vibration contributed to about a 0.4% and 0.1% decrease from baseline. This actually coincides with fatigue and muscle spindle research. When large motor units begin to fatigue, muscle spindles initiate a feedback contribution to decrease activation rates and lessen the muscle's loss of force during the contraction (Windhorst and Kokkoroyiannis 1991). Hortobagyi et al. showed that during counter movement jump (CMJ) performance after fatigue, subjects tended to compensate for fatigue by enhancing muscle spindle sensitivity (Hortobagyi, et al. 1991). In another study, fatigue and 3 min of rest actually decreased EMD, indicating that this fatigue effect may persist for a long period (Hakkinen and Komi 1983). Therefore, we might expect to see a muscle spindle or EMD response that coincides with fatigue of the muscle.

Besides WBV protocol, it should also be considered that gastrocnemius EMD might not be indicative of the lower limb response to WBV. More research will be needed to assess the implications of using gastrocnemius EMD.

The results of this study also showed no significant difference in vertical jump between the control and WBV treatment. Vertical jump performance was chosen as a measurement in the current study because of the improvements seen in vertical jump due to WBV in the literature (Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003) and would therefore be beneficial in correlating the effects of potential increases in muscle spindle sensitivity. Also, to add power to the study, the WBV treatment protocol was modeled after a previous study which claimed a significant increase in vertical jump after acute exposure to WBV (Bosco, et al. 2000).

However, choosing vertical jump as a measurement may have some limitations. There have been studies that showed acute WBV exposure does not increase vertical jump (Cardinale and Lim 2003a; Torvinen, et al. 2002c). The disparity between results appears to exist due to the variability of WBV parameters (frequency, amplitude and duration). For example, two different studies (Torvinen, et al. 2002a; Torvinen, et al. 2002c) of 4 minute WBV treatments (one using 2 mm amplitude and the other a 10 mm amplitude), both using progressive increases in frequency, reported differing results in vertical jump. One study found a significant increase in vertical jump (Torvinen, et al. 2002a) while the other study did not find a significant increase (Torvinen, et al. 2002c). From these and the results of the current study, it could be concluded that it is still

unknown whether WBV is beneficial to performance and what the optimal parameters are for use in a WBV treatment.

Not only were there no significant differences between groups in our study, both the control and WBV treatment displayed non significant decreases in vertical jump. These results differ from the reported improvements from Bosco et al. from which our research was modeled (Bosco, et al. 2000). This inconsistency could be due to a couple of factors; population used for the study, the protocol duration, and knee flexion angle. The population in our study was males and females who were recreationally active, whereas, the population in their study was all males, active, and undergoing a team sport training program. The type of sport is not mentioned, but may have an influence on the results noted by Bosco et al. Also, our study used a less aggressive knee flexion angle since our pilot work showed an inability of the subjects to tolerate 1 min bouts in a deeper squat similar to the Bosco et al. study. In addition, it subjectively appeared that the duration of 60 s of squatting repeated 10 times progressively produced fatigue in our population (both vibration and control groups), refer to Table 2. Likely, our data reflect fatigue of the neuromuscular system, which contradicts the Bosco et al. findings. Future studies are needed to determine the optimal protocol needed for acute neuromuscular and performance improvements in both athletes and recreationally active individuals. While WBV literature provides much variation in treatment parameters, our protocol, based on the literature, provided no benefit to vertical jump.

In conclusion, these findings suggest that the WBV protocol used in this study does not enhance vertical jump performance nor does it affect EMD. Future work may

search for an optimal training protocol, including WBV duration, frequency, and amplitude, that might have beneficial effects. More research will be needed to determine the applicability and reliability of EMD in measuring muscle spindle sensitivity.

References

- Aragon-Vargas LF (2000) Evaluation of Four Vertical Jump Tests: Methodology, Reliability, Validity, and Accuracy. *Meas Phys Edu Exerc Sci* 4(4): 215-228
- Bongiovanni LG, Hagbarth KE, Stjernberg L (1990) Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *J Physiol* 423: 15-26
- Bosco C, Cardinale M, Tsarpela O (1999) Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol* 79(4): 306-311
- Bosco C, Cardinale M, Tsarpela O, Colli R, Tihanyi J, Duvillard SP, Viru A (1998a) The influence of whole body vibration on jumping performance. *Biol Sport* 15(3): 157-164
- Bosco C, Colli R, Intorini E, Cardinale M, Tsarpela O, Madella A, Tihanyi J, Viru A (1998b) Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol* 19(2): 183-187
- Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, Viru A (2000) Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol* 81(6): 449-454
- Brooks GA, Fahey TD, White TP, Baldwin KM (2000) *Exercise Physiology: Human Bioenergetics and Its Applications*. Mayfield Publishing Company, Mountain View, 390-391

- Cardinale M, Bosco C (2003) The use of vibration as an exercise intervention. *Exerc Sport Sci Rev* 31(1): 3-7
- Cardinale M, Lim J (2003a) The acute effects of two different whole body vibration frequencies on vertical jump performance. *Medicina Dello Sport* 56(4): 287-292
- Cardinale M, Lim J (2003b) Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 17(3): 621-624
- Cardinale M, Pope, MH (2003) The effects of whole body vibration on humans: Dangerous or advantageous? *Acta Physiologica Hungarica* 90(3): 195-206
- de Gail P, Lance JW, Neilson PD (1966) Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J Neurol Neurosurg Psychiatry* 29(1): 1-11
- de Ruiter CJ, Van Raak SM, Schilperoort JV, Hollander AP, de Haan A (2003) The effects of 11 weeks whole body vibration training on jump height, contractile properties and activation of human knee extensors. *Eur J Appl Physiol* 90(5-6): 595-600
- Delecluse C, Roelants M, Verschueren SM (2003) Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 35(6): 1033-1041
- Desmedt JE, Godaux E (1978) Mechanism of the vibration paradox: excitatory and inhibitory effects of tendon vibration on single soleus muscle motor units in man. *J Physiol* 285: 197-207

- Hakkinen K, Komi PV (1983) Electromyographic and mechanical characteristics of human skeletal muscle during fatigue under voluntary and reflex conditions. *Electroencephalogr Clin Neurophysiol* 55(4): 436-444
- Hortobagyi T, Lambert NJ, Kroll WP (1991) Voluntary and reflex responses to fatigue with stretch-shortening exercise. *Can J Sport Sci* 16(2): 142-150
- Issurin VB, Tenenbaum G (1999) Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci* 17(3): 177-182
- Jursa AS (1985) Handbook of Geophysics and the Space Environment. Air Force Geophysics Laboratory, 14-17
- Lephart SM, Fu FH (2000) Proprioception and Neuromuscular Control in Joint Stability. Human Kinetics, Champaign, 24-25
- Marsden CD, Meadows JC, Hodgson HJ (1969) Observations on the reflex response to muscle vibration in man and its voluntary control. *Brain* 92(4): 829-846
- Mora I, Quinteiro-Blondin S, Perot C, Isabelle M, Sylvie QB, Chantal P (2003) Electromechanical assessment of ankle stability. *Eur J Appl Physiol* 88(6): 558-564
- Riemann BL, Lephart SM (2002) The Sensorimotor System, Part II: The role of proprioception in motor control and functional joint stability. *J Athl Train* 37(1): 80-84
- Rittweger J, Beller G, D. F (2000) Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin Physiol* 20(2): 134-142

