WHOLE-BODY VIBRATION: IS GRAVITATIONAL FORCE A VALID MEASUREMENT OF EXERCISE INTENSITY?

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To the Dean of the Graduate School:

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DEDICATION

To the Phizer Gods and Anheuser-Busch for always being a solid (and liquid) friend!

To Larry Tesler, the inventor of copy & paste, pure genius!

To one of the shortest but most important palindromes in the world. 'Mom' your endless support throughout this scholastic saga will never be forgotten! Love CJ

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ABSTRACT

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WHOLE-BODY VIBRATION: IS GRAVITATIONAL FORCE A VALID MEASUREMENT OF EXERCISE INTENSITY?

AUGUST 2010

The primary aim of the whole-body vibration (WBV) investigation was to determine if g-force is a valid measurement of vibration exercise intensity (VEI). For this purpose, twelve healthy lean adults (male, 7; female 5; age, 29.4 $\pm$ 6.4 years; height 171.4 $\pm$ 4.9 cm; weight, 67.4 $\pm$ 10.4 kg; BMI, 22.9 $\pm$ 2.6 kg/m^2) voluntarily participated for the study. To examine the relationship between g-force and VEI, a 3-way (4-muscle group x 4-frequency x 2-amplitude) repeated measures design was employed, which analyzed electromyography (EMG) muscle activity in the vastus lateralis (V.L.), vastus medialis (V.M.), gastrocnemius lateralis (G.L.) and gastrocnemius medialis (G.M.) muscles during WBV exercise. Participants, performed a standard unloaded isometric high-squat position (knee angle 30 degrees, hip angle 30 degrees, feet [middle toe to middle toe] 30cm apart) while at eight different levels (k = 8) of g-force. The levels of g-force were derived from four different preset frequency settings (30, 35, 40, and 50 Hz) measured at both the low and high amplitude settings. Each participant underwent four trials at each of the amplitudes. In each trial a participant experienced all four preset frequencies and a control condition. The VEI was operationally defined as the WBV-induced percent increase in EMGrms compared with the control condition (no vibration). Control data was expressed as a percent of maximum voluntary contraction (MVC), thus allowing for inter-subject comparisons. The results of the study clearly indicated that the highest g-forces were not associated with the highest VEI responses. The highest VEI responses were found at the lower frequencies (30 and 35 Hz) with exception of the G.M. (40 Hz). Furthermore the higher amplitude produced an approximately 35% higher VEI response than the low amplitude. Based on the findings it was concluded that g-force is not a valid measurement of VEI. Additionally, the study revealed that both a large degree of inter-subject variability in VEI responses exists and that WBV only produces a small amount of muscle activity when expressed relative to MVC data. Thus, it was concluded that WBV should only be used as a supplement to traditional exercise prescription, not as a replacement.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The American College of Sports Medicine (ACSM) defines exercise training as planned, structured, and repetitive body movement done to improve or maintain one or more components of physical fitness (The American College of Sports Medicine, 2006). A major assumption in exercise prescription is that chronic exercise leads to beneficial changes in the body. This assumption is based on several physiological principles, with the most important of these, being the principle of adaptation. The adaption principle states that if a specific physiologic system is taxed by a physical training stimulus within a certain range, and on a regular basis, this physiologic system usually improves (ACSM, 2006). The principle of adaptation relies on the two related principles of threshold and overload. If the exercise stimulus has an intensity that exceeds the threshold, it is a training overload which will bring about a physiologic adaptation (ACSM, 2006; Howley & Franks, 2007).

Exercise intensity is an important concept in exercise prescription. In the theoretical and applied exercise arenas, the mode, frequency, duration and intensity of exercise are important variables to consider when prescribing exercise or designing an exercise research study (ACSM, 2006; Howley & Franks, 2007). The exercise mode should typically be specific to the desired fitness goals, and the frequency, duration, and intensity have to be integrated in a systematic overload that will yield the desired physiologic adaptations (ACSM, 2006; Howley & Franks, 2007). Various categories of exercise use different measurements to express exercise intensity. In cardiorespiratory exercise heart rate or oxygen consumption is often used to express exercise intensity; whereas in resistance exercise a percentage of 1-repitition maximum (1-RM) is often employed (ACSM, 2006; Howley & Franks, 2007).

Whole-body vibration (WBV), also known as 'vibration exercise' or 'acceleration training™ is a new concept in exercise science. Vibration platforms are being used in various areas of exercise including athletics, general fitness and rehabilitation (Cardinale & Wakeling, 2005; Rehn, Lidstrom, Skoglund, & Lindstrom, 2007; Dolny & Reyes, 2008). Some WBV exercise studies have reported increases in athletic performance due to vibration training (Colson, Pensini, Espinosa, Garrandes, & Legros, 2010; Lamont et al., 2010; Wyon, Guinan, & Hawkey, 2010). However, these enhanced performance findings are not universal (Roelants, Delecluse, Goris, & Verschueren, 2004; Verschueren et al., 2004) and have been questioned by other scientists in the field, due to questionable research designs (Luo, McNamara, & Moran, 2005; Nordlund & Thorstensson, 2007; Wilcock, Whatman, Harris, & Keogh, 2009). Furthermore, several animal and human studies have shown vibration exercise to be beneficial in improving bone mineral density (Gilsanz et al., 2006; Gusi, Raimundo, & Leal, 2006; Rubinacci et al., 2008; Verschueren et al., 2004; Xie, Rubin, & Judex, 2008). Even though the popularity of WBV is increasing, current knowledge about safe and effective vibration exercise prescription is still in its nascent stage.

Whole-body vibration is defined as a mechanical stimulus characterized by an oscillatory motion delivered to the body from a vibrating platform (Cardinale & Wakeling, 2005). Whole-body vibration exercise typically involves an individual performing static or dynamic exercise on either a vertical or tilting platform. Vertical vibrating platforms mainly oscillate vertically while tilting vibrating platforms oscillate about a horizontal anteroposterior central axis (Lorenzen, Maschette, Koh, & Wilson, 2009). The biomechanical factors that constitute the vibration magnitude, often expressed in gravitational (g) forces or maximum accelerations (a_{max}), are the frequency and amplitude of vibration (Dolny & Reyes, 2008; Mansfield, 2004). Most of the commercially available vibration platforms on the market today deliver vibrations across a range of frequencies (15–60 Hz) and amplitudes (1-10 mm). The acceleration delivered to the body can reach in excess of 15 g (Cardinale & Wakeling, 2005). Taking into consideration the multitude of possible frequency and amplitude combinations it is evident that when it comes to prescribing WBV exercise intensity a great deal of variation could exist.

Electromyography (EMG) is the study of muscle function through the inquiry of the electrical signal the muscles emanate (Basmajian & DeLuca, 1985). Kinesiological EMG generally examines neuromuscular activity of muscles within functional movements, postural tasks, and exercise protocols (Kamen & Gabriel, 2010; Konrad, 2005). The electromyography instrument allows for the measurement of the motor unit action potential (MUAP) which comes in the form of an EMG signal. This signal is based on the change in action potential electrical activity due to muscle activity. The magnitude and density of the EMG signal are predominantly influenced by the recruitment of MUAPs and the muscle's firing frequency (Kamen & Gabriel, 2010; Konrad, 2005). Several whole-body vibration studies have employed EMG to examine the effects of vibration exercise on muscle activity. Essentially all the studies report an increase in EMG muscle activity in some muscle groups, particularly in the muscles closest to the vibrating plate (McBride et al., 2010; Melnyk, Kofler, Faist, Hodapp, & Gollhofer, 2008; Higashihara et al., 2009; Hopkins et al., 2008; Torvinen et al., 2002).

In whole-body vibration, the vibration magnitude (i.e. g-force or acceleration) is dependent upon the frequency (f) and amplitude (A) of the vibrating plate and can be calculated from the formula: $a_{max} = A\,(2\pi f)^2$ (Griffin, 1996; Lorenzen, Maschette, Koh, & Wilson, 2009; Mansfield, 2004). To calculate g-force, the a_{max} formula is then divided by 9.81 m/s^2; thus g-force = $A\,(2\pi f)^2/9.81$. Recall, in physics, 1 g is the acceleration due to the Earth's gravitational field which is approximately, 9.81 m/s^2 (Griffin, 1996). Even though, the term 'gravitational force' is an accurate expression of vibration magnitude, it may not be an accurate expression of vibration exercise intensity. Thus, when it comes to WBV exercise intensity, the use of g-force in prescription could potentially become confusing, misleading and a possible safety concern for two primary reasons. The first being that an individual could possibly exercise on the same vibration platform, at the same g-force, using two different frequency and amplitude setting combinations. Thus, if someone prescribes vibration exercise intensity at a particular g-force without specifying the frequency and amplitude confusion is likely to arise. Secondly, it is logical to reason that an increase in g-force strongly correlates with an increase in exercise intensity. In fact, some WBV manufacturers imply this unsubstantiated correlation between g-force, which is a form of acceleration, and exercise intensity, in their vibration exercise recommendations. For example, in the Power Plate Pro5ᵗᵐ user manual (2008) the company discusses how increasing the frequency and amplitude settings (therefore increasing the g-force) increases the vibration exercise intensity. The user manual makes the following statements:

1. "Acceleration Training™ exercise should be used on a regular basis, starting with low intensity, which means low frequency settings for short sessions. The body should be gently stimulated in a way that will allow you to adjust to vibration training, but will not overload your body. Over time, the intensity and duration can be increased in the same manner as other progressive training programs. Once the body has adapted to vibration, the training can be changed or intensified to keep improving performance, whether this improvement is desired for sports or daily life goals."

   (Power Plate Pro5ᵗᵐ user manual, 2008, p. 4)

2. "The correct step-by-step build up of intensity is extremely important for your training to be carried out both efficiently and responsibly."

   (Power Plate Pro5ᵗᵐ user manual, 2008, p. 10)

3. "For strength, power and speed, the intensity (i.e., Hertz settings) per exercise can be increased, but the total volume should be kept low."

   (Power Plate Pro5^{tm} user manual, 2008, p. 10)

4. "When frequency (Hz) is increased, the volume of the exercises should be decreased (duration, number of sets) and the rest period should be increased proportionally."

   (Power Plate Pro5^{tm} user manual, 2008, p. 11)

5. "When amplitude is increased from Low to High, frequency and volume of exercise should be (temporarily) decreased and the rest period increased proportionally."

   (Power Plate Pro5^{tm} user manual, 2008, p. 11)

Statement of the Problem

In the fields of WBV exercise prescription and research the term gravitational force is often used to express vibration magnitude. Even though this term is an accurate expression of vibration magnitude it may not be an accurate expression of vibration exercise intensity. To date, no whole-body vibration research has validated the relationship between gravitational force and exercise intensity. The purpose of this study is to determine if gravitational force is a valid measurement of WBV exercise intensity. In this study the operational definition of vibration exercise intensity (VEI) is the WBV-induced percent increase in EMGrms compared with the control condition—no vibration. Control data is expressed as a percentage of MVC.

To examine the purpose of this study, surface electromyography (EMG) muscle activity in both knee flexor muscles (vastus lateralis and vastus medialis) and plantar flexor muscles (gastrocnemius lateralis and gastrocnemius medialis) was measured while the participant stood in an isometric high-squat position at eight different levels (k = 8) of g-force ranging from low to high. The levels of g-force were derived from changing the frequency (Hz) setting in 5 Hz increments (30, 35, 40, and 50 Hz) at both a low and high amplitude. If gravitational force is a valid measurement of VEI then EMG muscle activity responses should strongly reflect the relationship. Figure 1 represents the slightly curvilinear relationship between frequency and gravitational force at an arbitrary fixed amplitude across a range of 25-50 Hz. Note that as the frequency doubles from 25-50 Hz, the g-force quadruples; this is due to the quadratic function effects on frequency in the g-force equation: $g = A\,(2\pi f)^2/9.81$.

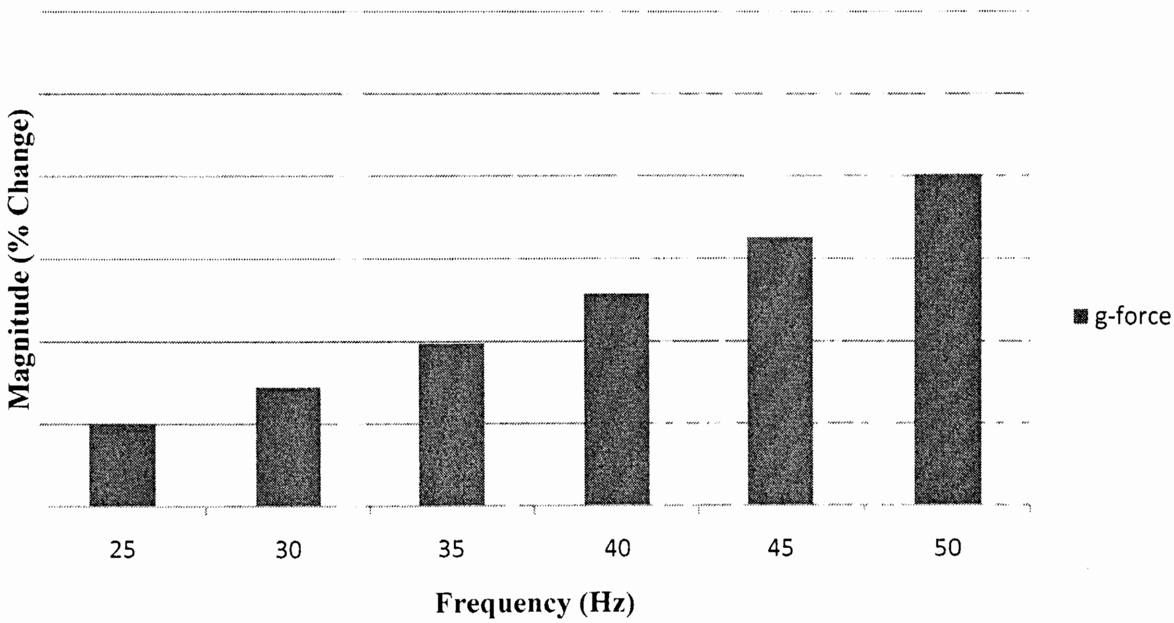

Figure 1. The relationship (2nd degree polynomial) between frequency (Hz) and g-Force at an arbitrary fixed amplitude.

Aims of the Study

1. Determine if gravitational force is a valid measurement of vibration exercise intensity.
2. Examine the leg muscles responses to vibration exercise intensity.

Null Hypotheses

Main Effects:

1. There will be no significant difference in EMG muscle activity between the muscle groups.
2. There will be no significant difference in EMG muscle activity between the frequencies.
3. There will be no significant difference in EMG muscle activity between the amplitudes.

Interaction Effects:

4. There will be no significant difference in EMG muscle activity between the muscle groups and frequencies.
5. There will be no significant difference in EMG muscle activity between the muscle groups and amplitudes.
6. There will be no significant difference in EMG muscle activity between the frequencies and amplitudes.
7. There will be no significant difference in EMG muscle activity between the muscle groups, frequencies and amplitudes.

Assumptions

1. Participants will achieve maximal contraction during maximal voluntary contractions.
2. Participants will be free of any physiological conditions which effect EMG data collection.
3. Surface electromyography is a valid and reliable instrument for measuring WBV muscle activity.
4. Muscle activity is a valid measurement of WBV exercise intensity.

Limitations

1. This study was limited to the instrumentation reliability of surface electromyography.
2. This study was limited to the assumptions of statistical tests used.
3. This study was limited to one body position-isometric high-squat.
4. This study was limited to the use of only two amplitudes and four frequencies to examine the relationship between gravitational force and exercise intensity
5. This study was limited to the examination of only four muscle groups: gastrocnemius medialis, gastrocnemius lateralis, vastus medialis and vastus lateralis.

Delimitations

1. This study was delimited to the population sampled, young (18-45 years) healthy (no positive response on PAR-Q) adults with body mass index (BMI) less than or equal to 24.9 kg/m^2.
2. This study was delimited to the type of exercises selected to measure maximal voluntary contractions.
3. This study was delimited to the type of vibration platform selected to measure vibration exercise intensity.

Significance of the Study

Exercise intensity is a very important variable in the fields of exercise research and exercise prescription. This variable is typically required to bring about various beneficial physiological adaptations to several systems of the body including the neuromuscular system. Whole-body vibration exercise researchers, and exercise prescription recommendations made by platform manufacturers, sometimes use the term gravitational force to express the variable of exercise intensity. However to date, no whole-body vibration research study has ever validated the relationship between an increase in gravitational force and vibration exercise intensity. The outcome of this study will advance the body of knowledge in WBV research and exercise prescription.

Definition of Terms

1. Acceleration: a vector quantity that specifies the rate of change of velocity (meter per second squared, $m\ s^{-2}$).
2. Acceleration Maximum (A max): maximal change in velocity over time.
3. Amplitude: the maximum displacement of an oscillating body from its equilibrium position.
4. Angular Frequency: the product of the frequency of a sinusoidal quantity with 2π.
5. Damped natural frequency: the frequency of free vibration of a damped linear system
6. Damping: the dissipation of energy with time or distance.
7. Electromyography (EMG): an experimental technique concerned with the development, recording and analysis of myoelectric signals.
8. EMG root mean square (rms): based on a square root calculation the RMS reflects the mean power in the signal.
9. Frequency: the reciprocal of the fundamental period (measured in Hertz).