- Rittweger J, Just K, Kautzsch K, Reeg P, Felsenberg D (2002) Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise. *Spine* 27(17): 1829-1834
- Roelants M, Delecluse C, Goris M, Verschueren S (2004a) Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med* 25(1): 1-5
- Roelants M, Delecluse C, Verschueren SM (2004b) Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *J Am Geriatr Soc* 52(6): 901-908
- Seroussi RE, Wilder DG, Pope MH (1989) Trunk muscle electromyography and whole body vibration. *J Biomech* 22(3): 219-229
- Thompson C, Belanger M (2002) Effects of vibration in inline skating on the Hoffmann reflex, force, and proprioception. *Med Sci Sports Exerc* 34(12): 2037-2044
- Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Jarvinen TLN, Jarvinen M, Oja P, Vuori I (2002a) Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol and Function Imaging* 22(2): 145-152
- Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Jarvinen TLN, Jarvinen M, Oja P, Vuori I (2002b) Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc* 34(9): 1523-1528

- Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Nenonen A, Jarvinen TLN, Paakkala T, Jarvinen M, Vuori I (2003) Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: A randomized controlled study. *J Bone Miner Res* 18(5): 876-884
- Torvinen S, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Kannus P (2002c) Effect of 4-min vertical whole body vibration on muscle performance and body balance: A randomized cross-over study. *Int J Sports Med* 23(5): 374-379
- Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S (2004) 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* 19(3): 352-359
- Windhorst U, Kokkoroyiannis T (1991) Interaction of recurrent inhibitory and muscle spindle afferent feedback during muscle fatigue. *Neurosci* 43(1): 249-259

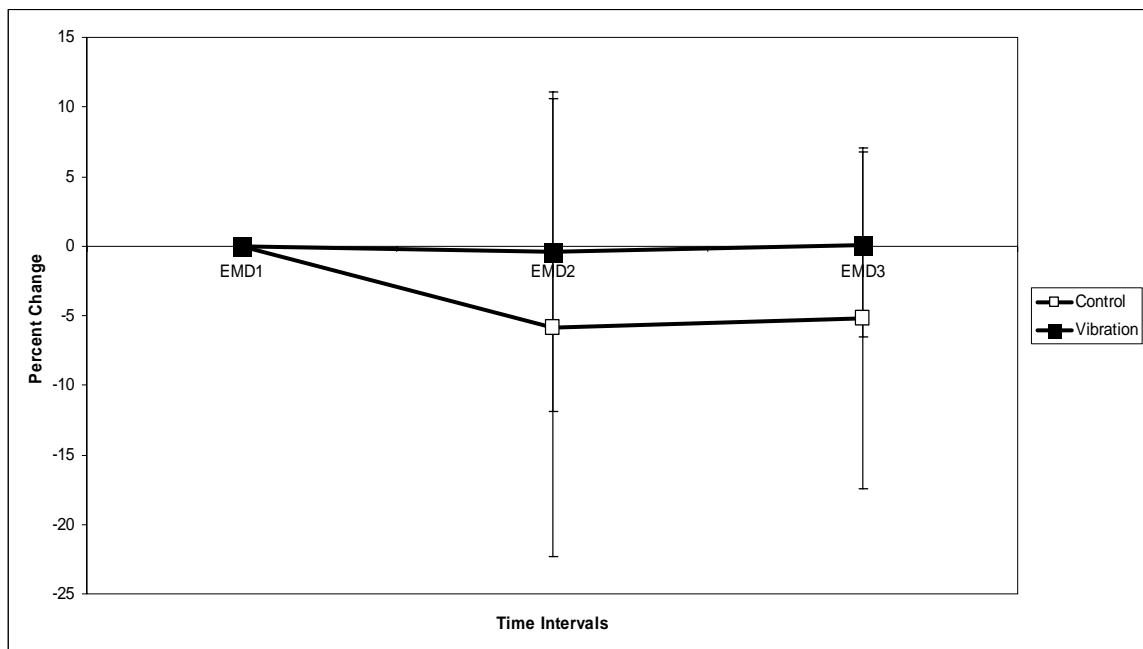
Table 1 Normalized EMD Data

Variable	Control Group		Vibration Group	
	(N = 20)		(N = 20)	
	M	(± SD)	M	(± SD)
EMD 1 Deviations	0.00	0.00	0.00	0.00
EMD 2 Deviations	-5.88	16.46	-0.39	11.49
EMD 3 Deviations	-5.20	12.26	0.10	6.63

Table 2 Normalized Vertical Jump Data

Variable	Control Group (N = 20)		Vibration Group (N = 20)	
	M	(± SD)	M	(± SD)
VJ 1 Deviations	0.00	0.00	0.00	0.00
VJ 2 Deviations	-3.98	3.21	-4.23	2.72
VJ 3 Deviations	-3.62	4.63	-3.54	4.91

Normalized EMD Graph

**Figure 1**

Normalized Vertical Jump Graph

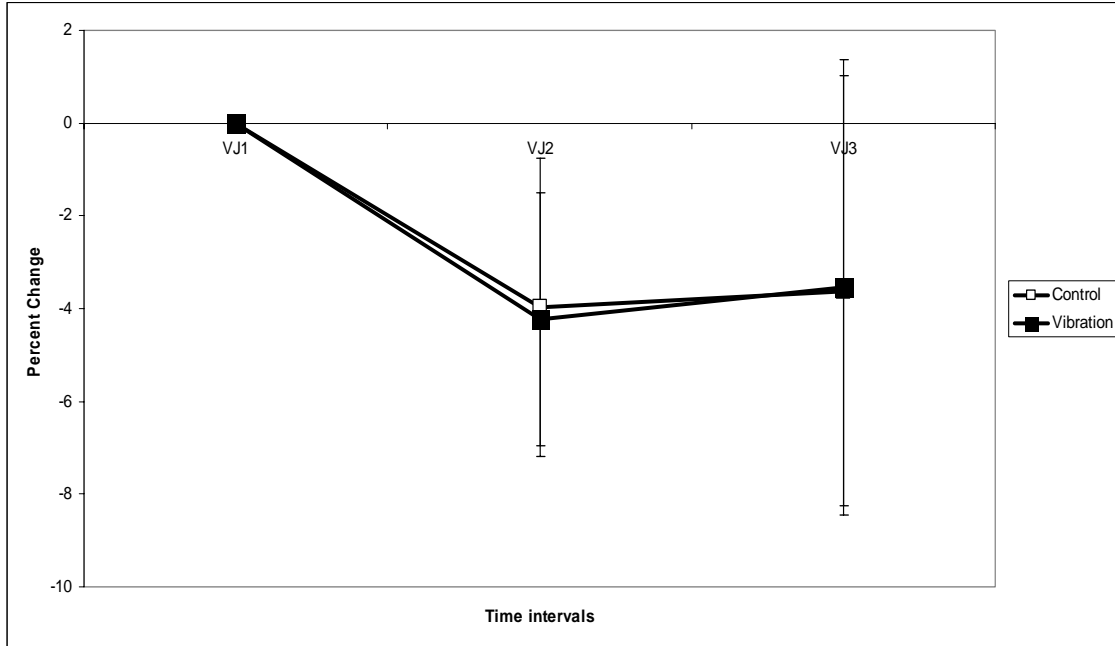


Figure 2

Appendix A
Prospectus

Chapter 1

Introduction

Original vibration research focuses on muscle activation, injuries, and rehabilitation using vibration at high frequencies. Recently the literature moved to studying vibration at lower frequencies, specifically, whole-body vibration. Whole-body vibration (WBV) is a term used to describe exercise performed on a vibration platform. Most WBV research focuses on muscle spindle activation (Bongiovanni, et al. 1990; de Gail, et al. 1966; Marsden, et al. 1969) and muscular performance enhancements caused by vibration (Bosco, et al. 1998a; Bosco, et al. 1998b; Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003; Verschueren, et al. 2004).

It has been found that WBV can possibly increase muscle spindle sensitivity (Marsden, et al. 1969). This is caused by a tonic vibration reflex that occurs due to vibration (Torvinen, et al. 2002b). However, WBV can cause fatigue which will decrease this reflexive response (Avela, et al. 2001). It is difficult however to provide definite evidence to these benefits due to an inability to directly measure spindle sensitivity. An indirect method of assessing spindle sensitivity, which has yet to be explored with WBV, is to measure electromechanical delay (EMD). If WBV could alter EMD, this will show the effects vibration has on muscle stiffness, the γ -motoneuron, muscle spindle sensitivity, and in turn muscle activation levels (Cardinale and Bosco 2003; Latash 1998;

Lephart and Fu 2000; Riemann and Lephart 2002). Research is needed to determine the effects of WBV on EMD.

Recent literature also shows that in addition to muscle spindle sensitivity, WBV also causes improvements in muscular performance, such as increased muscle strength and power (Bosco, et al. 1998a; Bosco, et al. 1998b; Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003; Verschueren, et al. 2004), hormone production (Bosco, et al. 2000), oxygen uptake (Rittweger, et al. 2002a; Rittweger, et al. 2001), EMG (Cardinale and Lim 2003; Rittweger, et al. 2003; Torvinen, et al. 2002a), and bone structure responses (Torvinen, et al. 2003; Verschueren, et al. 2004). Specifically WBV has been found to increase vertical jump (Bosco, et al. 1998a; Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2003), a measurement widely used to assess strength and power improvements. It is evident that WBV exercise has positive effects on the neuromuscular system, though there are other factors of WBV that must be considered in research and exercise. The vibration frequency, amplitude, and duration could have a large impact on the responses to WBV, including vertical jump. However, with all of the variance in the research, it is difficult to determine how to use these three factors to elicit the proper and intended response.

More studies are needed to explore WBV exercise. Although positive responses have been found, no research is available to determine the best frequency, amplitude, or duration for specific types of vibration training programs. Also, EMD needs to be

studied as a means to measure muscle spindle sensitivity, to better assess the effect of WBV.

Statement of the problem

The purpose of this study is to determine the effect ten minutes of whole-body vibration exercise has on electromechanical delay and vertical jump performance.

Hypothesis

Ten minutes of whole-body vibration exercise will decrease electromechanical delay and increase vertical jump height.

Null Hypothesis

Ten minutes of whole-body vibration exercise will have no effect on electromechanical delay or vertical jump height.

Operational Definitions

Whole-body vibration (WBV): Exercise in which an individual stands on a vibration platform.

Vibration platform: A platform which mechanically has oscillating vibration and the vibration can be varied with either level of frequency (10-90 Hz) or (2 or 5 mm) amplitude.

Recreationally active: Classification given to an individual who is physically active but not involved in any specific training program or moderate to vigorous activity more than 3 times a week.

Counter movement jump (CMJ): This refers to a specific vertical jump utilizing the stretch-shortening cycle, where the leg muscles are stretched immediately prior to the jump to elastically load the muscles.

Electromechanical Delay (EMD): The lag time between muscle stimulation/activation and contraction/force production.

Involuntary EMD: This refers to the lag time between muscle activation given involuntarily via a stimulator, and force production.

Assumptions

1. Subjects will adhere to the treatment protocol.
2. All measurements will be taken and calculated correctly.

Delimitations

The 20 subjects used for this study will be volunteers and will give informed consent. Subjects will be recreationally active and not be participating in any current rigorous athletic training program.

Limitations

Absence of a control group that receives no treatment at all, might limit the results.

Significance

If the hypothesis holds true, whole-body vibration will be able to improve electromechanical delay and vertical jump in recreationally active individuals. An increase in vertical jump will show the possible strength and power enhancements due to WBV. Also, a decrease in EMD will allow one to make more definite conclusions about

the affects of WBV on muscle spindle sensitivity. Then muscle spindle sensitivity can be used as an explanation for why WBV causes improvements in vertical jump.

Chapter 2

Review of Literature

Introduction to vibration

Vibration has been a topic of interest to exercise science researchers for many years. In the 1960's – 70's, high frequency vibration was used as a research method to study the actions of muscle spindles (de Gail, et al. 1966; Desmedt and Godaux 1978; Marsden, et al. 1969). Vibration was studied at first through the use of electromagnetic vibration (Desmedt and Godaux 1978; Marsden, et al. 1969) and was explored again in 2003 (Jackson and Turner 2003). Vibration research then moved to studying direct vibration or manual vibration applied to a tendon or muscle belly using a probe in both animals and humans (Bongiovanni and Hagbarth 1990; Bongiovanni, et al. 1990; de Gail, et al. 1966; Martin and Park 1997; McClosky, et al. 1972; Necking, et al. 1996). However, vibration in the past has also been considered an occupational hazard, and therefore was studied as a phenomenon which was harmful to one's health (Cardinale 2003), such as the excessive torque placed on the spine due to vibration (Seroussi, et al. 1989). Also studied were sports in which vibration negatively affected performance during competition such as downhill skiing and inline skating (Thompson and Belanger 2002). Other studies have considered vibration as a means of rehabilitation for such ailments as lower back pain and osteoporosis (Rittweger, et al. 2002b; Verschueren, et al. 2004). Although much research on vibration at high frequencies has been completed in the past, only recently has vibration at lower frequencies been considered to improve

muscular performance, such as explosive arm movements utilized by boxers (Bosco, et al. 1999; Issurin and Tenenbaum 1999).