10. Gravitational force, g-force, or acceleration of gravity: the acceleration produced by the force of gravity at the surface of the earth (9.806 m s^{-2}).
11. Hertz (Hz): A unit of frequency equal to one cycle per second
12. Hoffman (H) reflex: a monosynaptic reflex arising from stimulation of the tibial nerve.
13. Harmonic: a sinusoidal oscillation whose frequency is an integral multiple of the fundamental frequency.
14. Linear system: a system in which the response is proportional to the magnitude of the excitation.
15. Magnitude of vibration: measure of largeness or size of vibration.
16. Maximal Voluntary Contraction (MVC): an isometric exercise performed by participants for inter-subject comparisons. MVC allows normalization of data from microvolt's to percent of maximum innervation capacity.
17. Oscillation: the variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than some mean value.
18. Peak-to-Peak Amplitude (or displacement): total vibration excursion of a point between its positive and negative extremes.
19. Resonance: The increase in amplitude of oscillation of a mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undamped frequency of the system.
20. Resonance frequency: a frequency at which resonance occurs.
21. Tonic Vibration Reflex (TVR): a reflex contraction of a skeletal muscle produced by vibration.

22. Vibration Amplitude: the absolute value of the maximum displacement from a zero value during one period of an oscillation.

23. Vibration Exercise Intensity (VEI): the WBV-induced percent increase in EMGrms compared with the control condition—no vibration. Control trial data was expressed as a percent of MVC.

24. Whole-body vibration (WBV): transfer of an alternating mechanical wave from a vibrating platform to the body's tissues.

CHAPTER II

REVIEW OF THE LITERATURE

Vibration: Classification

Vibration is oscillatory motion which is not constant but fluctuates above and below an average value (Mansfield, 2004). The magnitude of vibration is based on the degree of the oscillation while the frequency of vibration is based on the oscillatory cycle repetition rate (Griffin, 1996). When the vibration motion is not predictable it is considered to be random. When vibration motion is predictable, it is considered deterministic motion. Deterministic vibration can further be dichotomized as either periodic or non-periodic motion. A shock wave is an example of non-periodic motion; whereas sinusoidal waves are an example of periodic motion. The vast majority of research relating to biodynamic responses to vibration is on sinusoidal wave forms as this type of vibration is considered a predictable, periodic motion and allows for empirically examination (Griffin, 1996).

Vibration: Magnitude

There are several ways to measure the magnitude of vibration including displacement, velocity and acceleration (Inman, 2007). If the magnitude of vibration has a low frequency and large amplitude, it is possible to observe the displacement between the peak movement in one direction and the peak movement in the opposite direction—this is referred to as the peak-to-peak displacement (Griffin, 1996). The vibration's magnitude can also be expressed as velocity, which gives more information about the energy associated with the oscillation. Velocity can also be measured from peak-to-peak by calculating the difference between the maximum velocities in both directions of the oscillation (Mansfield, 2004). Acceleration is the most common method for quantifying the magnitude of vibration due to ease of use and the high degree of accuracy of accelerometers (Griffin, 1996). Acceleration magnitude is typically measured in the S.I. unit, meters per second per second (m/s^2 or $m\ s^{-2}$). In vibration, a period is defined as the time required for a periodic motion to repeat itself (Griffin, 1996). The frequency of vibration is measured in Hertz (Hz) which is the number of cycles of motion per second (Inman, 2007). Angular frequency (ω) is expressed in radians per second. A complete cycle is 360 degrees, which equals 2π radians. Therefore the angular frequency (f) is $2\pi f$ radians per second (Griffin, 1996).

Vibration: Resonance and Damping

Resonance is the increase in amplitude of oscillation of a mechanical system exposed to a periodic motion whose frequency is equal or very close to the natural resonance frequency of the system. A resonance frequency is the frequency at which resonance occurs. Damping is the dissipation of energy with time or distance (Griffin, 1996). The human body has several mechanisms which it uses to control the transfer of impact shocks and vibrations though the body including: joint kinematics, bone, cartilage, synovial fluids, soft tissues and muscle activity. Adjustments in joint kinematics and muscle activity can occur rapidly to deal with various forms of energy absorption, including vibration. Researchers have proposed that the body has the ability to 'tune its muscle activity' so that it can reduce the harmful effects vibrations can have on soft tissue structures (Boyer & Nigg, 2004; Cardinale & Wakeling, 2005; Wakeling, Nigg, & Rozitis, 2002).

Research findings suggest that a fairly strong relationship exists between increases in externally applied forces to the body and increases in muscle activity (Nigg, Bahlsen, Luethi, & Stokes, 1988; Wakeling, Liphardt, & Nigg, 2003). This increase in muscle activity is thought to occur as a way to dampen oscillations. Vibration research has shown that an activated muscle absorbs more vibrational energy than an un-activated muscle (Wakeling, Nigg, & Rozitis, 2002).

Furthermore, some researchers have demonstrated that the most vibration absorption occurs when the vibration frequency matches the resonant frequency of the tissues—muscle tuning hypothesis. Some scientists propose that muscle tuning is the body's mechanism to minimize potentially harmful vibration, regardless of the mode of input force (Boyer & Nigg, 2004; Cardinale & Wakeling, 2005; Wakeling, Nigg, & Rozitis, 2002).

Whole-Body Vibration: Biodynamic Responses

If a vibration motion is translational then all the parts of a rigid body will oscillate in the equivalent motion (Griffin, 1996). However, if there is an element of rotation in the rigid body, then the motion will not be equivalent (Griffin, 1996). The human body's response to vibration will be affected differently by translational and rotational vibration. An individual's posture will also greatly affect how the vibration energy is transmitted to the body due to the fact that a small change in posture will alter the resonance of the body, therefore influencing how the energy is transmitted to the body (Griffin, 1996; Mansfield, 2004). The body's response to vibration is not well understood, due to the multifaceted, non-linear and dynamic nature of the phenomenon (Griffin, 1996; Mansfield, 2004). This is in part due to the vast degree of variance within and between humans (Griffin, 1996).

Skeletal Muscle Physiology

Extrafusal Muscle Fibers and the Motor Unit: Overview

Extrafusal muscle fibers and associated alpha motor neurons are called a motor unit. A motor unit is a single motorneuron which consists of an anterior horn cell, its motor axon, the muscle fibers it innervates, and the connecting neuromuscular junction between them (MacIntosh, Gardiner, & McComas, 2005). For extrafusal muscles to work efficiently the motorneuron needs to precisely innervate the muscle fibers and to be able to adjust the firing rate rapidly. The regulation of extrafusal muscle fiber requires a constant flow of information to the central nervous system. Muscle receptors play an important role in regulating extrafusal muscle fibers (MacIntosh, Gardiner, & McComas, 2005).

Muscle Receptors: General

Muscle receptors are typically classified into one of these four categories: 1) free nerve endings, 2) paciniform corpuscles, 3) Golgi tendon organs, and 4) muscle spindles (Proske, 2006). Of these four, the Golgi tendon and muscle spindle do the vast majority of signaling to the central nervous system relating to kinesthetic actions. The Golgi tendon organs primarily deal with tension within the muscle fiber; whereas the muscle spindles are primarily designed to sense the lengths of the contracting muscle fibers (Proske, Wise, & Gregory, 2000).

The Muscle Spindle

A muscle spindle is a mechano-sensory receptor embedded parallel in extrafusal muscle fibers and consists of 3-12 intrafusal fibers surrounded by a capsule of connective tissue. Each intrafusal fiber is innervated by primary and secondary sensory nerve fibers and gamma motorneurons (fusimotor). Three types of intrafusal fibers make up the muscle spindle: dynamic nuclear bag fibers (Bag1), static nuclear bag fibers (Bag2), and nuclear chain fibers (MacIntosh, Gardiner, & McComas, 2005). A muscle spindle will most typically have one bag1, one bag2 and four to eight chains, but variation can occur (MacIntosh, Gardiner, & McComas, 2005). The primary purpose of the muscle spindle is to sense changes in muscle length and relay that information through sensory neurons to the central nervous system (Matthews, 2008). The information provided by muscle spindles aids the brain in establishing body position (Hamill, 2010). The response of a muscle spindle to changes in muscle length also has a significant function in regulating muscle contraction through the activation of motorneurons via the stretch reflex, thus resisting muscle stretch (Matthews, 2008).

Afferent type Ia & II sensory innervations. Muscle spindles are innervated by two types of myelinated sensory afferent neurons. The type Ia sensory fiber, which is also known as primary afferent fiber, spirals around the equatorial region of each intrafusal fiber and senses the velocity of the stretch (Matthews, 2008). Although primary afferents are also length sensitive it is their unique ability to innervate the dynamic bag1 fibers that accounts for their velocity sensitivity (MacIntosh, Gardiner, & McComas, 2005). The secondary type II sensory fiber is a highly myelinated fiber that innervates close to the poles of each intrafusal fiber (MacIntosh, Gardiner, & McComas, 2005). The type II fiber is primarily length sensitive. This property is due to the fact that type II fibers only innervate the static bag2 and chain fibers which are only sensitive to displacement (MacIntosh, Gardiner, & McComas, 2005). Therefore the firing rate of the type II sensory fiber is strongly correlated to the muscle's position and length (Hamill, 2010). The secondary afferent is also a non-adapting sensory fiber which will continue to respond even if the muscle is in an isometric state (Hamill, 2010). There are usually 1-2 Ia fibers and 1-5 II fibers innervating each spindle (Prochazka, 1996).

Alpha motor neurons. The brainstem and spinal cord possess alpha motor neurons which are directly responsible for innervating extrafusal muscle fibers and skeletal muscle contraction (Matthews, 2008). The primary difference between alpha motor neurons and gamma motor neurons is that the gamma motor neurons are responsible for innervating the intrafusal muscle fibers in the muscle spindles (Matthews, 2008). The cell bodies of alpha motor neurons are located in the central nervous system; however, alpha motor neurons are classified within the somatic nervous system, due to the fact that their axons innervate skeletal muscle (Watkins, 2010). A motor unit consists of an alpha motor neuron and the muscle fibers it innervates (Watkins, 2010).

Alpha motor neurons are much like other neurons in the sense that they have both an afferent and efferent connection (Watkins, 2010). Alpha motor neurons obtain input from various sources, including interneurons, sensory neurons and upper motor neurons (Macintosh, Gardiner, & McComas, 2005). The major efferent role of alpha motor neurons is to innervate the extrafusal muscle fibers; both the afferent and efferent roles are pivotal in coordinating proper muscle activity (Macintosh, Gardiner, & McComas, 2005). Alpha motor neurons have a complex sensory input which involves numerous muscle spindles, thermoreceptors, golgi tendon organs, mechanoreceptors and various other sensory neurons located throughout the periphery (Watkins, 2010). These complex anatomical connections create the necessary neural circuit structure which triggers reflexes (Watkins, 2010). The body has various types of reflex circuits with the most basic being a monosynaptic reflex, like the knee-jerk reflex, which consists of a solo synapse between a sensory neuron and an alpha motor neuron (Watkins, 2010). Interneurons are the most abundant type of neuron in the spinal cord and are the most extensive source of input for alpha motor neurons (Macintosh, Gardiner, & McComas, 2005). Interneurons have a variety of important roles including synapsing with alpha motor neurons to create a more intricate reflex circuitry (Macintosh, Gardiner, & McComas, 2005).

Efferent output. The primary purpose of alpha motor neurons is to innervate extrafusal muscle fibers. Alpha motor neuron activity is controlled in part through renshaw cells. Renshaw cells are inhibitory interneurons that have the ability to synapse with alpha motor neurons and limit their activity in order to prevent muscle damage (Watkins, 2010). Alpha motor neurons, signal like many other neurons, via transmission of action potentials, which are rapid changes in electrical activity that initiate from the cell body of the alpha motor neuron to the axon terminal (Macintosh, Gardiner, & McComas, 2005). The physiological structure of the alpha motor neuron allows for a rapid action potential due to their large diameter and high degree of myelination by both Schwann cells and oligodendrocytes (Macintosh, Gardiner, & McComas, 2005). The oligodendrocytes myelinated components of the alpha motor neuron reside in the peripheral nervous system (Watkins, 2010).

The extrafusal muscle fiber connects with the axon of an alpha motor neuron through the neuromuscular junction. The neuromuscular junction is a highly specialized category of chemical synapse which has a unique structure and function compared to other chemical synapses (Macintosh, Gardiner, & McComas, 2005). Both the neuromuscular junction synapse and other chemical synapses require neurotransmitters to transform the electrical signal into a chemical signal and then back to an electrical signal (Watkins, 2010). A distinguishing factor of the neuromuscular junction synapse is that the sole neurotransmitter used in acetylcholine whereas general chemical synapses usually use either gamma-aminobutyric acid or glutamate. The extrafusal muscle fibers have nicotinic acetylcholine receptors which sense the acetylcholine thus inducing muscle contraction (Macintosh, Gardiner, & McComas, 2005).

Efferent innervations of muscle spindles. The fusimotor system gives the CNS specialized control over the mechanical properties of muscle spindles. Gamma-fusimotor axons, which strictly innervate intrafusal fibers, and to a lesser extent beta-skeletofusimotor axons which innervate both extrafusal and intrafusal fibers, make up the efferent component of the fusimotor system (Matthews, 2008). Both gamma and beta axons can be dynamic, ending on the contractile regions of bag1 fibers, or static, ending on the contractile regions of bag2 or chain fibers (Prochazka, 1996). Activating the dynamic fusimotor system will activate contraction of bag1 fibers resulting in increased tension therefore increased the firing rate of primary afferents. Activation of static motorneurons causes contraction of bag2 and chain fibers within the muscle spindle leading to increased firing of both primary and secondary afferents. This system helps to establish the baseline activity level in alpha motor neurons, thus leading to control of both muscle tone and length (Hamill, 2010; Matthews, 2008).

Sensitivity modification. An important function of gamma motorneurons is to adjust the responsiveness of the muscle spindle sensory afferents to stretch (Matthews, 2008). The regulation of the stretch reflex is in part due to the ability of gamma motor neurons to alter the degree of tension in the intrafusal muscle fibers, located within the muscle spindle (Hamill, 2010; Matthews, 2008). When an active gamma motorneuron releases acetylcholine the end portions of the intrafusal fibers contract, therefore elongating the non-contractile portion. This action opens stretch sensitive ion channels in the sensory endings causing an influx of sodium ions thus raising the resting potential and the probability of action potential firing. The end result is an increased stretch sensitivity for the muscle spindle afferents. The primary role of this system is to supply proprioceptive feedback for muscles (Hamill, 2010).

Reflex Arcs: Overview

The neural pathway that controls a reflex action is referred to as a reflex arc. In the human body most of the sensory neurons do not reach the brain, but synapse in the spinal cord; thus speeding up the reflex action by shortening the process (Sokolov, 1994). While the autonomic reflex arc affects the inner organs, the somatic reflex arc affects the muscles. The somatic reflex arc typically consists of five components: 1) the receptor at the end of a sensory neuron reacts to a stimulus, 2) the sensory (afferent) neuron conducts nerve impulses along an afferent pathway towards the central nervous system (CNS), 3) the integration center consists of one or more synapses in the CNS, 4) a motor (efferent) neuron conducts a nerve impulse along an efferent pathway from the integration center to an effector, and 5) an effector responds to the efferent impulses by contracting (Macintosh, Gardiner, & McComas, 2005; Sokolov, 1994). A monosynaptic reflex arc is comprised of both a sensory neuron and a motor neuron which use a single chemical synapse (Watkins, 2010). The muscle spindles of the peripheral muscle reflexes only require a brief stimulation to yield a muscle contraction (Hamill, 2010). Conversely, a polysynaptic reflex arc is comprised of one or more interneurons which connect afferent (sensory) and efferent (motor) signals (Sokolov, 1994). Only the simplest reflexes arcs are monosynaptic; the vast majority of reflexes arcs are polysynaptic, thus allowing control of the spinal cords polysynaptic reflexes (Macintosh, Gardiner, & McComas, 2005; Sokolov, 1994).

Stretch Reflex

The stretch reflex is a unique form of muscle reflex with a primary role to protect the muscle from increases in muscle length that could injure the muscle fiber (Gruber et al., 2007). This unique stretch reflex mechanism plays an important role in posture (Hopkins et al., 2009). Muscle spindles are typically arranged in parallel with skeletal muscle fibers. When under tension the muscle spindle will respond via depolarization of a sensory neuron which in turn synapses with a motor neuron located within the spinal cord and leads to muscle contraction. This contraction of the extrafusal fibers reduces tension on the muscle spindle thus reducing the muscle spindle's neuron stimulation (Matthews, 2008).