The research has moved to studying more specific muscle adaptation. Researchers more recently explored weight training where a weight, cable, and pulley machine was modified by transmitting vibration into the cable, to look at muscle adaptations (Bosco, et al. 1999; Issurin, et al. 1994; Issurin and Tenenbaum 1999). Vibration has also been observed where subjects were seated and the vibration treatment was given through the seat (Ando and Noduchi 2003; Seroussi, et al. 1989). The positive findings in vibration research have led to more recent studies focused on using vibration as an exercise method. More specifically, whole-body vibration (WBV) using a vibration platform is being researched as a possible means for athletes and others to train and exercise.

The idea of WBV is to utilize the effects of vibration for the whole body. A few companies have started to manufacture whole-body vibration platforms for the use of health club patrons and professional athletic facilities. Although a very new area, WBV research has shown positive effects in the areas of muscle spindle activation (Bongiovanni, et al. 1990; Brooks, et al. 2000; de Gail, et al. 1966; Marsden, et al. 1969; Torvinen, et al. 2002b) and muscular performance (Bosco, et al. 1998a; Bosco, et al. 1998b; Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003; Verschueren, et al. 2004).

Vibration

Theory of muscle activation. Theoretically, the concept of WBV is based on activation of muscle spindles. Muscle spindles provide feedback from position and muscle stretch to γ afferents. The feedback signal sent from these γ afferents is sent through the γ –loop back to the α -motoneuron cell body to affect impulse firing to the muscle fiber. This is known as α and γ co-activation (Brooks, et al. 2000). At high frequencies (60-150 Hz), vibration applied to muscle bellies and tendons excite Ia muscle spindles and Ib tendon organ afferents, causing autogenic inhibition (Bongiovanni, et al. 1990; de Gail, et al. 1966; Marsden, et al. 1969). The advantage of activating muscle spindles is the muscles are being primed and readied for contraction or increasing the muscle spindle sensitivity (Marsden, et al. 1969). Increased muscle spindle sensitivity could improve the neuromuscular response.

Activation of muscle spindles causes a tonic vibration reflex or a tonic contraction, mediated through the stretch reflex arc. This is observed through tension produced when vibration is applied to a muscle (Bongiovanni, et al. 1990; de Gail, et al. 1966; Marsden, et al. 1969). Researchers have even seen maximal contractions reached when vibration is applied to the center of the muscle belly due to tonic contraction (de Gail, et al. 1966). More recently, a four-month study of whole-body vibration applied a treatment of 4 minutes of vibration at a progressive frequency of 25-40 Hz. A tonic vibration reflex, muscle spindle and larger motoneuron activation and an increase in the number of motor units activated was observed after the four-month vibration treatment (Torvinen, et al. 2002b). These findings imply vibration can activate muscle spindles and

therefore fire up large numbers and maybe even all motor units integrated with that muscle.

More evidence for the influence vibration has on motor units has been found. In a study on the tonic vibration reflex and motor unit synchronization, tendon vibration at frequencies of 40-200 Hz was applied at two different amplitudes. Researchers found even at low frequencies all Ia afferents were recruited and harmonic synchronization occurred between 40-100 Hz. It was concluded that the motor unit synchronization is dependent on vibration frequency and initial contraction level. Also found was that tonic vibration contraction can increase the firing rates of the activated Ia afferents, thus fatigue takes place faster (Martin and Park 1997).

Another concept researchers have studied is the effect fatigue has on activating motor units. Two studies looked at the effects vibration and fatigue has on peripheral reflexes. After performing maximal voluntary contractions with and without direct vibration, researchers found vibration to enhance the fatigued alpha-motor output and contraction strength (Bongiovanni and Hagbarth 1990). Another study used electrical stimulation to vibrate calf muscles during 1 hour sessions to fatigue and observed adaptation after 2 weeks. Fatigue caused an 18.5% decrease in force output and associated neural changes. The fatigue caused reduced reflex sensitivity, lower frequency torque, increased blood lactate and a possibility of central fatigue (Avela, et al. 2001). These findings show the neuromuscular and slight metabolic overloads vibration can induce.

Electromechanical delay. The problem with these findings of muscle activation and increased spindle sensitivity is it is difficult to narrow and measure these vibration adaptations. One possibility of measuring muscle spindle sensitivity is to measure electromechanical delay (EMD). EMD is the lag time between muscle stimulation and force production. A reduction in EMD due to vibration would provide evidence for increased muscle spindle sensitivity due to several factors.

The gamma motor neurons are what control muscle spindle sensitivity. The γ -motoneurons transmit impulses to the intrafusal fibers in muscle spindles and contribute to the pre-programming of muscle stiffness (Lephart and Fu 2000). When muscles are vibrated, the muscle stiffness increases in an attempt to dampen the vibratory waves (Cardinale and Bosco 2003). This stiffness causes the γ -motoneurons to change muscle spindle sensitivity which then decreases the muscle spindle firing threshold. These spindle changes cause a tonic stretch reflex, increasing the α -motoneuron activity of those neurons innervating the muscle (Latash 1998). This increases the levels of muscle activation and contraction or the number of actin-myosin cross-bridges. Therefore, the stiffer muscles have less slack in the series elastic component, reducing the amount of time necessary to generate tension, and reducing EMD (Riemann and Lephart 2002). Considering these variables hold constant, it is possible then that EMD would be a good method for measuring muscle spindle sensitivity and further proving the theories of muscle activation due to vibration.

Examining the muscle activation findings stated above, one could conclude that muscle spindle and motor unit activation can be enhanced using vibration. Also, a

possible measurement of these enhancements to muscle activation would be to assess EMD. However, if the vibration causes fatigue it could impair the neuromuscular and reflex responses. This is why when considering using WBV, one must take into account the vibration components of frequency, amplitude, and duration to achieve optimal results.