The primary sensory fibers (Group Ia afferent neurons) in a muscle spindle of a stretched muscle will react to both changes in muscle velocity and length (Gruber et al., 2007). The response of the muscle spindle will alter the rate of action potentials in the spinal cord. Furthermore, secondary sensory fibers (Group II afferent neurons) have the ability to react to changes in muscle length by relaying the information to the spinal cord (Hamill, 2010). The monosynaptic transmission of the Ia afferent signals is received by the alpha motor neurons of the muscle receptor which is then conveyed through the efferent axons to the extrafusal fibers of the muscle, which allows the muscle to oppose stretch through the generation of muscle force (Gruber et al., 2007; Hamill, 2010). The Ia afferent signal also controls the stretch reflex by being transmitted polysynaptically via interneurons which causes the antagonist muscles to relax by inhibiting the alpha motor neurons response (Hamill, 2010; Matthews 2008).

Hoffmann-Reflex (H-Reflex)

The Hoffman reflex is comparable to the mechanically induced muscle spindle stretch reflex due to the fact that both have the ability to innervate muscle spindle fibers. The Hoffmann-reflex is a unique spinal reflex due to the fact that it can be elicited by a comparatively low threshold of electrical stimulation of a mixed peripheral nerve (Fornari & Kohn, 2008; Watkins, 2010). The H-reflex is also affected by a vibratory stimulus (which will be discussed in the following section). Generally the Hoffmann-reflex is considered monosynaptic, although there are some studies which propose that it may also be di- or trisynaptic in nature (Fornari & Kohn, 2008; Knikou, 2008; Watkins, 2010). The response of the H-reflex is nearly instantaneous (Fornari & Kohn, 2008). Once a peripheral nerve is stimulated it prompts the sensory impulses to travel up the afferent fibers (Ia), which allows for high-speed travel through the dorsal root to the spinal cord (Macintosh, Gardiner, & McComas, 2005). The matching alpha motorneurons located in the spinal cord, form synaptic connections which allow these alpha motor neuron impulses to orthodromically return to the muscle (Fornari & Kohn, 2008; Watkins, 2010).

Neuromuscular Response to Vibration

The effects of vibration on the function of tendons and muscles have been studied for well over a century (Rood, 1860). However, many of the pioneering vibration research studies occurred almost half a century ago (Lance, Neilson, & Tassinari, 1968; Walsh, 1968). One of the more important findings during this era comes from De Gail, Lance and Neilson (1966) who pioneered vibration research that delineated between phasic reflexes and tonic reflexes. The researchers noted that a muscle exposed to vibration brought forth a sustained contraction of the muscle while phasic reflexes such as the Hoffman reflex were diminished. The researchers hypothesized that the tonic muscle reflex was possibly due to stimulation of the muscle spindles by the vibratory stimulus whereas the diminished phasic reflex was possible due to an unknown mechanism within the central nervous system. A similar hypothesis was given by Matthews (1966) who studied how vibration affected the dependence of the reflex muscle contraction in cats. The researcher proposed that a vibration stimulus caused a stretching force on the muscle which triggered the muscle spindles to cause a stretch reflex which in turn creates a tonic contraction of the muscle. This phenomenon is predominantly referred to as the tonic vibration reflex (Kanda, 1972; Martin & Park, 1997; Nakajima, Izumizaki, Sekihara, Atsumi, & Homma, 2009).

The tonic vibration reflex or TVR is elicited when the primary ending of muscle spindles are stimulated by vibration, thus causing stimulation of the alpha motor neurons, which ultimately results in muscle contraction (Martin & Park, 1997). Tonic vibration reflex research reveals that this phenomenon has both monosynaptic and polysynaptic elements. Other tonic vibration research indicates that this reflex is influenced by several variables, including body position, precontraction of the muscle and magnitude of vibration (Desmedt, 1983; Kanda, 1972; Mansfield, 2004). Numerous research studies have revealed that a vibratory stimulus can elicit the tonic vibration reflex, but inhibits the stretch reflex and the Hoffmann-reflex; this observed phenomenon is now commonly referred to as the vibration paradox (Desmedt, 1983; Desmedt & Godaux, 1978; Flieger, Karachalios, Khaldi, Raptou, & Lyritis, 1998; Martin, Roll, & Gauthier, 1986). The vibration paradox is thought to occur because of the presynaptic inhibition of Ia afferents in the muscle spindle, thus simultaneously causing inhibition of the stretch response pathways, while stimulating vibratory pathways (Desmedt, 1983; Martin, Roll, & Gauthier, 1986).

Research reveals that the depression of the H-reflex is significantly greater than the stretch reflex. Furthermore during the post-vibratory state the Hoffmann reflex has a notably slow return to baseline values compared to the stretch reflex (Clark, Matthews, & Muir, 1981; Desmedt, 1983; Martin & Park, 1997). There is evidence to suggest that the inhibition of the Hoffman-reflex is due to a vibratory stimulus which is increased when the amplitude of vibration increases at a fixed frequency. However, inhibition of the Hoffman-reflex is not affected by an increase in vibratory frequency at a fixed amplitude (Fornari & Kohn, 2008; Hodgson, Docherty, & Zehr, 2008; Knikou, 2008). While there have been numerous studies on the effects of vibration on skeletal muscle the findings from these studies may not translate to the world of whole-body vibration exercise research. Additional empirical research on the effects of vibration exercise on the neuromuscular system needs to be conducted before valid conclusions can be drawn.

Electromyography: Overview

In muscle physiology, the neural control of excitable muscle fibers is predicated on the action potential mechanism. Motor unit recruitment and firing rate are the two principal methods which the central nervous system employs to increase force output (Basmajian & De Luca, 1985; Kamen & Gabriel, 2010). Electromyography is an instrument which can be used to examine both the motor unit recruitment and firing rates of the neuromuscular system (Enoka, 1994; Kamen & Gabriel, 2010). The EMG signal offers a valid and reliable means to quantify and examine muscular information within postural tasks, functional movements, occupation conditions and exercise protocols (Kamen & Gabriel, 2010; Konrad, 2005). Due to the relative ease of use, low invasiveness and range of applications, EMG is employed in a variety of clinical and research settings (Konrad, 2005).

Electromyography: Electrodes

The two types of electrodes used in electromyography are intramuscular and surface electrodes. Intramuscular electrodes use a fine wire or needle which can be inserted into a specific muscle thus allowing for the EMG recording of neuromuscular activity of single muscle units. For this reason diagnostic or clinical settings often use intramuscular electrodes. Due to its very low invasiveness, surface electromyography is carried out in both clinical and research environments (Kamen & Gabriel, 2010; Konrad, 2005). In surface electromyography, the electrodes are placed over the muscle sites of interest. Multiple muscle sites can be measured simultaneously, thus allowing for examination of activation patterns. Accurate placement of surface electrodes is very important for a reliable signal (De Luca, 1997; Kamen & Gabriel, 2010; Konrad, 2005). Surface electrodes need to be placed on the muscle belly so that they are oriented parallel to the direction of the muscle fibers (Kamen & Gabriel, 2010; Konrad, 2005).

Electromyography: Processing and Display

As a muscle unit, which typically consists of many muscle fibers, undergoes the process of depolarization and repolarization it creates an electrical impulse, known as a motor unit action potential (MUAP) which can be detected by electromyography (Kamen & Gabriel, 2010; Konrad, 2005). The MUAP's will vary in both size and form, primarily due to differences in the physical properties of the fiber orientation in relation to the electrode site (Kamen & Gabriel, 2010; Konrad, 2005). The EMG electrode is able to convert this detected MUAP electrical activity into a raw signal that is electrically superimposed and observed as a bipolar signal with a symmetrical distribution of both negative and positive amplitudes, which when averaged have a mean value of zero. Raw signals typically are found within a range of 6-500Hz with the vast majority of the frequency power found between 20-150Hz (Kamen & Gabriel, 2010; Konrad, 2005).

Once a raw EMG signal is obtained, it is typically full wave rectified—all negative values are converted to positive amplitudes. The rectified signal will partly contain an interference pattern of a random nature, which is brought about by the dynamic recruitment of available motor units and the arbitrary way the motor unit action potentials superpose (Kamen & Gabriel, 2010; Konrad, 2005). Because of this phenomenon the exact shape of the EMG bursts cannot be reproduced identically. To deal with this interference pattern, digital smoothing algorithms are applied that help to minimize the non-reproducible part of the signal. This smoothing process allows for steep amplitude spikes to be removed, thus creating a linear envelope which aids in establishing the mean trend of signal (Kamen & Gabriel, 2010; Konrad, 2005). The root mean square (rms) is the most common and recommended method for smoothing. This square root calculation based method, represents the signal's mean power (Kamen & Gabriel, 2010; Konrad, 2005).

The rectified and smoothed signal allows for standard amplitude computations, including the most common calculation, the amplitude mean value. The amplitude mean value is typically recommended due to the fact that this computation is more robust to duration differences in analysis intervals (Kamen & Gabriel, 2010; Konrad, 2005). The value of the mean EMG is considered the most accurate representation of the gross innervation input for the muscle under investigation; thus the mean EMG is generally recommended in analyses which involve comparison (Konrad, 2005). Integrated EMG, or IEMG signal, is based on the mean value calculation and can be employed when the input percent value of each muscle is desired or to determine the total amount of activity for a selected time period (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004). Deriving the IEMG involves a two step process. The first step is to summate the mean EMG values for the muscles under investigation and define the summation as

100%. In the second step, the percentage involvement of each muscle is determined, thus allowing for a distribution analysis which can help when comparison is desired (Konrad, 2005).

To improve the reliability of the information, data filtering is applied. Filtering is a method which helps to reduce noise and other possible extraneous sources of error which could affect the data. Generally there are four essential types of filters which can be applied to the data: 1) band-pass filter, 2) band-stop filter, 3) low-pass filter and 4) high-pass filter. A very common band-pass filter configuration would be 10 Hz high-pass to 500 Hz low-pass. This essentially means that the EMG instrument would only identify signals which fall within this range. If a signal does not fall within the range, it will be given a value of zero thus not influencing the results. In some limited situations data within a certain frequency range may want to be excluded in the data processing. In such a case, a band-stop filter may be employed to help remove a specific bandwidth. A band-stop filter is essentially two band-pass filters which allow all signals which fall between the settings to be attenuated to zero (De Luca, 2001). For example, if there was a valid reason to remove the signal between 30-40 Hz, a band-stop filter could be used, thus any signal found within that range would be removed. After appropriate signal processing, data analysis is possible. However, to make accurate conclusions about the meaning of the results requires a strong understanding of the neuromuscular system. The three most common methods used in EMG data analysis, involve examining the amplitude, time duration and shape of the signal (Konrad, 2005). Electromyography typically answers 5 general types of questions: 1) Is the muscle active? 2) Is the muscle more or less active? 3) When is the muscle active? 4) How much is the muscle active? and 5) Does the muscle fatigue?

Whole-Body Vibration Exercise: EMG Muscle Activity Research

Several whole-body vibration research studies have incorporated electromyography to help examine the neuromuscular activity of the skeletal muscles during vibration. Roelants, Verschueren, Delecluse, Levin and Stijnen (2006) examined the effects of vibration exercise (35 Hz at 2.5 mm) on leg muscle activity (gastrocnemius medialis, gastrocnemius lateralis, vastus medialis & vastus lateralis) by employing a repeated measures design which compared EMG muscle activity both with and without (control) vibration during 3 different isometric squat stances (high-squat, low-squat, one-legged squat). The results of the study found that WBV elicited a significantly higher ($p < 0.05$) EMGrms signal compared to the control condition in all four muscle groups and all three static squat exercises (between +39.9 +/- 17.5% and +360.6 +/- 57.5%). The researchers indicate that the greatest changes in EMG activity occurred in the gastrocnemius muscle, which was the muscle closest to the vibration platform; while the least amount of change in EMG activity occurred in the rectus femoris, which was the muscle furthest from the vibration platform.

Tihanyi, T. K., Horváth, Fazekas, Hortobágyi and Tihanyi, J (2007) employed a randomized controlled study which examined the effects of WBV on isometric and eccentric torque and electromyography (EMG) variables of knee extensors on the affected side of stroke patients. Sixteen ($n = 16$) stroke patients (age 58.2+/-9.4 years) were partaking in a stroke rehabilitation program shortly after having a stroke (27.2+/-10.4 days). Half the participants were randomly assigned to the vibration group (20 Hz at 5 mm; 1 minute six times in one session). The control group ($n = 8$) stood on the platform but without vibration. Measurements were taken for maximum isometric and eccentric torque, rate of torque development, root-mean-squared EMG, median frequency of the vastus lateralis, and co-activation of knee flexors. The results of the study found significant ($P < 0.05$) torque increases in both isometric (36.6%) and eccentric knee extension (22.2%) after vibration exercise compared with (isometric knee extension control, 8.4% and eccentric knee extension control, 5.3%) the control condition. Whole-body vibration significantly ($P < 0.05$) improved EMG amplitude 44.9% and the median frequency in the vastus lateralis by 13.1% with no significant change reported for the control group. The researchers concluded that in leg muscles affected by a stroke, one session of WBV can transiently increase voluntary force and muscle activation of the quadriceps muscle affected by a stroke.

Cochrane, Loram, Stannard and Rittweger (2009) conducted an observational study to establish if acute WBV would yield a change in muscle length concurrently with a change in EMG muscle activity of the lower leg. Nine healthy males underwent two fifteen second treatment conditions (without vibration and with vibration at (26 Hz, 6 mm) at a set knee angle of 18 degrees. Data from the medial gastrocnemius muscle revealed that the vibration condition yielded significantly ($P < 0.05$) greater muscle tendon complex amplitude (375 micron) when compared to the control condition (35 micron). The medial gastrocnemius muscle data also showed a significantly ($P < 0.01$) greater contractile length amplitude (176 micron) compared to the control condition (4 micron). The key finding of this study was that approximately 50% of the observed elongation was found within the muscle and was associated with an increase in EMG muscle activity. The researchers conclude this finding indicates that muscle lengthening may be a prerequisite needed to activate the stretch reflex.

Torvinen et al. (2002) employed a randomized cross-over study to examine the effects of WBV exercise (4-min, 2-mm & 30 Hz) on muscle performance and balance. Sixteen ($n = 16$) healthy participants (8 male & 8 female) aged 18-35 years did both the four minute vibration and a control (sham-intervention) in a cross-over randomized order on different days. Pre (10-min) and post (2 & 60-min) performance and balance tests were conducted (stability platform, grip strength, extension strength of lower extremities, tandem-walk, vertical-jump and shuttle-run). Furthermore, EMG of the soleus, vastus lateralis, gluteus medius, and paravertebralis muscles were examined during WBV. The pre and post results indicated that the 4-min WBV treatment did not induce any statistically significant ($P < 0.05$) change in the performance or balance tests.

The results indicated that the mean power frequency of the EMG in the vastus lateralis and gluteus medius muscles were reduced during WBV. The researchers hypothesized that this reduction, which was most pronounced in the hip region, was probably due to muscle fatigue.

Melnyk, Kofler, Faist, Hodapp and Gollhofer (2008) examined the effects of WBV on stretch reflexes involved in knee joint control. Twenty three (n = 23) healthy participants were divided into a either a control group or WBV intervention group. Both groups had the stretch reflex of the hamstring muscles triggered by inducing an anterior tibial translation while standing. The WBV group received two one minute vibration (30 Hz, 4 mm) sessions before having their stretch reflex evoked. Both short and medium latency responses of the hamstring muscles and tibia translation were measured through the use of potentiometers and EMG. There were no significant changes in latency; however a significant increase in the size of the lateral ($p = 0.039$) and medial ($p = 0.043$) hamstring muscle short latency responses were found after WBV. A significant ($p = 0.031$) decrease in maximum tibial translation was found after WBV. Based on these findings the researchers concluded that WBV exercise has a positive effect on knee joint stability which is likely due to the increase in hamstring short latency response size in reaction to the anterior tibial movement which might have caused the decrease found in the anterior tibial translation.

McBride et al. (2010) examined the effects of an acute bout of WBV on motor neuron excitability and muscle force output. Nineteen (n = 19) males were randomly assigned to either a WBV intervention, which consisted of a sequence of isometric body weight squats while vibrating (30 Hz, 3.5 mm) or a sham (control) group which did the same exercise sequence but without vibration. Pre and post measurements involved ballistic isometric voluntary contraction of the triceps muscles measured by EMG, and electrical stimulation of the tibial nerve for assessment of motorneuron excitability. No significant changes in motor neuron excitability or triceps average integrated EMG muscle activity were reported. However, a significant ($P < 0.05$) increase in peak force was found immediately post WBV (9.4%) and 8-minutes post WBV (10.4%).

Cardinale and Lim (2003) conducted a repeated measures study which examined the effects of different frequencies on EMGrms responses in the vastus lateralis in female athletes. Sixteen (n = 16) female college volleyball players (age, 23.9 $\pm$ 3.6 years; height, 182.5 $\pm$ 11.1 cm; weight, 78.4 $\pm$ 5.6 kg) participated in the research study. For each trial participants received one minute of WBV at the various frequencies (30 Hz, 40 Hz, & 50 Hz) while in a static squat position (100 degree knee angle) at a fixed amplitude (5 mm). The results were compared to a control condition (no vibration). There were statistically significant ($p < 0.05$) increases in muscle activity in all conditions compared to control. The increases in EMGrms were minimal and decreased with an increase in frequency (30 Hz = 34%, 40 Hz = 20%, & 50 Hz = 10%). The researchers concluded that the highest reflex response was at 30 Hz which they postulated was likely close to the natural resonance frequency of the vastus medialis.

Hazell, Jakobi and Kenno (2007) employed a repeated measures design which examined the effects of WBV on both upper- and lower-body muscle activities, while under different exercise conditions in an attempt to determine optimal frequency and amplitude settings. Ten (n = 10) recreationally active male university students (24.4 + 2.0 years) each experienced 10 different WBV setting combinations ([2 amplitudes: 2 & 4 mm] x [5 frequencies (Hz): 25, 30, 35, 40, & 45]) and a control condition (no vibration) while performing various exercises (isometric semi-squat, dynamic leg squats, and static and dynamic bilateral bicep curls). EMG muscle activity was measured in both the lower-body (vastus lateralis (VL) & biceps femoris (BF)) and upper-body (biceps brachii (BB) & triceps brachii (TB)). Some small but significant ($p < 0.05$) results were reported. In the static semi-squat condition an increase in EMG was found in the VL (2.9%-

6.7%) and in the BF (0.8%-1.2%). In the dynamic squatting condition an increase in EMG was found in the VL (3.7%-8.7%) and in the BF (0.4%-2.0%). In the static biceps curl condition the researchers reported no significant change in muscle activity. However, the researchers did find a small increase in EMG in the TB (0.3%-0.7%). In the dynamic bicep curl condition an increase in EMG was found in the BB (0.6%-0.8%) and TB (0.2%-1.0%). The researchers concluded that WBV elicited the largest changes in EMG muscle activity in the lower-body and at the higher amplitude (4 mm) and higher frequencies (35 Hz, 40 Hz, & 45 Hz).

In conclusion, based on the several WBV studies which have examined EMG muscle activity while under various vibratory conditions; it is evident that vibration produces some neuromuscular stimulus in some muscle groups. Most of the studies use a non-vibration control condition to compare the changes in EMG muscle activity. Furthermore, most of the studies chose a squat stance for body position as this stance likely has the most real world application. The majority of studies which measure EMG activity in both the lower and upper leg muscles are reporting the greatest change in EMG muscle activity in the muscles closest to the vibratory stimulus—lower leg muscles. To date, no studies have employed a repeated measures research design which examines muscle activity in both plantar flexor and knee extensor muscles at eight (2 amplitudes x 4 frequencies) different levels of g-force while all four levels of frequency are experienced in the same trial.

CHAPTER III

METHODOLOGY

Experimental Approach to the Problem

To examine the relationship between gravitational force and exercise intensity, a repeated measures design was used to examine surface electromyography (SEMG) muscle activity in the vastus lateralis (V.L.), vastus medialis (V.M.), gastrocnemius lateralis (G.L.) and gastrocnemius medialis (G.M.) muscles during WBV exercise (Power Plate Pro5^{tm}). Participants, performed a standard unloaded isometric high-squat exercise at eight different levels (k = 8) of g-force. The 8 different levels of g-force were derived from four different preset frequency settings (30, 35, 40, and 50 Hz) measured at both the low and high amplitude settings. Each participant underwent four trials at both amplitude settings for a total of eight trials. In each trial a participant experienced all four preset frequencies and a control condition. Each trial was 50-seconds in total, which was broken down into five 10-second sub-trials. The first 10-second sub-trial was without vibration thus allowing this phase to act as a control trial. The following four 10-second sub-trials were at the four preset frequencies assigned in a four-by-four balanced Latin square (see Appendix E) to protect against a potential order effect. The vibration exercise intensity (VEI) was operationally defined as the WBV-induced percent increase in EMGrms compared with the control condition (no vibration). Control trial data was expressed as a percent of maximum voluntary contraction (MVC) thus allowing for inter-subject comparisons. The VEI was determined for each level of g-force in each of the four muscle groups, therefore allowing the relationship between g-force and VEI to be examined.

Participants

For this study, twenty healthy adults (n = 12: 7 male, 5 female) within an age range of 18-45 years were recruited to volunteer for participation. Reasons for exclusion were a positive (yes) response to any of the seven questions on the physical activity readiness questionnaire (PAR-Q) or a body mass index (BMI) greater than the normal range (24.9 kg/m^2). This study was approved by Texas Woman's University Institutional Review Board (IRB) before data collection commenced (see Appendix A).

EMG Analysis

The surface EMG signals (Noraxon Telemyo^{tm} 900, Noraxon Inc., U.S.A.) from the knee extensor muscles (V.L. and V.M.) and plantar flexor muscles (G.L. and G.M.) of the dominant leg (see Appendix F for detailed electrode attachment locations and orientations) were recorded with single disposable Ag-AgCl gel surface electrodes (Noraxon, Inc. U.S.A., single electrodes with a diameter of the circular adhesive area, 3.8 cm; diameter of the circular conductive surface, 1.0 cm) with an inter-electrode distance of 2.0 cm. At electrode attachment sites, the skin was properly prepared by ensuring that all hair was shaven if needed and then cleaned with a sterile alcohol prep pad and allowed to thoroughly dry before electrode placement. A reference electrode was attached to the Tibial Tuberosity. The preamplified EMG signals were amplified (x 1000), band-pass filtered (10 Hz - 500 Hz), full-wave rectified, smoothed (RMS = 200 ms), and sampled at 1,000 Hz (MyoResearch XP Masters Edition 1.04, Noraxon Inc., U.S.A.) for off-line analysis. To reduce artifact, notch filters were placed at the vibration frequencies used in the study (30, 35, 40, and 50 Hz). Electromyography cables were secured with a light tensor bandage to prevent cable movement and motion artifact.

Maximal Voluntary Contractions (MVC's)

After positioning the electrodes the experiment session started with a recommended standard warm-up consisting of 5-minutes of ergometer cycling without resistance, to reduce the risk of possible muscle strain from the MVC's. Maximal voluntary contraction data for the plantar flexor muscles (G.L. and G.M.) was determined by performing an isometric seated toe press (unilateral plantar flexion at 90 degrees ankle flexion) on the seated calve press machine (Cybex International Inc., Medway M.A.). Maximal voluntary contraction data for the knee extensor muscles (V.L. and V.M.) was determined by performing an isometric seated single leg knee extension (70-90 degrees) on the leg extension machine (Cybex International Inc., Medway M.A.). For each exercise, participants performed two maximal voluntary isometric contraction trials. Each trial was performed over 5-seconds on the dominant leg with a 90-second rest period in between trials. If MVC trial data differed by more than 10%, a third trial was conducted. A 3-minute rest period was given between MVCs data collection and the WBV exercise trials.

Whole-body Vibration Exercise Trials

Before the WBV exercise trials began all participants experienced a mock trial to familiarize themselves with the WBV trial procedures and correct body position. During all WBV trials, participants were placed in a standard unloaded isometric high-squat position (knee angle 30 degrees, hip angle 30 degrees, feet [middle toe to middle toe] 30cm apart). Furthermore, participants had a slight touch on the handle of the vibration platform, as pilot work indicated that this improved static body position while vibrating. Posture was strictly controlled during all trials by having both knee and hip joint angles standardized through the use of a goniometer. In addition, a straight back was required for all trials. The whole-body vibration testing procedures consisted of eight different g-force levels (k = 8) which were derived from the four different preset frequency settings (30, 35, 40, and 50 Hz) measured at both the low and high preset amplitude settings on the Power Plate Pro5^{tm}. Eight trials were conducted in total starting with four trials at the low amplitude followed by four more trials at the high amplitude. Each trial included all four preset frequency levels. Each trial was 50-seconds in total, which was broken down into five 10-second sub-trials. The first 10-second sub-trial was without vibration. The following four 10-second sub-trials consisted of the four frequency levels, which were assigned in a four-by-four balanced Latin square design (see Appendix E) to protect against a potential order effect. Between all 50-second trials participants were given a 5-minute rest period in which they will be seated in a chair to unload the muscles and to avoid any potential carry-over effects of vibration exercise.

Data Analysis

The amplified raw EMG signal was converted to an average rms signal. The middle 4-seconds of each sub-trial were computed for each level of g-force in each muscle group for all trials. The effect of WBV on muscle activity was referred to as the vibration exercise intensity (VEI) and was operationally defined as the WBV-induced percent increase in EMGrms compared with the control condition (no vibration). Control trial data was expressed as a percent of maximum voluntary contraction (MVC) thus allowing for inter-subject comparisons. The mean values and the standard deviation for each muscle group of all trials were selected for statistical analysis.

Statistical Analysis

Statistical analysis was performed using a 3-way (muscle groups x amplitude x frequency) repeated measures ANOVA. When an overall F value was found to be significant, contrast analyses (Tukey HSD post hoc analysis with a Bonferroni correction) were performed to determine which means were significantly different. Effect sizes (partial eta^2) and data trends were determined for all hypotheses. All analyses were conducted by the statistical package SPSS, version 15.0 (SPSS, Inc., Chicago IL). Significance level was set at $p \leq 0.05$.

CHAPTER IV

RESULTS

To examine the relationship between gravitational force and exercise intensity, a 3-way (4-muscle groups x 4-frequencies x 2-amplitudes) repeated measures ANOVA was employed which analyzed surface electromyography (EMG) muscle activity in both plantar flexors (G.L. and G.M.) and knee extensors (V.L. and V.M.) muscles during WBV training while standing in a static high-squat position. Recall that the operational definition of VEI was the WBV-induced percent increase in EMGrms compared with the control condition—no vibration. Control trial data was expressed as a percent of MVC's. The mean and standard deviation values for the VEI were determined for each level ($k = 8$) of g-force. In all figures in this chapter, the VEI was expressed on the ordinate axis. Significant ($p < .05$) differences were found in all three of the main effects but only in one of the interaction effects—muscle group x frequency. Contrast analyses (Tukey HSD Post-hoc analysis with a Bonferroni correction) were performed on all significant findings to determine which means were significantly different from one another. The results of this study are presented in the following order:

1. Participant's descriptive statistics.
2. Summary table of group data
3. ANOVA summary table.
4. Summary tables for contrast analyses.
5. Hypotheses testing for main and interaction effects.
6. Figures representing pertinent data trends.

Table 1

Participants (N = 12) Descriptive Statistics.

Variable	N	Mean	S.D.
Participants	12	-	-
Male	7	-	-
Female	5	-	-
Age (years)	12	29.4	6.4
Height (cm)	12	171.4	4.9
Weight (kg)	12	67.4	10.4
Body Mass Index (kg/m^2)	12	22.9	2.6

Table 2

Summary Table of Group Data.

Muscle	30 Hz				35 Hz			
	Low Amp.		High Amp.		Low Amp.		High Amp.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
G.M.	1.06	0.28	1.82	0.38	1.13	0.17	1.80	0.35
G.L.	1.14	0.32	1.42	0.34	0.95	1.90	1.27	0.30
V.M.	0.36	0.14	0.85	0.19	0.39	0.15	0.68	0.20
V.L.	0.37	0.11	0.62	0.12	0.37	0.10	0.63	0.19
Muscle	**40 Hz**				**50 Hz**			
	Low Amp.		High Amp.		Low Amp.		High Amp.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
G.M.	1.57	0.43	1.94	0.61	1.27	0.32	1.66	0.40
G.L.	0.75	0.19	1.19	0.36	0.77	0.20	1.14	0.35
V.M.	0.23	0.10	0.44	0.18	0.13	0.11	0.28	0.17
V.L.	0.25	0.10	0.45	0.09	0.18	0.11	0.31	0.15

Note: Values represent the mean ± S.D. for the VEI response (percent increase from control) at both levels of amplitude (Low Amp. and High Amp.) across all four levels of frequency (30, 35, 40, and 50 Hz) in all four muscle groups: gastrocnemius medialis (G.M.), gastrocnemius lateralis (G.L.), vastus medialis (V.M.), and vastus lateralis (V.L.).

Table 3

Summary Table for a 3-Way Repeated Measures Analysis of Variance: Muscle Group, Frequency (Hz) and Amplitude (N = 12).

Source	df	SS	MS	F	P	Partial Eta^2 (Trend)
Muscle Group	3	87.08	29.03	11.17	.001	.573
Error	33	85.78	2.60			(cubic)
Frequency (Hz)	3	3.01	1.00	6.47	.001	.450
Error	33	5.13	.16			(linear)
Amplitude	1	11.60	11.60	30.81	.001	.737
Error	11	4.14	.38			(linear)
Muscle Group by Frequency	9	3.73	.41	2.61	.010	.365
Error	99	15.74	.16			(cubic/cubic)
Muscle Group by Amplitude	3	1.51	.50	1.23	.314	.063
Error	33	13.49	.41			(linear)
Frequency by Amplitude	3	.47	.16	2.69	.062	.518
Error	33	1.91	.06			(linear)
Muscle Group by Frequency by Amplitude	9	.73	.08	1.08	.387	.350
Error	99	7.50	.08			(cubic/linear/linear)

Note: $Df_{error} = (n - 1)(Df_{effect})$.

Table 4

Significant Differences (*) Among Main Effect Means for Muscle Group Using Tukey's HSD Test.

	G.L.	G.M.	V.L.	V.M.
G.L.	-	-.453	.681*	.659
G.M.		-	1.134*	1.112*
V.L.			-	-.022
V.M.				-

Note: gastrocnemius medialis (G.M.), gastrocnemius lateralis (G.L.), vastus medialis (V.M.), and vastus lateralis (V.L.). Values represent percent differences between means for the VEI response.

$\alpha < 0.05$*

Table 5

Significant Differences (*) Among Main Effect Means for Frequency (Hz) Using Tukey's HSD Test.

	Frequency (Hz)			
	30 Hz	35 Hz	40 Hz	50 Hz
30 Hz	-	.053	.103	.239*
35 Hz		-	.050	.185*
40 Hz			-	.135*
50 Hz				-

Note: Values represent percent differences between means for the VEI response. $\alpha < 0.05$*

Table 6

Significant Differences (*) Among Interaction Effect Means for Muscle Group and Frequency (Hz) Using Tukey's HSD Test.

		30 Hz		
	G.L.	G.M.	V.L.	V.M.
GL	-	-.163	.780***	.672***
GM		-	.943***	.835***
VL			-	-.108
VM				-
		35 Hz		
	G.L.	G.M.	V.L.	V.M.
GL	-	-.354*	.613***	.580***
GM		-	.967***	.934***
VL			-	-.033
VM				-
		40 Hz		
	G.L.	G.M.	V.L.	V.M.
GL	-	-.781***	.621***	.638***
GM		-	1.402***	1.419***
VL			-	-.017
VM				-
		50 Hz		
	G.L.	G.M.	V.L.	V.M.
GL	-	-.515***	.712***	.747***
GM		-	1.227***	1.262***
VL			-	-.035
VM				-

Note: Frequency (Hz) in the gastrocnemius medialis (G.M.), gastrocnemius lateralis (G.L.), vastus medialis (V.M.), and vastus lateralis (V.L.). Values represent percent differences between means for the VEI response. $\alpha < 0.05$*, $\alpha < 0.01$**, $\alpha < 0.001$***

Table 7

Significant Differences (*) Among Interaction Effect Means for Frequency (Hz) and Amplitude Using Tukey's HSD Test.

High Amplitude				
	30 Hz	35 Hz	40 Hz	50 Hz
30 Hz	-	.083	.173	.330*
35 Hz		-	.090	.248*
40 Hz			-	.158
50 Hz				-
Low Amplitude				
	30 Hz	35 Hz	40 Hz	50 Hz
30 Hz	-	.023	.033	.145
35 Hz		-	.010	.123
40 Hz			-	-.033
50 Hz				-

Note: Values represent percent differences between means for the VEI response. $\alpha < 0.05$*

Null Hypotheses Testing

Main Effects

1. The null hypothesis for muscle groups was rejected as a significant difference in EMG muscle activity between the muscle groups was determined (see Table 3). Contrast analyses (see Table 4) indicate where the significant differences among means for muscle groups exist.
2. The null hypothesis for frequency was rejected as a significant difference in EMG muscle activity between the frequencies was determined (see Table 3). Contrast analyses (see Table 5) indicate where the significant differences among means for frequencies exist. The trend data (see Figure 2) illustrates a negative linear trend.
3. The null hypothesis for amplitude was rejected as a significant difference in EMG muscle activity between the amplitudes was determined (see Table 3). The findings indicate an approximately 35% difference exists among the means for the low amplitude (68.2% $\pm$ 3.7%) and high amplitude (103.0% $\pm$ 7.6%) exist.

Interaction Effects

4. The null hypothesis for muscle group by frequency was rejected as a significant difference in EMG muscle activity between the muscle groups and frequencies was determined (see Table 3). Contrast analyses (see Table 6) indicate where the significant differences among means for muscle groups and frequencies exist. The trend data (see Figure 3) illustrates very similar VEI responses in both knee extensors, but varying VEI responses in the plantar flexors.
5. The null hypothesis for muscle group by amplitude was accepted as no significant difference in EMG muscle activity between the muscle groups and amplitudes was determined (see Table 3).