Vibration frequency. Most WBV platform devices are made to vibrate using oscillating motion in an up and down direction. Frequency is the rate of reoccurrence of oscillations (Rittweger, et al. 2001). Originally vibration was studied at high frequencies (60-300 Hz). For instance, one study observed effects of vibration at a frequency of 150 Hz. Two minutes of vibration did stimulate a tonic vibration reflex, but also decreased muscle electromyography (EMG) activity and maximal voluntary contraction (Bongiovanni, et al. 1990). In a study of adult cats, where direct vibration at frequencies of 100-200 Hz was applied to the triceps surae of hindlimbs, no reflex contractions or muscle spindle afferents were significantly activated (McClosky, et al. 1972). Another study observed vibration effects at low frequencies (< 50 Hz) and found tonic contraction to reach maximum within 30 – 60 seconds with progressive increase of frequency. However, the tonic contraction began to decrease at frequencies above 50 Hz (de Gail, et al. 1966). Two similar studies have compared different frequencies of WBV. These two studies looked at WBV frequencies from 18-50 Hz. Researchers observed greatest increases in specific $\dot{V}O_2$ ($s\dot{V}O_2$) and the highest reflex responses at 34 and 30 Hz, with responses tapering above and below this range (Cardinale and Lim 2003; Rittweger, et al.

2002a). These observations suggest lower frequencies to be optimal when desiring to activate muscle spindles and the ensuing tonic vibration reflex.

WBV exercise frequencies are now assumed effective in this low frequency range (18-50 Hz). Several studies have utilized frequency as a method to increase load or intensity, progressively increasing frequency during a WBV session or whole training period (Delecluse, et al. 2003; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003; Torvinen, et al. 2002c; Verschueren, et al. 2003). Other researchers used a constant frequency throughout the WBV treatment or training, 18 Hz (Rittweger, et al. 2002b), 26 Hz (Bosco, et al. 1998a; Bosco, et al. 1998b; Bosco, et al. 2000; Kerschan-Schindl, et al. 2001; Rittweger, et al. 2000; Rittweger, et al. 2003; Rittweger, et al. 2001), and 30 Hz (de Ruitter, et al. 2003). It is now suggested that 26 Hz is the optimal frequency for WBV exercise.

Vibration amplitude and acceleration. Since WBV platform devices use oscillation, amplitude refers to the magnitude of oscillation, usually given in millimeters (Rittweger, et al. 2001). The vibration component of amplitude has not been exclusively studied much. One study compared a vibration treatment at constant frequency but at different amplitudes. The results showed greater sVO₂ increases between amplitudes of 2.5-7.5 mm (Rittweger, et al. 2002a). The most common amplitude used in WBV is ~10 mm (Bosco, et al. 1998a; Bosco, et al. 1998b; Cardinale and Lim 2003; Rittweger, et al. 2000; Torvinen, et al. 2002a). Another common WBV amplitude is 6 mm (Rittweger, et al. 2002b; Rittweger, et al. 2003; Rittweger, et al. 2001) while other studies range in amplitudes from 1-8 mm (Bosco, et al. 2000; de Ruitter, et al.

2003; Delecluse, et al. 2003; Kersch-Schindl, et al. 2001; Rittweger, et al. 2002a; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002b; Torvinen, et al. 2003; Torvinen, et al. 2002c; Verschueren, et al. 2004). The variance in amplitude in these studies can be contributed to the concept of gravitational load.

Gravitational load is the acceleration that occurs due to gravity. This acceleration can be calculated using the vibration amplitude and frequency. Many studies have used acceleration or gravitational load (g) as another variable that can affect vibration (Bosco, et al. 1998a; Bosco, et al. 1998b; Bosco, et al. 2000; Delecluse, et al. 2003; Kersch-Schindl, et al. 2001; Rittweger, et al. 2000; Rittweger, et al. 2001; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Verschueren, et al. 2004). The gravitational load (g) placed on an individual due to vibration is increased with increasing amplitude and frequency (Roelants, et al. 2004b). It is clear there are a wide range of amplitudes utilized and therefore different accelerations. More research could be useful in determining what is best.

Vibration duration. The other important vibration component, duration, like amplitude, is widely varied in the literature. Many studies have looked at acute or short-term vibration responses where the total vibration treatment consists of 3-10 minutes of vibration exposure (Bosco, et al. 1998b; Bosco, et al. 2000; Cardinale and Lim 2003; Kersch-Schindl, et al. 2001; Rittweger, et al. 2002a; Rittweger, et al. 2001; Torvinen, et al. 2002a; Torvinen, et al. 2002c). Other researchers have looked at the effects of WBV when the subjects stand or do exercises on a vibration platform until exhaustion (Rittweger, et al. 2000; Rittweger, et al. 2003). Many other studies have used vibration

as a long-term training method. The duration of these training programs range from 3-8 months, with 2-5 vibration sessions per week, and with various vibration exposure times per session (de Ruiter, et al. 2003; Delecluse, et al. 2003; Rittweger, et al. 2002b; Roelants, et al. 2004a; Roelants, et al. 2004b; Torvinen, et al. 2002b; Torvinen, et al. 2003; Verschueren, et al. 2004). While one study only observed a daily WBV training program for 10 days and found positive results (Bosco, et al. 1998a).

These three components of WBV, frequency, amplitude, and duration allow for a variety of vibration treatment protocols. Alteration of even one of these components can have an affect on the vibration responses observed. Currently the frequency of 26 Hz is suggested as most advantageous; however, more research could make the use of this frequency more definite. Other than frequency, no foundation has really been laid as to what amplitude, duration, or even gravitational load works best. Although training protocols are not clearly set, WBV in recent literature has shown some positive responses.

Vibration responses

Strength and power responses. Many studies have researched WBV exercise and found positive responses in strength and power components of muscular performance. Researchers have looked at the immediate results of WBV and found an increase in isometric lower limb extension strength and also vertical jump height after four minutes of vibration exercise at frequencies of 20-30 Hz and an amplitude of 10 mm (Torvinen, et al. 2002a). Following ten minutes of WBV at a frequency of 26 Hz and an amplitude of 4 mm, investigators found significant improvements in leg press average force, velocity,

and power, improving the velocity-force and power-force curves (Bosco, et al. 1998b). At the same ten minute duration, frequency, and amplitude researchers recorded a significant increase in leg extensor mechanical power and vertical jump performance (Bosco, et al. 2000).

More positive responses have been found in studies of longer duration. Ten days of WBV training at a frequency of 26 Hz and amplitude of 10 mm, showed improvement was shown in the power output and height of vertical jump. Researchers also showed a significant improvement in height of five seconds of continuous jumping (Bosco, et al. 1998a). Three months of WBV training at frequencies of 35 Hz and 40 Hz and amplitudes of 2.5 mm and 5 mm improved isometric leg strength, dynamic strength and vertical jump height (Delecluse, et al. 2003); and increases in isometric leg strength and vertical jump were also seen at frequencies of 25-40 Hz and an amplitude of 2 mm after four months (Torvinen, et al. 2002b). Further studies of six months of WBV training at frequencies of 35-45 Hz and an amplitude of 2.5-5 mm found significant increases in isometric and dynamic knee extension strength (Roelants, et al. 2004a; Roelants, et al. 2004b), speed of leg extension movement, and countermovement jump performance (Roelants, et al. 2004b). A separate study by Verschueren, also showed a significant increase in knee extensor isometric and dynamic strength after six months of WBV, at a frequency of 35-40 Hz and amplitude of 1.7-2.5 mm (Verschueren, et al. 2004). Researchers also WBV trained subjects for eight months at frequencies of 25-45 Hz and amplitude of 2 mm, resulting in a significant vertical jump height increase (Torvinen, et

al. 2003). The results from these studies show that WBV can have a positive effect on strength and power performance.