6. The null hypothesis for frequency by amplitude was accepted as no significant difference in EMG muscle activity between the frequencies and amplitudes was determined (see Table 3). The trend data (see Figure 4 and 5) illustrates a positive linear trend in amplitude, and a negative linear trend in frequency.
7. The null hypothesis for muscle group by frequency by amplitude was accepted as no significant difference in EMG muscle activity between the muscle groups and frequencies and amplitudes was determined (see Table 3). The trend data illustrates that no discernable relationship between g-force and VEI exists in either the plantar flexors (see Figure 6) or knee extensors (see Figure 7).

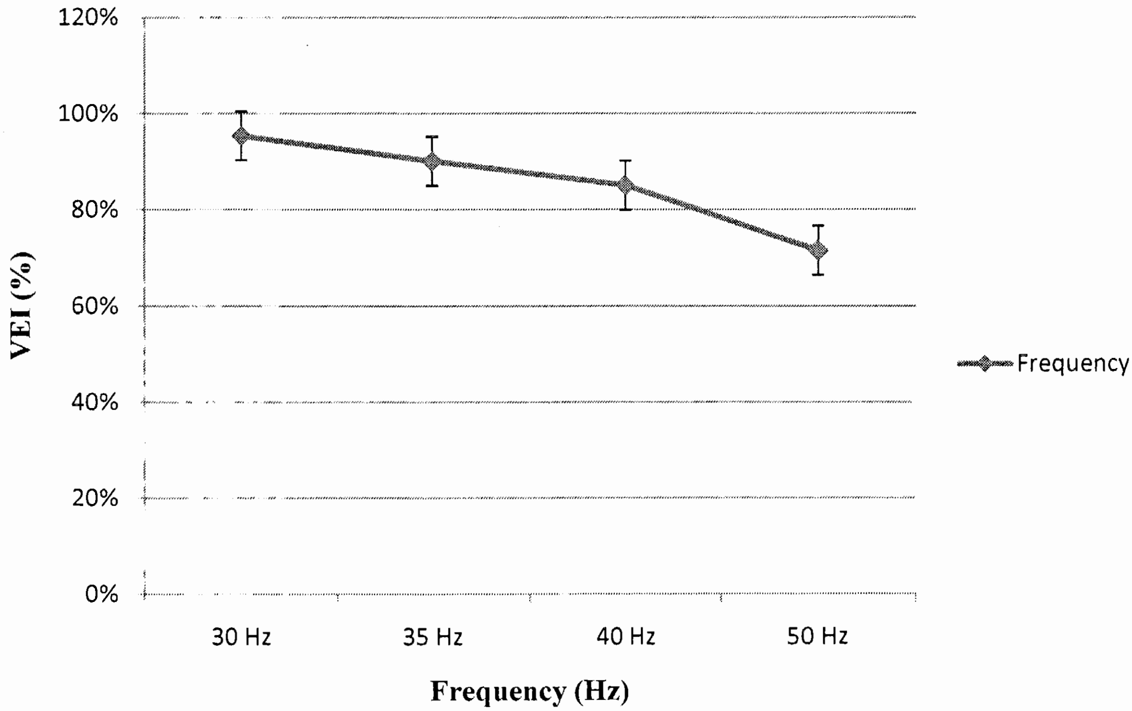

Figure 2. Main effect for frequency's (Hz). Note: values represent the mean ± S.E. of the VEI response (percent increase from control). See Table 5 for significant differences.

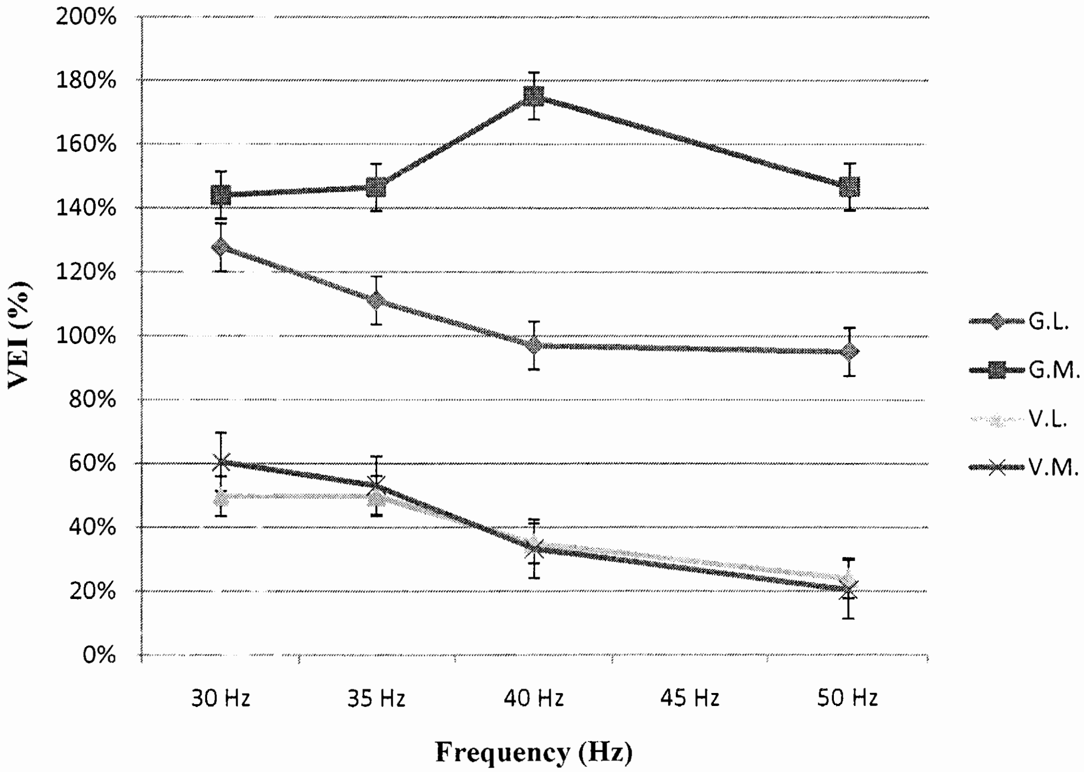

Figure 3. Interaction effect between muscle groups and frequency's (Hz). Note: gastrocnemius medialis (G.M.), gastrocnemius lateralis (G.L.), vastus medialis (V.M.), and vastus lateralis (V.L.). Values represent the mean $\pm$ S.E. of the VEI response (percent increase from control). See Table 6 for significant differences.

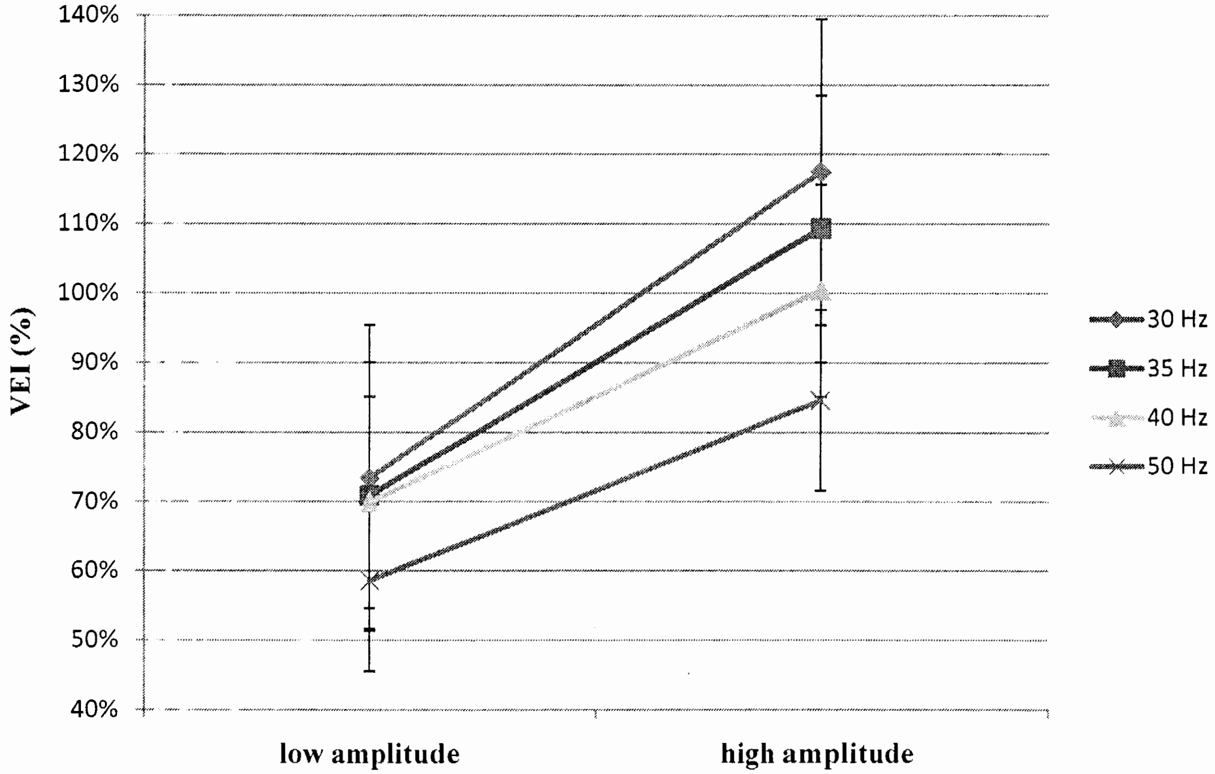

Figure 4. Interaction effect between frequency (Hz) and amplitude. Note: amplitude is plotted on the abscissa. Values represent the mean $\pm$ S.E. of the VEI response (percent increase from control). See Table 7 for significant differences.

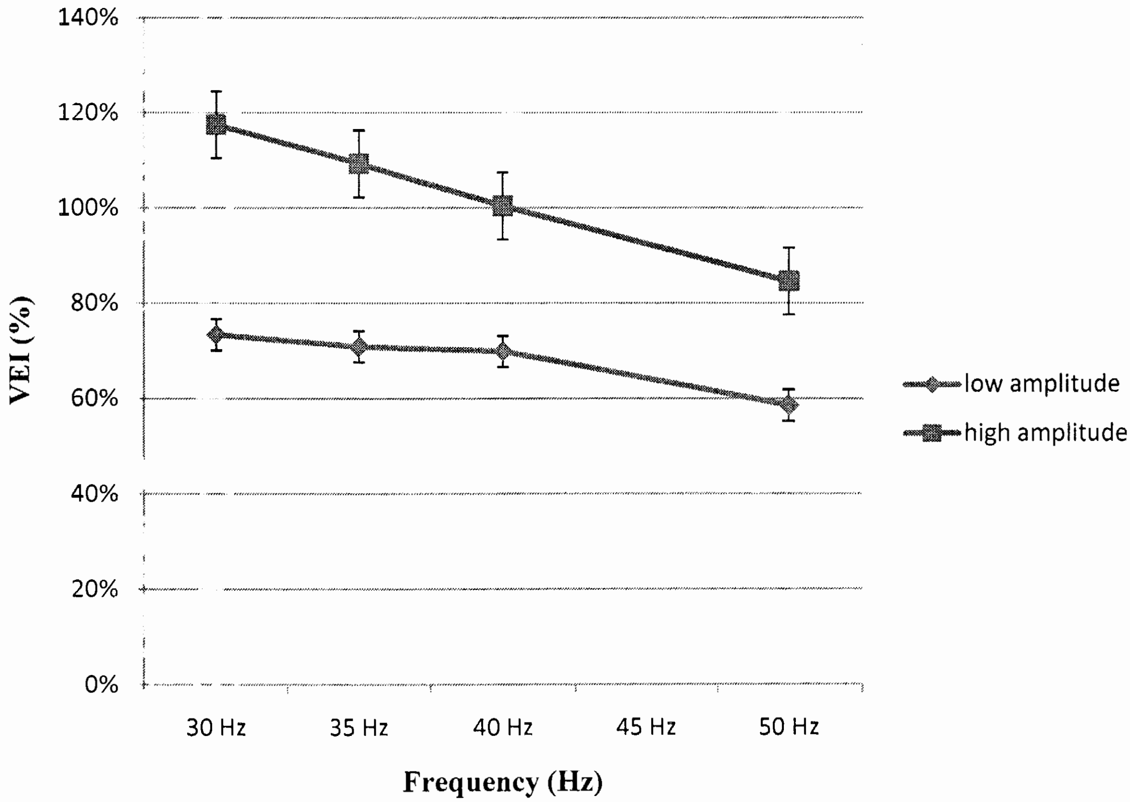

Figure 5. Interaction effects between frequency (Hz) and amplitude. Note: frequency is plotted on the abscissa. Values represent the mean ± S.E. of the VEI response (percent increase from control). See Table 7 for significant differences.

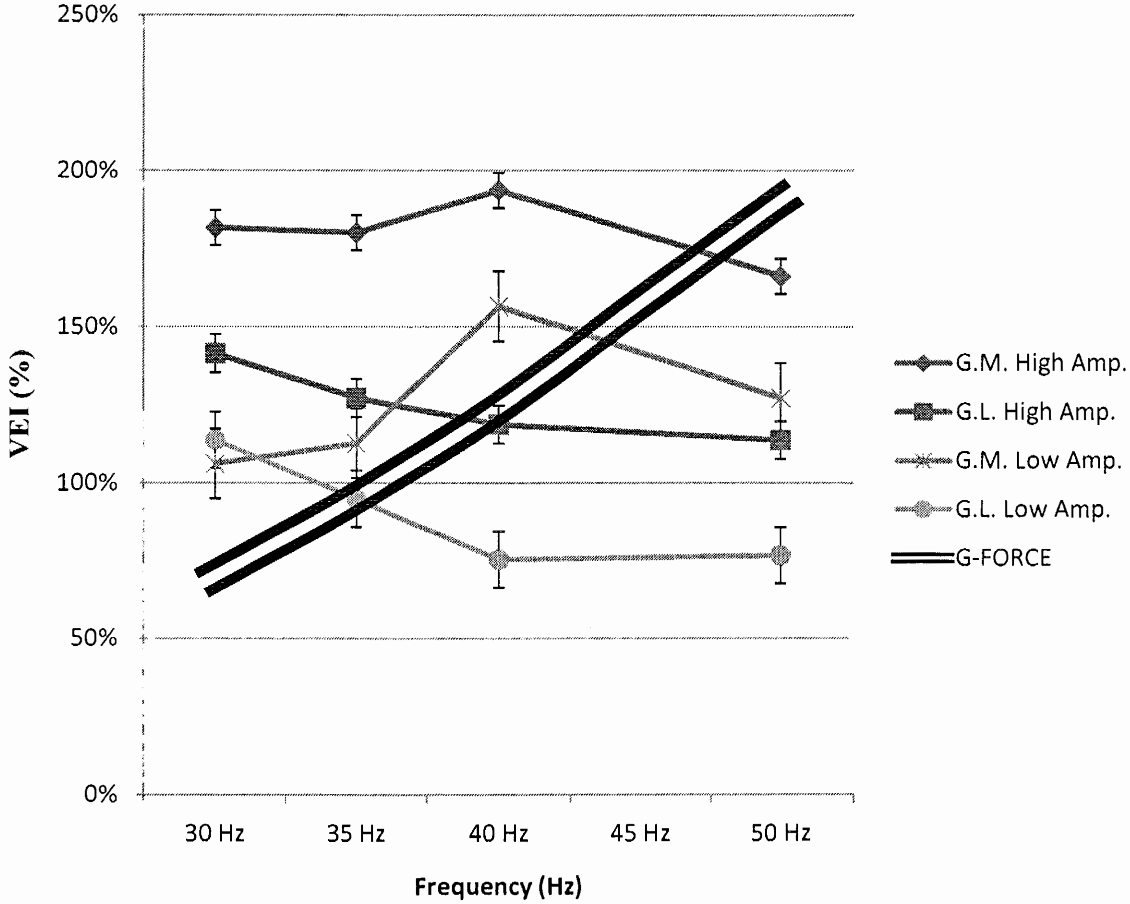

Figure 6. The relationship between g-force and VEI responses in the plantar flexor muscles. Note: vastus medialis (V.M.) and vastus lateralis (V.L.) at both the high amplitude (High Amp.) and low amplitude (Low Amp.) settings across all four frequency levels (30, 35, 40, and 50 Hz). Due to the higher VEI responses in the plantar flexor muscles, the ordinate axis is in a different scale than in Figure 8. Values represent the mean ± S.E. of the VEI response (percent increase from control). The g-force trend line represents the relationship between frequency and g-force at an arbitrary fixed amplitude, not the actual g-forces used in the study.

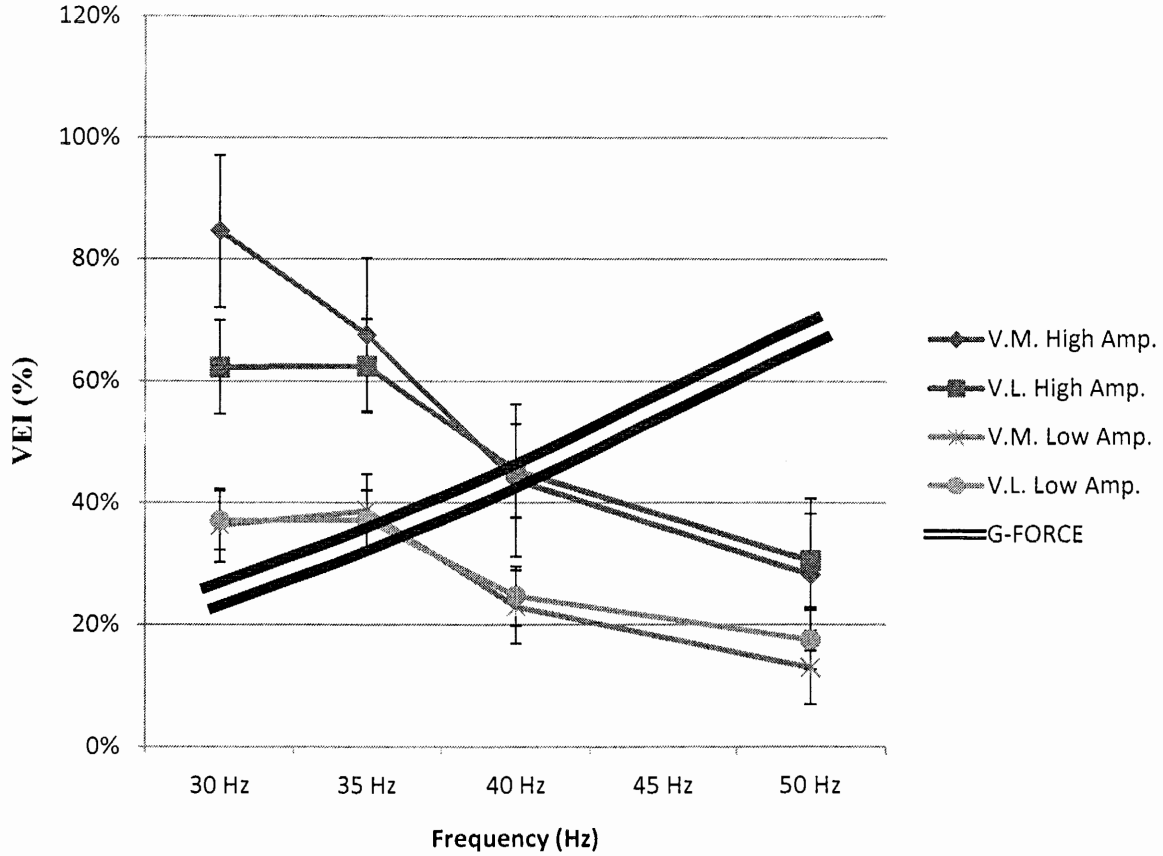

Figure 7. The relationship between g-Force and VEI responses in the knee extensors muscles. Note: vastus medialis (V.M.) and vastus lateralis (V.L.) at both the high amplitude (High Amp.) and low amplitude (Low Amp.) settings across all four frequency levels (30, 35, 40, and 50 Hz). Due to the lower VEI found in the knee extensor muscles, the ordinate axis is in a different scale than in Figure 7. Values represent the mean ± S.E. of the VEI response (percent increase from control). The g-force trend line represents the relationship between frequency and g-force at an arbitrary fixed amplitude, not the actual g-forces used in the study.

CHAPTER V

DISCUSSION AND CONCLUSION

The primary aim of this investigation was to determine if gravitational force is a valid measurement of VEI. The secondary aim is to examine the muscle activity responses of the plantar flexors (gastrocnemius lateralis, G.L. and gastrocnemius medialis, G.M.) and knee extensors (vastus lateralis, V.L. and vastus medialis, V.M.) to the various frequency and amplitude settings. Vibration exercise intensity (VEI) was defined as the WBV-induced percent increase in EMGrms compared to the control condition (no vibration). Additionally, to allow inter-subject comparisons, control data was expressed as a percentage of MVC data. In all figures in chapter IV, the ordinate axis represents the VEI. Significant ($P < .05$) differences were found in all three of the main effects (muscle group, frequency and amplitude) but only in one of the interaction effects—muscle group by frequency. Contrast analyses (Tukey HSD Post-hoc analysis with a Bonferroni correction) were performed on all significant findings to determine which means were significantly different from one another. This discussion focuses on the two aims of this study as opposed to each separate hypothesis. Unfortunately a paucity of research exists on EMG muscle activity at various frequency and amplitude settings, thus making comparisons of the present investigation findings to numerous other studies impossible.

G-Force

Recall that in the WBV g-force equation ($g = A \times (2\pi f)^2/9.81$) the amplitude (A) is a first degree polynomial; thus the amplitude will affect g-force in a linear fashion. In simpler terms, if the amplitude was doubled at a fixed frequency, the resultant g-force would also be doubled. Furthermore, the frequency (f) is a second degree polynomial; thus frequency will affect g-force in a quadratic fashion. In simpler terms, if the frequency was doubled at a fixed amplitude, the resulted g-force would be quadrupled. Therefore, when comparing equal percent changes in both amplitude and frequency, it is evident that frequency has the greater affect on g-force. If gravitational force is a valid measurement of VEI then EMG muscle activity responses should reflect a strong positive relationship. The findings (see Figure 6) of this study clearly indicate that in both plantar flexor muscles examined the VEI response trend does not reflect a positive relationship with g-force. Note that in both the G.L. and G.M. the VEI responses for both amplitudes show at least one value at 50 Hz (frequency which produces the largest g-force) that is lower than the VEI responses at the smaller frequencies (30, 35, and 40 Hz). Furthermore, the findings (see Figure 7) of this study clearly indicate that in both knee flexor muscles examined the VEI response does not reflect a positive relationship with g-force. Note that in both the V.L. and V.M. the VEI responses at both amplitudes are lower at 50 Hz than at all other frequency levels (30, 35, and 40 Hz). The results (see Figure 7 and 8) of this study strongly suggest that that in all muscles examined, gravitational force is not a valid measurement of VEI. The relationship of frequency and amplitude on muscle activity will be discussed.

Frequency

The null hypothesis for the main effect of frequency was rejected as there was a significant difference in VEI responses between the frequencies. A moderate effect size (partial eta^2 = 45.0%) for frequency was reported along with a predominantly linear trend (see Table 3). Contrast analyses (see Table 5) reveal that the 50 Hz frequency yields a significantly lower VEI response than all other frequency levels (30, 35, and 40 Hz). No other significant differences in VEI responses were found between the means. The results (see Table 5) reveal that approximately a 25% mean difference exists between the highest VEI response, which was found at the lowest frequency (30 Hz = 95.4% $\pm$ 7.3%), and the lowest VEI response which was found at the highest frequency (50 Hz = 71.6% $\pm$ 4.7%). The trend data (see Figure 2) of the main effects for frequency clearly indicate that a reduced VEI response is occurring with an increase in frequency. This finding is not implying that a true inverse relationship between frequency and muscle activity responses exists; if it did then the maximal muscle activity responses would occur as frequency approached a zero value, which is certainly not the case. What the findings for the main effect of frequency illustrate is that an increase in g-force due to an increase in frequency does not elicit a higher VEI response.

A vast amount of empirical research has been conducted on traditional vibration research. In general the research indicates that the degree to which vibration is transmitted to the body predominately depends on the frequency of vibration. Furthermore, the biodynamic responses of the body are generally considered frequency dependent (Dong, Rakheja, Schopper, Han, & Smutz, 2001; Griffin, 1996). These traditional vibration research biodynamic responses likely translate into the WBV exercise arena. Thus the WBV muscle activity responses are most likely primarily frequency dependent but not as a linear function, in which an increase in frequency leads to a proportional increase in muscle activity. The natural resonant frequency of the body's tissues, including a muscle group like the G.M., will influence the biodynamic response of muscle activity. Recall from the review of literature that resonance is the tendency of a mechanical system (e.g. G.M.) to oscillate at an increased magnitude while at or near the natural resonance frequency of the system. Thus the magnitude of the vibrations in a muscle is amplified when the natural resonant frequency of the muscle is close to that of the frequency. It is possible for a mechanical system to have more than one natural resonant frequency. The natural resonance frequency of a muscle can be altered by various factors, including changes in length and level of preactivation (Burke, Hagbarth, Lofstedt, & Wallin, 1976; Martin & Park, 1997; Nordin & Hagbarth, 1996; Park & Martin, 1993). The magnitude of these larger frequency vibrations can be reduced by damping from the tissues of the body, particularly via an increase in muscle activity. This muscle response is hypothesized to occur in an attempt to dampen the vibration energy experienced by the body by tuning the muscles—muscle tuning hypothesis (Boyer & Nigg, 2004; Cardinale & Wakeling, 2005; Wakeling, Nigg, & Rozitis, 2002).

Another possible explanation for the increase in frequency corresponding with the lower VEI responses could relate to the transmissibility of vibration to the body. Traditional vibration research by Fairley and Griffin (1989) reported that increased muscle tension can lead to an increase in the resonance frequency of the tissue. Furthermore, the researchers reported that an increase in vibration magnitude can cause a decrease in muscle tension, or 'softening' of the system (body) and a cause a lowering of the resonance frequency. The investigators postulated that a softening of the system could be due to involuntary loss of muscle tone, phasic muscle activity excited by vibration, or the thixotropic behavior of muscles. Another possible explanation may be from the frequency of vibration, which has been theorized to effect the response time of muscle activity. A traditional vibration study by Seidel, Bluethner and Hinz (1986) examined EMG muscle activity in the lumbar spine across a range of frequencies (1-15 Hz) and found that the timing of muscle activity responses varied at different frequencies. Based on the findings, the investigators hypothesized that the timing of muscle activity responses is likely due to the timing of the sinusoidal wave. Furthermore, the investigators hypothesized that the timing of the muscle activity responses is crucial to whether or not a beneficial or detrimental biodynamic response occurs and that some frequencies may be unfavorably timed for muscle activity.

The frequency results of the present study are congruent with research conducted by Cardinale and Lim (2003) on EMG activity of the V.L. muscle of professional female volleyball players ($n = 16$) during whole-body vibration exercise at different frequencies (30, 40, and 50 Hz). The researchers reported an approximate 20% ($p < 0.05$) higher EMG response at 30 Hz

(+34%) than at 50 Hz (+15%). Additionally, an approximately 10% ($p < 0.05$) higher EMG response was found at 40 Hz (+25%) than at 50 Hz. The investigators concluded that 30 Hz yielded the highest muscle activity in the V.L. and that the response decreased with an increase in frequency.

Conversely, a study by Hazell, Jakobi and Kenno (2007) examined EMG muscle activity in the V.L., while participants stood in a static squat position at various frequencies (25, 30, 35, 40, and 45 Hz) and amplitudes (2mm & 4mm). The investigators reported that the greatest muscle activity responses occurred at the higher frequencies (40 and 45 Hz). Based on their findings researchers concluded that the highest EMG responses were generally at the higher frequency and amplitude (4mm) settings. The higher muscle activity responses they reported at the higher amplitude setting are in accordance with the findings of this present investigation. However, the results (see Figure 7) of the present study indicate that the highest VEI responses in the V.L. were at the lower frequencies (30 and 35Hz) as opposed to the higher frequencies (40 and 45 Hz) reported in the Hazell et al. (2007) investigation. The discrepancy in results between the present study and Hazell et al. (2007) may be attributed to several differences between the two research designs. The Hazell et al. (2007) study chose a different sample population, including only males, whereas the present study was open to both genders. The present study also chose a higher static squat body-position, which knee angle that was thirty degrees less (30 degrees vs. 60 degrees) and a different MVC data collection process (Cybex machines vs. using a nylon strap attached to an immovable object). In addition, the EMG filtering methods used in both studies varied greatly. In this present study, notch filters were placed at the specific vibration frequencies used in the trials (30, 35, 40, and 50 Hz), while a commonly recommended band-pass filter of 10-500 Hz was employed. This is a very typical band-pass filter configuration based on the fact that with EMG muscle activity, the frequency contents ranges between 6-500 Hz, displaying the most frequency power between approximately 20 and 150 Hz (Kamen & Gabriel, 2010; Konrad, 2005). However, in the Hazell et al. (2007) study the researchers selected to avoid notch filtering by selecting a band-pass filter of 100-450 Hz. By selecting such a band-pass filter range, the researchers likely lost valuable signal power at frequencies below 100 Hz. Increased reliability would likely be produced from selecting a band-pass filter just slightly above the highest frequency used (e.g. 50-450 Hz); thus allowing more important true signal to be recorded. Also, the Hazell et al. (2007) investigation collected EMG data over two testing sessions one week apart, as compared to the current study which collected all data in one testing session. Due to the natural variation associated with EMG data collection, it is generally recommended to collect data in one session when possible (Kamen & Gabriel, 2010; Konrad, 2005). Additionally, the large variability in both intra-subject and inter-subject variability will cause the biodynamic responses to change over time. For these reasons, traditional vibration research design experts typically recommend collecting data in one session when possible (Griffin, 1996; Mansfield, 2004). Another important difference in research design is that the present study performed four trials at each of the amplitudes; whereas the Hazell et al. (2007) study only reports collecting data over a single trial. With the large degree of both intra-subject and inter-subject variability associated with both WBV and EMG measurements, it is likely that the results of the Hazell et al. (2007) investigation have reliability issues. Thus the considerable differences in research methods likely accounts for the incongruent V.L. muscle responses. Unfortunately there are no other peer reviewed WBV studies which measured EMG muscle activity in the V.L. at various frequencies to further compare the differences in results found between the two studies.

Amplitude

The null hypothesis for the main effect of amplitude was rejected as a significant difference in VEI responses between the two amplitudes was determined. A medium effect size (partial eta^2 = 73.7%) for amplitude was reported along with a linear trend (see Table 3). Note that the amplitude trend will have to be linear in this situation as there were only two amplitudes measured. The results indicate that the high amplitude (103.0% $\pm$ 7.6%) had approximately a 35% greater VEI response than the low amplitude (68.2% $\pm$ 3.7%) setting. The observed individual data (see Appendix D) indicate that in nearly all cases the participants yielded higher VEI values at the higher amplitude and that the increase in VEI response from the low to high amplitude was fairly consistent amongst individuals; hence the low standard deviations associated with the amplitude means.

The positive relationship between amplitude and muscle activity found in this study is difficult to compare to other studies as there is a scarcity of muscle activity data related to various amplitudes. However, even with the questionable reliability of the Hazell et al. (2007) study discussed in the previous section on frequency, the researchers did report higher muscle activity responses under the higher amplitude condition (2 mm vs. 4 mm). A void in WBV exercise research exists when considering the effects of amplitude on EMG muscle activity as most of the studies focus on frequency. This is in part due to the fact that few commercially available plates are designed with more than one or two amplitude settings. However, several manufacturers offer plates with a multitude of frequency setting options. The increase in VEI response due to an increase in amplitude may be due to the positive relationship of amplitude on g-force which in turn has a positive relationship with muscle activity response. However, the positive relationship between amplitude and VEI could be due to other mechanisms not associated with the effects of amplitude on g-force. One possible mechanism to explain the increase in muscle activity with increased amplitude could be the effects amplitude has on the muscle spindle. An increase in amplitude may cause the muscle spindle to be stretched further, which could potentially cause an increase in muscle activity. Muscle spindle research reveals that a large variance exists in the dynamic responses of muscle spindles to different amplitudes of stretch. At a fixed frequency of sinusoidal stretch, a positive relationship between the amplitude of stretch and the response of muscle spindles has been observed (Hasan, 1983; Hasan & Houk, 1975). Unfortunately no WBV exercise research has examined the effects of various amplitudes on the muscle spindle. Another possible explanation may involve the effects of amplitude on the Hoffman reflex. Several studies indicate that the inhibition of the Hoffman reflex is amplitude dependent, irrespective of frequency (Fornari & Kohn, 2008; Hodgson, Docherty, & Zehr, 2008; Knikou, 2008; Martin, Roll, & Gauthier, 1986). Vibration research reveals that a vibration can stimulate the tonic vibration reflex (TVR), but also inhibits the stretch reflex and the Hoffmann-reflex; this observed phenomenon is now commonly referred to as the vibration paradox (Desmedt, 1983; Desmedt & Godaux, 1978; Flieger, Karachalios, Khaldi, Raptou, & Lyritis, 1998; Martin, Roll, & Gauthier, 1986). The vibration paradox is thought to be a result of presynaptic inhibition of the Ia afferents in the muscle spindle, thus simultaneously causing inhibition of the stretch response pathways, while stimulating vibratory pathways (Desmedt, 1983; Martin, Roll, & Gauthier, 1986). Thus it is possible that an increase in amplitude causes an inhibition of the Hoffman reflex, which in turn stimulates the TVR, leading to increased muscle contraction.

Frequency by Amplitude

The combination of frequency and amplitude are the two variables which determine g-force. Thus the frequency by amplitude hypothesis is perhaps the most important of the investigation. In the present study, the combination did not reach statistical significance ($p = .063$) as it was slightly above the traditional cut-off level ($p < .05$). Traditional statistics would accept the null hypothesis, but in doing so there would be a high probability of making a type II error due to the true variance being masked by the high degree of error variance associated with both vibration and EMG data. It is very likely that with just a few more participants, the frequency by amplitude interaction effect would have reached the traditional level of significance. Several well known experts in the field of statistics debate the traditional statistical hypothesis testing; arguing that from an ontological perspective, there is no distinct cut-off between a significant and a non-significant difference; significance in statistics, like the significance of a value in the universe of values, varies continuously between extremes (Boring, 1950; Gigerenzer & Murray, 1987; Rosnow & Rosenthal, 1989). In the present study it was decided to reject traditional statistics in favor of risking a type II error over a type I error. Even though the null hypothesis for frequency by amplitude was accepted, the interaction effects for these two variables will be discussed as if the null hypothesis had been rejected.