However, negative strength and power responses from WBV exercise have also been documented (de Ruiters, et al. 2003; Rittweger, et al. 2000; Torvinen, et al. 2002c). Researchers have shown that four minutes of WBV had no significant change on performance (Torvinen, et al. 2002c) and exhaustive WBV to significantly decrease jump height and knee extension torque (Rittweger, et al. 2000). These decreases however are expected if the legs are fatigued to exhaustion. An 11-week study by de Ruiters, of WBV training at a frequency of 30 Hz and amplitude of 8 mm, showed no improvements in isometric quadriceps force, voluntary activation, or rate of force rise (de Ruiters, et al. 2003). These studies may need to be explored more to eliminate the possibility of WBV causing negative effects.

Although few studies show WBV can cause unwanted responses in strength and power, the positive findings are more prevalent. The negative effects could be due to poor study design or fatigue. Since there are many more positive strength and power results from WBV, it can be assumed that WBV training can be used to improve these muscular performance components.

Other responses. Studies have also looked at other body responses to WBV. Recording EMG during vibration is one way to see if the vibration is causing muscle activation. It has been shown that during vibration there is a decrease in muscle activity mean power frequency, showing possible fatigue, and an increase in EMG root mean square voltage (EMGrms), suggesting recruitment of more motor units (Torvinen, et al.

2002a). EMGrms was observed during different WBV frequencies (30-50 Hz) and found increases in EMGrms activity highest at 30 Hz (Cardinale and Lim 2003). Greater EMG activity and patellar tendon reflex amplitude was also detected in WBV when compared to a no vibration treatment (Rittweger, et al. 2003). Researchers have also found that WBV treatment has reduced EMGrms during post leg press measurements (Bosco, et al. 2000). The results of these studies suggest a possibility of WBV causing fatigue and an increased amount of muscle activity.

Since WBV is being considered as a possible mode of exercise, oxygen uptake and blood responses due to vibration have also been explored. During a study of different vibration frequencies and amplitudes researchers discovered that sVO_2 significantly increases with increasing frequency and amplitude, and with additional load placed on the subject (Rittweger, et al. 2002a). This was shown again that VO_2 and RPE was greater with vibration than without (Rittweger, et al. 2001). When compared to cycle ergometry, WBV caused significant increases in heart rate, lactate concentration, O_2 uptake but was not comparable to the increases during cycle ergometry (Rittweger, et al. 2000). It has also been found that WBV causes significant serum increases of testosterone and growth hormone and decreases of cortisol in men (Bosco, et al. 2000), suggesting a possible beneficial hormonal response to vibration. Significant increases in muscle blood flow and decreases in blood flow velocity after WBV exposure have also been found (Kersch-Schindl, et al. 2001). These findings suggest WBV can induce significant oxygen uptake, blood volume, and hormonal responses to be considered as an effective exercise method.

Research has also looked at whether WBV can positively affect body balance. However, most studies have found that WBV training has no effect on body balance and postural sway abilities (Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003; Torvinen, et al. 2002c; Verschueren, et al. 2004). It does not seem that WBV has any affect on balance, although the majority of these studies measured sway by using a tilting platform (Biodex, Shirley, NY) and may not be a good representation of postural sway.

WBV is also being investigated as a means of treatment for pain and osteoporosis. Studies have shown no significant affect on bone mass, structure, or strength (Torvinen, et al. 2003), or serum bone turnover due to WBV (Verschueren, et al. 2004). Significant increases in hip bone-mass-density (Verschueren, et al. 2004) and free fat mass have been found to occur after WBV treatments (Roelants, et al. 2004a). In investigating back pain WBV treatment provided significant back pain and associated disability reduction comparable to common pain relieving exercises (Rittweger, et al. 2002b). It is evident that because of the conflicting findings in bone mass changes due to WBV, more research is needed and to confirm these and back pain relief claims.

It is evident there can be benefits to WBV exercise. However, these studies only answer the question of what can WBV accomplish. More studies are needed to conclude why WBV can give individuals these benefits.

Conclusion

The recent literature has branched from original research and focused more on WBV. Although the research varies in methods, including vibration frequency,

amplitude, and duration, the results all point in a common direction. The literature has shown that WBV exercise has potential benefits when it comes to muscular performance and other performance responses. However, because there is so much variance between studies, more research is needed to narrow down the possibilities.

More studies are needed to definitely propose the best frequency, amplitude, and duration or combination of all three, to use in WBV exercise. More research is also needed to bring original vibration and muscle spindle research together with the more recent WBV literature. Although there is much to be done, it does seem that WBV can have positive effects on human performance.

Chapter 3

Methods

The purpose of this study is to determine whether ten minutes of WBV exercise will affect electromechanical delay (EMD) and vertical jump performance. Baseline measurements for involuntary EMD and vertical jump will be taken in order to assess muscle spindle sensitivity. Vertical jump performance is being tested because in the literature it has shown to improve due to WBV exposure and therefore would be beneficial to establish the effects of possible increases in muscle spindle sensitivity (Bosco, et al. 2000; Delecluse, et al. 2003; Roelants, et al. 2004b; Torvinen, et al. 2002a; Torvinen, et al. 2002b; Torvinen, et al. 2003). Subjects will participate in both the treatment and control condition. The treatment consists of ten minutes of WBV exercise and the other condition acts as a control, by exercising with no WBV. Subjects will be randomly assigned to one of two groups (one group starting as a control and the other receiving the vibration treatment). Randomization, to limit the “order effect,” will be assigned using the Latin Square design. Involuntary EMD and vertical jump will be measured prior to, half way through and directly after the exercise interventions.

Subjects and Orientation

The subjects for this study will be students, male and female (ages 18-30), from Brigham Young University who volunteer to participate. At least 20 subjects will be tested. Each subject will be recreationally active and not currently participating in any rigorous athletic training program. All subjects will sign an institutionally approved informed consent form.

All participating subjects will be familiarized with the methods and procedures 2-3 days prior to testing. This will include practicing the treatment exercises with and without WBV, and the counter movement jump.