The null hypothesis for frequency by amplitude was rejected as a significant difference in VEI responses between the frequencies and amplitudes was determined (see Table 3). A moderate effect size (partial $eta^2 = 51.8\%$) for frequency by amplitude was reported along with linear trends (see Table 3). Interestingly, even though the interaction effect for frequency by amplitude did not reach the traditional level of significance ($p < .05$), contrast analyses (see Table 7) reveal that the highest frequency (50 Hz) had a significantly ($p < .05$) lower VEI response than the two lowest frequencies (30 and 35 Hz) at the high amplitude setting. If traditional statistical hypothesis testing hadn't been challenged then this statistically significant ($p < .05$) difference among interaction effect means for frequency and amplitude would have remained undiscovered. The trend data (see Figure 4) of the interaction between frequency and amplitude, with amplitude displayed on the abscissa, clearly demonstrates a positive relationship of amplitude on VEI. Noteworthy is that all four frequencies have relatively similar positive slopes. This possibly indicates that muscle activity may have a potentially linear response to amplitude. Unfortunately a limitation of this study was that only two amplitudes were measured; thus not allowing a thorough examination of the effects of amplitude on VEI. To clearly visualize the effects of frequency on VEI, frequency should be displayed on the abscissa. The trend data (see Figure 5) clearly indicates that the VEI response is decreasing while frequency is increasing, particularly at the high amplitude. Unfortunately the vibration apparatus only goes up to 50 Hz or it would have been interesting to collect data at some higher sequential frequencies (55, 60, and 65 Hz) to see if the decreasing trend in VEI responses continued. Nevertheless the findings from the interaction effects between frequency and amplitude strongly reinforce the conclusion that gravitational force is not a valid measurement of VEI.

Muscle Responses

The null hypothesis for the main effects for muscle group was rejected as a significant difference in VEI response between the muscle groups was determined (see Table 3). A medium effect size (partial eta^2 = 57.3%) for muscle groups was reported (see Table 3). Contrast analyses (see Table 4) revealed that no significant mean difference exists between the G.L. and GM., even though the G.M. (153.1% $\pm$ 22.0%) yielded an approximately 45% greater VEI than the G.L. (107.8% $\pm$ 12.3%). Furthermore, both the G.M. and G.L. had significantly higher VEI responses than both the V.M. (41.9% $\pm$ 13.2%) and V.L (39.6% $\pm$ 10.3%). No significant difference (see Table 4) in VEI response was found between the V.L. and V.M.

The null hypothesis for the interaction effects of muscle groups by frequencies was rejected as a significant difference in VEI responses between the muscle groups and frequencies was determined. A small effect size (partial eta^2 = 36.5%) for muscle groups by frequency was reported along with cubic trends (see Table 3). Contrast analysis (see Table 6) revealed that the greatest differences among interaction means for the G.M. and both knee extensors were at 40 Hz. However, the response was different in the G.L. which had its greatest significant difference among interaction means (see Table 6) with the V.L. at 30 Hz and the V.M. at 50 Hz. The trend data (see Figure 3) for the VEI responses in the V.M. and V.L. reveal that the two muscles responded to the various levels of frequency in a nearly identical fashion, except for a slight deviation at 30 Hz. Several EMG studies that have used more traditional forms of exercise have reported similarity in muscle activity responses between the V.M. and V.L.; thus indicating that these two muscles likely share a lot of the same characteristics, including their natural resonant frequencies (Escamilla et al., 1998; Escamilla et al., 1997; Signorile et al., 1994).

The data (see Figure 3) also indicated that the VEI response in the G.L. followed a somewhat similar trend as the knee extensors, but with a higher degree of VEI response. However, the VEI response of the G.M. had quite a different trend than the G.L., which resulted in significant differences among interactions means (see Table 6) at every level of frequency, except 30 Hz. The G.M.'s trend (see Figure 3) which clearly had the highest VEI response across all levels of frequency, followed a quadratic trend, as it sharply increased between 35 Hz and 40 Hz, then quickly dropped off between 40 Hz and 50 Hz. The large variance in response between the G.M. and G.L. is most likely due to several differences in muscle morphology, including the G.M.'s generally larger size and somewhat different shape (Enoka, 1994). Some studies indicate that the G.M. is typically recruited first and of the two plantar flexors it is predominantly activated until the additional force required for plantar flexion is produced, at which time, the muscle activity in the G.L. will increase (Muramatsu et al., 2001; Yanagisawa, Niitsu, Yoshioka, Goto, & Itai, 2003). Additionally, all of these characteristics will ultimately influence the natural resonant frequencies of the two different muscles. The trend data (see Figure 3) clearly demonstrates that both of the plantar flexor muscles elicited significantly higher muscle activity than the knee extensors at all frequency levels. This finding is in accordance with previous research which reported that muscle activity was clearly dependent on the distance between the muscle and the vibration platform (Roelants, Verschueren, Delecluse, Levin, & Stignen, 2006). This is theorized to occur as the muscles closest to the vibration stimulus are less damped due to muscle and segment stiffness (Mester, Spitzenfeil, Schwarzer, & Seifriz, 1999; Roelants, Verschueren, Delecluse, Levin, & Stignen, 2006).

Furthermore, vibration research has demonstrated that muscle activity is influenced by the initial length of the muscles (Burke, Hagbarth, Lofstedt, & Wallin, 1976; Cardinale & Lim, 2003; Nordin & Hagbarth, 1996). Studies have shown that a pre-stretched muscle is more responsive to a vibratory stimulus which typically translates into a higher degree of muscle activity (Bishop 1974; Rohmert, Wos, Norlander, & Helbig, 1989). The leading explanation for this observation is that a pre-stretched muscle causes an increase in muscle spindle sensitivity (Burke, Hagbarth, Lofstedt, & Wallin, 1976; Mester, Spitzenfeil, Schwarzer, & Seifriz, 1999; Nordin & Hagbarth, 1996). Based on the effects of pre-stretch activity and length of muscles on muscle activity, a WBV study by Roelants et al. (2006) hypothesized that quadriceps muscles, including the V.L. and V.M., would elicit more muscle activity in a static low-squat than a static high-squat position. Interestingly, the research hypothesis on the different squat positions was rejected as no significant difference in muscle activity was found between the different body positions. The researchers concluded that other parameters, including the pre-activation level of the muscle, muscle length and the natural resonant frequencies of the muscles may be more important than the initial body position.

Variability: Intra-Subject and Inter-Subject

In traditional vibration research, there is a general consensus that a large degree of both intra-subject and inter-subject variability exists in the biodynamic responses to vibration (Griffin, 1996; Inman, 2007; Mansfield, 2004). There are numerous factors which can account for such a large degree of variability including body dynamics, body dimensions, body masses, age, gender, health, experience and training, and sensitivity and susceptibility (Griffin, 1996). Body position is one of the most influential factors affecting biodynamic responses to vibration (Berschin &

Sommer, 2010; Lundstrom, Holmlund, & Lindberg, 1998). Interestingly there is evidence to suggest that biodynamic responses to WBV may have a psychological component based on an individual's attitude and motivation (Griffin, 1996; Mansfield, 2004). Due to the multitude of factors affecting individual's or group's biodynamic responses to vibration, there will nearly always be a sizeable degree of both intra-subject and inter-subject variability, regardless of the measures a researcher may employ to control extraneous variables. Therefore, when it comes to WBV exercise research, conventional research methodology and statistics could mask important findings, including the degree of biodynamic response of an individual.

For example, in the present study the inter-subject variability in VEI response (see Appendix D) between two individuals was approximately 440% (473.3% $\pm$ 123.4% vs. 35.0% $\pm$ 9.1%) for the G.M. of the plantar flexors, at the same frequency (30 Hz) and amplitude (high). This extreme variability indicates that under these conditions WBV is not guaranteed to be a beneficial form of exercise in the G.M. for all individuals. The inter-subject variability in biodynamic responses to vibration exercise was not as extreme in the knee flexors primarily due to the fact that these muscles exhibited, on average, a much lower VEI response (see Table 5 and Figure 3) compared to the plantar flexors—muscles closest to the plate. Nevertheless, the inter-subject variability in these muscles was still very pronounced. For example (see Appendix D) the difference in VEI response between two individuals was approximately 160% (138.6% $\pm$ 64.8 vs. -19.1% $\pm$ 7.7%) in the vastus medialis at the same frequency (50 Hz) and amplitude (high). Also noteworthy, is that one of the participants in this example had a negative VEI value in this muscle at these settings.

This negative value associated with the knee extensor muscle was not an anomaly. In fact approximately 18% (34 of 192) of the VEI values in the two knee extensor muscles were negative. The negative values were predominantly associated with the low amplitude setting and the number of negative values generally increased with frequency, with approximately 45% of the negative values (15 of 34) being found at the 50 Hz setting. However, these negative values were typically very small with a relatively high standard deviation (e.g. VEI = -8.2% $\pm$ 7.0%). This indicates that these values are likely not due to true variance associated with the diminishing effects of vibration on muscle activity but are more likely due to error variance or a slight change in posture. What these negative values do reveal is that some participants had almost no VEI response in the knee extensors. In fact, in the vastus medialis under all levels of g-force, one individual only yielded positive values 37.5% of the time(3 out of 8), with the highest value (5.8% $\pm$ 15.7%) indicating very little change, if any. In summary, inter-subject variability is extremely prevalent in biodynamic responses to vibration and while some subjects may show impressive responses others may show little response, particularly in the muscles furthest from the vibration platform.

Relative Vibration Exercise Intensity

Some of the VEI responses appear particularly impressive, such as the G.M. muscle's nearly 200% increase in VEI (194% $\pm$ 61%) at 40 Hz at the high amplitude setting. However, this was the highest response out of all the muscles at any of the levels of g-force and is essentially only twice the control condition. In this particular case the group average for the control condition averaged slightly less than 5% of MVC's (4.65% $\pm$ 0.32%); thus the highest VEI response was slightly less than 15% of MVC, which sounds far less impressive than an approximately 200% increase in muscle activity. The results become even less impressive when the VEI responses in the knee extensors are examined. The highest VEI in the knee extensors was found in the V.L. at 40 Hz at the high amplitude which yielded a 45% VEI response. In this particular case the group average for the control condition averaged slightly less than 10% of MVC's (9.91% $\pm$ 1.18%); thus the highest VEI response found in the knee extensors was very similar to the plantar flexors--

slightly less than 15% of MVC. Now when one considers that the lowest VEI response in the plantar flexors was 75% and the lowest in the knee extensors was 13%, it becomes evident that WBV exercise does not yield a great degree of muscle activity in these leg muscles relative to MVC's. Based on previous research it is likely that the muscles even further from the vibration platform receive substantially less muscle activity if any (Hazell, Jakobi, & Kenno, 2007; Mester, Spitzenfeil, Schwarzer, & Seifriz, 1999; Roelants, Verschueren, Delecluse, Levin, & Stignen, 2006).

Consideration for Future Research

A power spectrum analysis was conducted in this study to remove artifact at the frequency levels used in this study. Typically in the EMG (Noraxon) software a power spectrum analysis is broken down into several blocks with each block representing several frequencies—for example 25-30 Hz. However, the Noraxon software does allow power spectrum analysis to be conducted in 1 Hz increments. The power spectrum analysis for this study was conducted in 1 Hz increments. By doing so, it became evident that the true frequency of the vibration platform at the preset 50 Hz frequency was actually 49 Hz. Thus, doing the analysis in 1 Hz increments not only allowed the true artifact to be removed it also is a way to validate the true frequency settings of a vibration platform. The other preset frequencies used in the study were accurate. To avoid confusion for the reader the true frequency of vibration platform (49 Hz) was reported throughout the present study as the preset frequency on that platform (50 Hz).

Whole-body vibration exercise research will likely result in a large degree of inter-subject variability. It was evident from the results in this study that a very large degree of inter-subject variability exists even in a reasonably homogenous sample population. Thus traditional research designs and statistics may mask important individual biodynamic responses. As was discussed earlier some participants had relatively impressive VEI responses while others had meager responses under the same conditions. This vast variability indicates that vibration exercise is not consistently an effective form of exercise. Future research should attempt to develop valid and reliable methods for determining an individual's level of biodynamic response to vibration exercise with the purpose to elucidate if WBV is an effective exercise method for a particular individual as opposed to a particular population.

This study employed the use of two amplitudes. The results clearly indicated that the higher amplitude yielded a higher VEI response than the lower amplitude. There have been a few studies attempting to determine the most effective WBV exercise frequency and amplitude settings (Cardinale & Wakeling, 2005; Norlund & Thorstensson, 2007). However, the majority of these studies focus on the frequency setting over the amplitude setting. In this study, 4 frequency levels were examined compared to 2 amplitude levels. This is due to the fact that the vibration platform only has two possible amplitude settings. Vibration exercise research generally finds that most muscle activity occurs between 25-40 Hz (Cardinale & Wakeling, 2005). However, a paucity of research exists on the optimal amplitude setting(s). Future studies should be conducted on several amplitudes to examine the effects of amplitude on muscle activity.

One of the major contributors to inter-subject variability in vibration exercise is a change in body position. Getting the body in the exact same position between trials is virtually impossible. Furthermore, during trials there may be slight variation in posture due to the effects of vibration on body position. Pilot work for this study revealed that a slight touch of the platforms handrails helped maintain the body's static position during vibration. Furthermore, using the preset frequencies which can be changed instantaneously while vibrating, allowed for far fewer trials, thus decreasing the amount of variability in body position between trials. Furthermore, within a trial the body position was very static between the frequency setting changes; thus changing the preset frequency settings throughout a trial, rather than doing numerous single trials may help decrease error variance and should therefore be considered in future WBV research designs which investigate multiple frequencies.

Conclusions

The primary aim of this investigation was to determine if gravitational force is a valid measurement of vibration exercise intensity. The results of this study clearly indicate that the highest VEI responses were not at the highest g-force levels. Thus, gravitational force is not a valid measurement of vibration exercise intensity. The second aim was to examine the leg muscle response to WBV to determine if the muscles respond in a similar fashion. The results indicated that the two knee extensors responded nearly identically to one another while the two plantar flexors varied considerably in response. It is quite possible that the muscle activity responses are predominantly frequency dependent; which is likely heavily influenced by a muscles natural resonant frequency. The study also determined that the muscles closest to the vibration plate (plantar flexors) yielded far greater VEI responses. Furthermore, the VEI responses may sound impressive when expressed as a percentage of control (no vibration), but when expressed relative to MVC data, it becomes evident that WBV is likely not an intense enough neuromuscular stimulus to cause various physiological adaptations, such as muscle hypertrophy. However, there is evidence to suggest that WBV exercise may positively impact other health parameters, such as the neuromuscular system (Bosco et al., 2000; Cardinale & Bosco, 2003; Delecluse, Roelants, & Verschueren, 2003; Issurin & Tenenbaum, 1999) and bone mineral density (Gusi, Raimundo, & Leal, 2006; Verschueren et al., 2004; Ward et al., 2004). It should be mentioned that g-force may be a valid measurement of vibration exercise intensity to influence other biodynamic parameters. However, this is beyond the scope of the present study.

Based on the existing WBV research and the findings of this study, individuals should approach vibration exercise with some level of skepticism due to the fact that many of the claims made by vibration platform manufacturers are unsubstantiated and potentially misleading. Vibration platforms often look state-of-the-art and claim to be an effective and sophisticated form of exercise that takes relatively little time and effort. Individuals who perform traditional forms of recommended exercise but who forgo them for WBV exercise may not experience the same level of training effect. If vibration training is going to be used it should only be a supplement to traditionally recommended exercise prescriptions, not a replacement.

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APPENDIX A

Institutional Review Board Committee Letter of Approval

TWU
TEXAS WOMAN'S UNIVERSITY
DENTON DALLAS HOUSTON

Institutional Review Board
Office of Research and Sponsored Programs
P.O. Box 425619, Denton, TX 76204-5619
940-898-3378 Fax 940-898-3416
e-mail: IRB@twu.edu

March 12, 2010

Mr. Chris Robinson
Department of Kinesiology

Dear Mr. Robinson:

Re: Whole-Body Vibration: Is Gravitational Force a Valid Measurement of Exercise Intensity?

The above referenced study has been reviewed by the TWU Institutional Review Board (IRB) and appears to meet our requirements for the protection of individuals' rights.

If applicable, agency approval letters must be submitted to the IRB upon receipt PRIOR to any data collection at that agency. A copy of the approved consent form with the IRB approval stamp and a copy of the annual/final report are enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. The signed consent forms and final report must be filed with the Institutional Review Board at the completion of the study.

This approval is valid one year from February 12, 2010. According to regulations from the Department of Health and Human Services, another review by the IRB is required if your project changes in any way, and the IRB must be notified immediately regarding any adverse events. If you have any questions, feel free to call the TWU Institutional Review Board.

Sincerely,

Kathy DeOrnellas, Ph.D.