Instruments

The following instruments will be used to determine EMD:

1. Surface electromyography (MP150, BIOPAC Systems Inc., Santa Barbara, CA).
2. Amplifier (DA100B, BIOPAC Systems Inc., Santa Barbara, CA)
3. Disposable, pre-gelled Ag-AgCl electrodes (Type Blue Sensor P00S, Medicotest, Ølstykke, Denmark)
4. Percutaneous electric muscle stimulator (BIOPAC Systems Inc., Santa Barbara, CA)
5. 3-D ground reaction force plate (AMTI Measurements Group, Watertown, MA)
6. Microsoft Visual Basic (Microsoft, Portland, OR)

The following instruments will be used to determine vertical jump:

1. 3-D ground reaction force plate (AMTI Measurements Group, Watertown, MA)
2. Analog to digital conversion card (Keithley 3100, Keithley Instruments Inc., Cleveland, OH)
3. Excelinx IA (Keithley Instruments Inc., Cleveland, OH)

Measurement Methods

Two variables will be tested in this study – involuntary EMD and vertical jump height. This will be tested and measured at baseline, half way through treatment and after the treatment for each subject. Involuntary EMD will be tested by measuring the lag

time between tibial nerve stimulation and plantar flexion force production. Vertical jump will be tested by calculating CMJ height in meters, based upon flight time when jumping from a forceplate.

Subject Preparation. The subjects' right leg will be prepped for testing. The skin area around the medial head of the gastrocnemius and medial malleolus will be shaved if needed and cleaned with isopropyl alcohol. Two pre-gelled Ag-AgCl electrodes (Type Blue Sensor P00S, Medicotest, Ølstykke, Denmark) will be placed on the medial head of the gastroc, parallel to the muscle fibers and 2 cm from the distal end. The ground electrode will be placed on the medial malleolus.

Involuntary EMD. To assess involuntary EMD, a supramaximal percutaneous electrical muscle stimulation (BIOPAC Systems Inc., Santa Barbara, CA) of the tibial nerve will be used, similar to the peroneal method used by Mora (Mora, et al. 2003). A water-based gel will be used on the stimulator and the stimulation electrode will be placed over the tibial nerve, which is located in the posterior aspect of the knee, just above the popliteal space. The stimulator will then be tested to ensure correct position over the tibial nerve. The position is correct when a supramaximal stimulation (maximum m-wave) of the gastroc is detected. Once proper positioning of the stimulator is found, it will be secured to the leg with conform athletic tape. The subject will then be instructed to place the right leg on the force plate and the left leg on the ground, with both heels on previously marked locations. The subject will then place hands on a support stand located 12 inches in front of toes and at the level of the naval, and will be instructed not to lean on it, but use only for balance. Instructions will then be given to relax with

weight equally distributed to both legs and knees fully extended. Three stimuli will then be administered with 30 seconds of rest between each stimulation.

Electromyography (EMG) will measure muscle activation from the gastroc, using surface electromyography (MP150, BIOPAC Systems Inc., Santa Barbara, CA). Signals will be amplified (DA100B, BIOPAC Systems Inc., Santa Barbara, CA) from the disposable surface electrodes. The plantar flexion moment will be measured using a force plate (AMTI Measurements Group, Watertown, MA). Vertical ground reaction force, detected on the force plate, will represent the force induced by stimulation and timing of the movement. Using Microsoft Visual Basic (Microsoft, Portland, Oregon), with a specifically designed EMD program, EMD will be calculated from the time EMG first detects stimulation to the time a moment/force is observed.

Vertical Jump. A simple method will be used to test vertical jump. Each subject will perform 3 maximal counter movement jumps (CMJ) with their hands on their hips. Force data will be collected at 1000 Hz during each CMJ using a force plate (AMTI Measurements Group, Watertown, MA). An analog to digital conversion card (Keithley 3100, Keithley Instruments Inc., Cleveland, OH) combined with Excelinx IA (Keithley Instruments Inc., Cleveland, OH) will provide the vertical force. Flight time will be calculated using the time when force was below 20 N. Jump height will be estimated using the following equation:

$$\text{VJ height} = 0.5g * [\text{Tair} / 2]^2$$

Where g = the gravitational acceleration for Provo, UT, which is estimated at 9.797 m/s^2

(Jursa 1985)

The maximal height between the three jumps will be used for comparisons. This method of determining vertical jump height has been found to be both very reliable and valid (Aragon-Vargas 2000).

Procedures

At baseline, each subject will be tested for involuntary EMD and perform 3 CMJ to obtain maximal vertical jump height. After baseline measurements have been taken, the subjects will be assigned using a counterbalanced order of treatment. Each subject will either be given the ten minute WBV treatment or no WBV, just ten minutes of exercise. Five to seven days following the first treatment, each subject will receive the alternate treatment.

The WBV treatment will involve exercise on a vibration platform (Power Plate North America, Inc., Northbrook, IL) at a frequency of 26 Hz and amplitude of 5 mm. Each training session will consist of WBV for 60 second intervals, with 60 seconds of rest between each interval. Five WBV exercise intervals will be performed, followed by 6 minutes of rest. This rest period will include the second session of testing for EMD and vertical jump. The remaining five intervals of WBV exercise will then be performed, for a total of ten minutes of vibration, after which EMD and vertical jump will be measured again. The subjects will stand on the platform with their weight distributed to the balls of their feet, in a half-squat (45° knee flexion set by a goniometer), with hands placed on the machine's railing for balance only. To insure subjects will remain in the half squat position an elastic band apparatus will be set underneath their gluteal region, once in 45° of knee flexion, and subjects must stay in contact with the elastic throughout the

treatment. This treatment procedure is modeled after a study by Bosco, in which positive vertical jump results were found (Bosco, et al. 2000).

After baseline testing, the no WBV treatment will consist of the exact same exercises on the vibration platform, only with no vibration. An in between testing session will also be administered to measure EMD and vertical jump following the first five intervals of exercise. Then the final five intervals of exercise will be performed.

Directly after both treatments, all subjects will be tested for involuntary EMD and immediately following, maximal vertical jump height will be measured. The same methods will be used as was at baseline and the half way testing.

Design and Statistical Analysis

The purpose of this study is to expose the experimental group to 10 minutes of WBV and compare the results with a control group. The average EMD and maximal vertical jump height will be used for data analysis. Two 2 x 2 ANOVAs with repeated measures on time will be computed to detect differences between groups over time for both dependent variables using the SAS system. The significance level will be accepted at $p \leq 0.05$ for all tests.

References

- Ando H, MD, Noduchi R, MD (2003) Dependence of palmar sweating response and central nervous system activity on the frequency of whole-body vibration. *Scandinavian J Work Environment Health* 29(3): 216-219
- Aragon-Vargas LF (2000) Evaluation of Four Vertical Jump Tests: Methodology, Reliability, Validity, and Accuracy. *Meas Phys Edu Exerc Sci* 4(4): 215-228
- Avela J, Kyrolainen H, Komi PV (2001) Neuromuscular changes after long-lasting mechanically and electrically elicited fatigue. *Eur J Appl Physiol* 85: 317-325
- Bongiovanni LG, Hagbarth KE (1990) Tonic vibration reflexes elicited during fatigue from maximal voluntary contractions in man. *J Physiol* 423: 1-14
- Bongiovanni LG, Hagbarth KE, Stjernberg L (1990) Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *J Physiol* 423: 15-26
- Bosco C, Cardinale M, Tsarpela O (1999) Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol* 79(4): 306-311
- Bosco C, Cardinale M, Tsarpela O, Colli R, Tihanyi J, Duvillard SP, Viru A (1998a) The influence of whole body vibration on jumping performance. *Biol Sport* 15(3): 157-164
- Bosco C, Colli R, Intorini E, Cardinale M, Tsarpela O, Madella A, Tihanyi J, Viru A (1998b) Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol* 19(2): 183-187

- Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, Viru A (2000) Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol* 81(6): 449-454
- Brooks GA, Fahey TD, White TP, Baldwin KM (2000) *Exercise Physiology: Human Bioenergetics and Its Applications*. Mayfield Publishing Company, Mountain View, pp. 390-391
- Cardinale M, Bosco C (2003) The use of vibration as an exercise intervention. *Exerc Sport Sci Rev* 31(1): 3-7
- Cardinale M, Lim J (2003) Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 17(3): 621-624
- Cardinale M, Pope, MH (2003) The effects of whole body vibration on humans: Dangerous or advantageous? *Acta Physiologica Hungarica* 90(3): 195-206
- de Gail P, Lance JW, Neilson PD (1966) Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J Neurol Neurosurg Psychiatry* 29(1): 1-11
- de Ruitter CJ, Van Raak SM, Schilperoort JV, Hollander AP, de Haan A (2003) The effects of 11 weeks whole body vibration training on jump height, contractile properties and activation of human knee extensors. *Eur J Appl Physiol* 90(5-6): 595-600

- Delecluse C, Roelants M, Verschueren SM (2003) Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 35(6): 1033-1041
- Desmedt JE, Godaux E (1978) Mechanism of the vibration paradox: excitatory and inhibitory effects of tendon vibration on single soleus muscle motor units in man. *J Physiol* 285: 197-207
- Issurin VB, Liebermann DG, Tenenbaum G (1994) Effect of vibratory stimulation training on maximal force and flexibility. *J Sports Sci* 12(6): 561-566
- Issurin VB, Tenenbaum G (1999) Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci* 17(3): 177-182
- Jackson SW, Turner DL (2003) Prolonged muscle vibration reduces maximal voluntary knee extension performance in both the ipsilateral and the contralateral limb in man. *Eur J Appl Physiol* 88(4-5): 380-386
- Jursa AS (1985) *Handbook of Geophysics and the Space Environment*. Air Force Geophysics Laboratory, pp. 14-17
- Kerschman-Schindl K, Grampp S, Henk C, Resch H, Preisinger E, Fialka-Moser V, Imhof H (2001) Whole-body vibration exercise leads to alterations in muscle blood volume. *Clin Physiol* 21(3): 377-382
- Latash ML (1998) *Neurophysiological Basis of Movement*. Human Kinetics, Champaign, pp. 84
- Lephart SM, Fu FH (2000) *Proprioception and Neuromuscular Control in Joint Stability*. Human Kinetics, Champaign, pp. 24-25

- Marsden CD, Meadows JC, Hodgson HJ (1969) Observations on the reflex response to muscle vibration in man and its voluntary control. *Brain* 92(4): 829-846
- Martin BJ, Park HS (1997) Analysis of the tonic vibration reflex: influence of vibration variables on motor unit synchronization and fatigue. *Eur J Appl Physiol Occup Physiol* 75(6): 504-511
- McClosky DI, Matthews PBC, Mitchell JH (1972) Absence of appreciable cardiovascular and respiratory responses to muscle vibration. *J Appl Physiol* 33(5): 623-626
- Mora I, Quinteiro-Blondin S, Perot C, Isabelle M, Sylvie QB, Chantal P (2003) Electromechanical assessment of ankle stability. *Eur J Appl Physiol* 88(6): 558-564
- Necking LE, Lundstrom R, Lundborg G, Thornell LE, Friden J (1996) Skeletal muscle changes after short term vibration. *Scand J Plast Reconstr Surg Hand Surg* 30(2): 99-103
- Riemann BL, Lephart SM (2002) The Sensorimotor System, Part II: The role of proprioception in motor control and functional joint stability. *J Athl Train* 37(1): 80-84
- Rittweger J, Beller G, D. F (2000) Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin Physiol* 20(2): 134-142
- Rittweger J, Ehrig J, Just K, Mutschelknauss M, Kirsch KA, Felsenberg D (2002a) Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. *Int J Sports Med* 23(6): 428-432

- Rittweger J, Just K, Kautzsch K, Reeg P, Felsenberg D (2002b) Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise. *Spine* 27(17): 1829-1834
- Rittweger J, Mutschelknauss M, Felsenberg D (2003) Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. *Clin Physiol and Function Imaging* 23(2): 81-86
- Rittweger J, Schiessl H, Felsenberg D (2001) Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. *Eur J Appl Physiol* 86(2): 169-173
- Roelants M, Delecluse C, Goris M, Verschueren S (2004a) Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med* 25(1): 1-5
- Roelants M, Delecluse C, Verschueren SM (2004b) Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *J Am Geriatr Soc* 52(6): 901-908
- Seroussi RE, Wilder DG, Pope MH (1989) Trunk muscle electromyography and whole body vibration. *J Biomech* 22(3): 219-229
- Thompson C, Belanger M (2002) Effects of vibration in inline skating on the Hoffmann reflex, force, and proprioception. *Med Sci Sports Exerc* 34(12): 2037-2044
- Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Jarvinen TLN, Jarvinen M, Oja P, Vuori I (2002a) Effect of a vibration exposure on

- muscular performance and body balance. Randomized cross-over study. *Clin Physiol and Function Imaging* 22(2): 145-152
- Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Jarvinen TLN, Jarvinen M, Oja P, Vuori I (2002b) Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc* 34(9): 1523-1528
- Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Nenonen A, Jarvinen TLN, Paakkala T, Jarvinen M, Vuori I (2003) Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: A randomized controlled study. *J Bone Miner Res* 18(5): 876-884
- Torvinen S, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Kannus P (2002c) Effect of 4-min vertical whole body vibration on muscle performance and body balance: A randomized cross-over study. *Int J Sports Med* 23(5): 374-379
- Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S (2003) 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* 19(3): 352-359
- Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S (2004) 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* 19(3): 352-359