Dr. Kathy DeOrnellas, Chair
Institutional Review Board - Denton

enc.

cc. Dr. Charlotte Sanborn, Department of Kinesiology
Dr. Vic Ben-Ezra, Department of Kinesiology
Graduate School

APPENDIX B

Informed Consent

TEXAS WOMAN'S UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

Title: Whole-Body Vibration: is Gravitational Force a Valid Measurement of Exercise Intensity?

Principal Investigator:	Chris Robinson M.S.	betaoxidation2002@yahoo.com	(214) 545-2621
Faculty Research Advisor	Vic Ben-Ezra Ph.D.	vbenezra@mail.twu.edu	(940) 898-2597
Research Assistant:	Chris Lambert M.S.	bcrlambert@hotmail.com	(940) 231-6908
Research Assistant:	Manisha Rao	mrao@twu.edu	(940) 545-6404

Explanation and Purpose of Research

You are being asked to voluntarily participate in a research study for Mr. Chris Robinson's dissertation at Texas Woman's University. Exercise intensity is an important component of both the exercise prescription and exercise science field. Various types of exercise use different ways to express exercise intensity. Whole-body vibration exercise is quite a new topic in exercise science .The biomechanical variables that determine whole-body vibrations exercise intensity, often expressed in gravitational (g) forces, are the frequency, and amplitude of vibration. The primary purpose of this research is to determine whether or not gravitational force is a valid measurement of exercise intensity.

Description of Research Procedures

As a participant of this study you will be asked to volunteer approximately 90-minutes of your time to complete all testing procedures in one testing session. All testing procedures will be conducted in the Pioneer Hall fitness room (223), at Texas Woman's University, Denton campus. Before any of the experimental procedures begin it is important that you thoroughly read this consent form and voice any questions or concerns of which you may have about any aspect of the research study. Furthermore before experimental testing begins it is important that you meet all the inclusion criteria for this study, which includes willing to wear a pair of shorts and socks for all parts of the research process which involve surface electromyography (EMG) data collection, completing a 7-question Physical Activity Readiness Questionnaire (PAR-Q) without a positive (yes) response, and have a body mass index (BMI) $\leq$ 24 9 kg/m^2. To determine your BMI, you will be asked to stand on a standard scale that measures both height and weight. Body mass index is a measurement used to determine a person's body composition by comparing the ratio of an individual's weight to height. After you have filled out the consent form and met all the inclusion criteria for the study, including having your BMI taken, the research team will familiarize you with all of the experimental procedures, which are as follows: 1) randomization of treatment order & coding of data, 2) surface electromyography (EMG) preparation, 3) maximal voluntary contractions (MVC's), 4) whole-body vibration (WBV) exercise trials, and 5) post testing procedures

1 **Randomization of treatment order & de-identifiable coding of data:** This study involves a repeated measures design with numerous possible treatment orders. All participants will undergo all treatment conditions. However to help control for a potential order-effect, the treatment order will be randomly assigned to all participants, through using a hat-draw. At this time each participant will be assigned a de-identifiable data code which will be used for all aspects of data collection analysis.

2 **Surface electromyography (EMG) preparation:** EMG is considered a low invasive technique which is used to measure muscle activity through small disposable surface electrodes placed directly over the muscle belly. One surface electrode is used for each muscle under investigation, while an additional reference electrode is placed in close proximity to one of the muscle electrodes. All EMG electrodes will be recorded using a battery-powered processer that will be clipped around the waist of the participant. The signals will be processed to obtain muscle strength and electrical activity within the four selected muscles of study: 1) vastus lateralis, 2) vastus medialis, 3) gastrocnemius medialis and gastrocnemius lateralis. The reference electrode will be attached to the tibial tuberosity. Electromyography cables will be fixated to the participant's dominant leg with a tensor bandage to prevent the cables from swinging and to diminish movement artifact. Due to the placements of the surface electrodes on the leg muscles, all participants will be required to wear shorts and socks during the EMG testing procedures. Furthermore, to improve the adhesion and conduction of the electrodes, some participants may require a small area (approximately 5 cm^2) where the electrodes are attached to the leg muscles to be shaven and cleaned. If a participant has hair in the area where the electrode is to be attached, the participant will be shaven using shaving gel and a new sanitary disposable razor. The participant will then have the shaven area wiped with a new disposable sterile alcohol prep pad before having the surface electrode attached.

3. **Maximal Voluntary Contractions (MVC's):** Electromyography often uses MVC's of the muscle groups under investigation to normalize the data by determining the maximal voluntary effort capable by a particular muscle group(s). MVC's for the gastrocnemius lateralis & gastrocnemius medialis will be determined by performing an isometric seated toe press (unilateral plantar flexion at 90 degrees ankle flexion) on the Cybex seated calve press machine. MVC's for the vastus lateralis and vastus medialis will be determined by performing an isometric seated single leg knee extension on the Cybex leg extension machine. To prevent possible muscle strain, a 5-minute warm-up on a stationary cycle ergometer without resistance will be given before the MVC's data collection commences. 4 trials will be conducted for each of the two exercises on the participant's dominant leg with a 90-second rest period in between trials.

4 **Whole-body vibration exercise trials:** Before conducting any vibration exercise trial, all participants will go through a mock trial without vibration to familiarize themselves with the WBV trial procedures and correct body position. All WBV trials will use an identical standard unloaded isometric high-squat position (knee angle 125 degrees, hip angle 140 degrees). Posture will be strictly controlled during all trials by having both knee and hip joint angles standardized by the use of an electric goniometer. In addition, a straight back will be required for all vibration exercise trials. The whole-body vibration testing procedures will consist of 8 trials in total (4 trials at each of the two amplitudes). The 8 different levels of gravitational force will be derived from changing the 4 preset frequency (Hz) setting in 5 Hz increments (30, 35, 40, and 50 Hz) while at either a high or low amplitude setting. Each trial will require the participant to be in the isometric high-squat position for a total of 50-seconds of which the first 10 seconds will be without vibration (control) followed by 40-seconds of vibration exercise. Between all trials the participants will be given a 5 minute rest period in which they will be seated in a chair to unload the muscles and to avoid any potential effects of vibration exercise. Thus the WBV exercise trial data collection portion of the testing procedures should be completed in approximately 45-minutes: 8 trials x 50-seconds per trial = 400 seconds of trial time (80 seconds no vibration (control) + 320 seconds vibration exercise) + 35-minutes of rest periods (7 rest periods x 5 minutes each).

5 **Post testing procedures:** After the last whole-body vibration exercise trial the participant will be rested in a seated position while all surface electrodes are removed. The research team will monitor the participant for up to 10-minutes post vibration exercise for any possible redness and itching or redness on the skin of the legs. In the unlikely event that this skin irritation occurs, the research team will supply the participant with ice or a cold compress to help alleviate the symptoms.

Approved by the Texas Woman's University Institutional Review Board
Date 2-12-10

Initials

Potential Risks

Note: the researchers will try to prevent any problem that could happen because of this research. You should let the researchers know at once if there is a problem and they will help you. However, TWU does not provide medical services or financial assistance for injuries that might happen because you are taking part in this research.

Below are the potential risks and the steps the research team has taken to minimize risk.

Risk	Steps to Minimize Risk
Loss of anonymity:	Because WBV training will take place in a public facility some loss of anonymity will occur. Research personnel will avoid stating participant's names during testing. The purpose of the research study will also be kept confidential. Data collection will try and be scheduled at times when the fitness center is closed or has very low public usage. The Power Plate platform and all testing procedures will be located in the far back corner of the fitness center, which is of low visibility to the public. Furthermore the Power Plate platform area also has two privacy screens which can be used to shield the public's visibility during testing
Loss of confidentiality:	All data collected will be coded and names will not be used. The principal investigator will keep hard copies of each participant's de-identifiable data and personal information in a folder of a locked filing cabinet in the office of the faculty research advisor. Only the PI and faculty research advisor will have access to the cabinet. All testing information will be treated as privileged and confidential. Participants will be allowed to withdraw from the study at any time without penalty or prejudice. Members of the research team will not be doing any downloading and internet transactions, besides email, with any of the participants. Only the PI will be involved in email transactions with participants. Members of the research team will be instructed not to discuss confidential issues with participants. Only the principal investigator will discuss confidential information with participants. All email correspondence with participants will not include any confidential information about participants. In cases where confidential information needs to be communicated between the principal investigator and participant, it will either be done face-to-face in a private setting or by telephone. Participants will be informed about potential loss of confidentiality over the internet on the consent to participate in research form. Findings of the study will only be sent via postal mail to any participant who requests a copy of the findings on the consent form.
Surface electromyography (EMG): risk of skin infection and/or cut from shaving a small area	The participants required area on the skin will be shaven using shaving gel and a new sanitary razor which will be disposed of after use on one participant. The participant will then have the shaven area wiped with a sterile alcohol prep pad before having the surface electrode attached.

Initials

	Disposable new sanitary surface electrodes will be used which are disposed of after a participant has finished with the EMG testing procedures
Whole-Body Vibration Exercise Testing: possibility of injury from vibration or falling	Transmission of the vibration to the head or neck poses the greatest risk of injury. To avoid this, participants will be instructed to stand with hips, knees and ankles in a flexed position with a straight back for all trials. Vibration exercise exposure per trial will be kept brief (40 seconds). 5 minute rest periods will be given between all WBV trials. A guard rail is available on the Power Plate for participants to grab if need be. In addition, research personnel will monitor all training sessions and will be positioned close to the Power Plate to assist participants. Research personnel will monitor all training sessions and are trained in CPR and first aid
Whole-Body Vibration Exercise Testing: poses a slight possible reaction to vibration exposure, such as a risk of redness and itching or redness on the skin of the legs.	This is a slight risk and is generally only mild and short lived if it occurs. Ice or a cold compress will generally alleviate the symptoms and will be available to participants if this symptom occurs. Low amount of vibration exercise: 40 seconds per trail with 5 minutes of rest between trials. Although rare, itching and redness has been reported in other research, why it occurs is not known.
Maximal Voluntary Contractions: slight risk of muscle strain	Warm-up muscles with 5-minutes of cycle ergometry without added resistance. Give a 90-second rest period, between MVC trials. Inform participant to stop contraction immediately if any negative pain occurs. If a muscle strain does occur, the participant will be provided with an ice-pack and a member of the research team will apply the R.I.C.E. (rest, ice, compression and elevation) to the injured muscle.
Possible reaction to the EMG adhesive/tensor bandage	The tensor bandage will be wrapped very lightly around the participant, for the sole purpose of securing the EMG cables. If the participant has a reaction to the tensor bandage, a cotton cloth will be substituted to secure the cables.

Initials

Questions Regarding the Study

You will be given a copy of this signed and dated consent form to keep. If you have any questions about the research study you should ask the researchers; their phone numbers are at the top of this form. If you have questions about your rights as a participant in this research or the way this study has been conducted, you may contact the Texas Woman's University Office of Research and Sponsored Programs at 940-898-3378 or via e-mail at IRB@twu.edu.

Participation and Benefits

Your involvement in this study is completely voluntary and you may withdraw from the study at any time, for any reason without penalty or prejudice. There are no direct benefits for the completion of this study. If you would like to know the results of this study they will be mailed to you.

Confidentiality will be protected to the extent that is allowed by law.

______________________________ ____________________

Signature of Participant Date

Results of this research study should be available by 01/07/2010. If you would like to know the results of this study please tell us where you want them to be mailed:

Address: ____________________

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Approved by the
Texas Woman's University
Institutional Review Board
Date: 2-12-10

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Initials

APPENDIX C

Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness Questionnaire PAR-Q: questions 1-7

Please read the questions carefully and answer each one honestly: circle Yes or No

1)	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?	Yes	No
2)	Do you feel pain in your chest when you do physical activity?	Yes	No
3)	In the past month, have you had chest pain when you were not doing physical activity?	Yes	No
4)	Do you lose your balance because of dizziness or do you ever lose consciousness?	Yes	No
5)	Do you have a bone or joint problem that could be made worse by a change in your physical activity?	Yes	No
6)	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?	Yes	No
7)	Do you know of any other reason why you should not do physical activity?	Yes	No
8)	Are you between the ages of 18 and 45 years old?	Yes	No
9)	Do you agree to wear shorts and running shoes from the data collection portion of this study?	Yes	No

____________________________ ____________________

Signature of Participant Date

APPENDIX D

Participant Raw Data

GM	Control				Increase: Control to 30 HZ				Increase: Control to 35 HZ				Increase: Control to 40 HZ				Increase: Control to 50 HZ			
	Low		High		Low		High		Low		High		Low		High		Low		High	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P1	5.82	0.50	7.20	0.60	0.53	0.22	0.35	0.09	0.83	0.12	0.80	0.06	1.66	0.04	1.73	0.21	1.65	0.14	1.72	0.16
P2	2.55	0.18	2.54	0.13	2.64	1.34	4.73	1.23	2.28	0.78	4.93	0.91	2.45	0.50	3.19	2.39	1.73	0.40	3.83	1.13
P3	3.19	0.20	5.98	0.53	1.20	0.24	2.18	0.74	1.94	0.16	1.27	0.15	2.11	1.24	1.78	0.69	1.96	0.19	1.63	0.76
P4	5.05	0.59	3.59	0.25	1.10	0.16	1.13	0.32	1.15	0.16	1.21	0.06	0.61	0.01	1.70	0.35	0.74	0.12	1.46	0.72
P5	1.91	0.26	1.77	0.11	1.20	0.22	2.20	0.11	1.39	0.14	2.04	0.21	1.19	0.16	1.75	0.23	1.26	0.24	1.47	0.45
P6	2.54	0.16	4.81	0.12	1.13	0.25	1.28	0.09	0.78	0.09	0.94	0.18	1.99	0.43	1.15	0.14	1.47	0.09	1.04	0.09
P7	3.49	0.19	3.13	0.11	0.91	0.37	1.59	0.78	1.01	0.13	0.86	0.27	2.44	1.28	2.34	1.63	1.67	1.38	1.50	0.05
P8	4.38	0.18	3.52	0.16	0.56	0.12	1.30	0.18	0.25	0.05	0.84	0.14	0.56	0.13	0.80	0.13	0.62	0.18	1.06	0.09
P9	3.38	0.39	3.14	0.32	1.17	0.19	2.23	0.40	1.07	0.15	2.17	0.49	1.19	0.21	1.90	0.20	1.03	0.29	1.34	0.27
P10	6.70	0.58	10.53	0.89	0.47	0.07	0.75	0.12	0.88	0.18	0.74	0.38	1.10	0.12	0.80	0.12	1.36	0.20	0.78	0.10
P11	2.74	0.13	2.56	0.17	1.63	0.15	3.06	0.27	1.60	0.09	4.65	0.72	2.92	0.69	4.32	0.42	1.21	0.34	2.92	0.62
P12	10.95	0.40	7.08	0.53	0.22	0.05	1.01	0.28	0.35	0.00	1.16	0.62	0.59	0.35	1.79	0.76	0.56	0.33	1.20	0.33
AVG	**4.39**	**0.31**	**4.65**	**0.32**	**1.06**	**0.28**	**1.82**	**0.38**	**1.13**	**0.17**	**1.80**	**0.35**	**1.57**	**0.43**	**1.94**	**0.61**	**1.27**	**0.32**	**1.66**	**0.40**

Note: EMG muscle activity in the gastrocnemius medialis (GM). Control data is expressed as a percentage of MVC. VEI data is expressed as the percent change from control.

GL	Control				Increase: Control to 30 HZ				Increase: Control to 35 HZ				Increase: Control to 40 HZ				Increase: Control to 50 HZ			
	Low		High		Low		High		Low		High		Low		High		Low		High	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P1	12.21	1.31	17.00	1.64	0.68	0.29	0.45	0.12	0.67	0.40	0.48	0.04	0.46	0.06	0.63	0.25	0.71	0.35	0.55	0.10
P2	3.93	0.42	2.53	0.28	0.89	0.30	1.67	0.14	0.51	0.09	1.90	0.66	0.59	0.23	2.03	1.04	0.51	0.17	2.06	0.43
P3	7.36	0.47	7.71	0.63	1.54	0.30	1.49	0.30	1.84	0.29	1.59	0.60	1.37	0.10	1.91	0.64	1.42	0.43	2.38	1.06
P4	9.65	1.08	8.46	0.57	0.43	0.06	0.42	0.06	0.59	0.17	1.05	0.15	0.25	0.03	1.13	0.17	0.43	0.16	0.46	0.08
P5	1.34	0.29	1.30	0.15	0.76	0.47	2.42	1.16	0.76	0.07	1.66	0.26	0.92	0.56	1.20	0.41	1.08	0.10	1.34	0.81
P6	3.75	0.19	4.78	0.18	2.28	0.56	1.14	0.28	0.81	0.19	2.16	0.40	0.53	0.24	1.17	0.25	0.67	0.27	0.91	0.50
P7	4.67	0.45	3.54	0.29	1.37	0.64	1.48	1.02	0.86	0.24	1.88	0.49	0.86	0.04	1.52	0.38	0.38	0.50	0.37	0.31
P8	3.56	0.27	2.49	0.23	0.42	0.14	0.67	0.19	0.58	0.13	0.50	0.04	0.43	0.07	0.46	0.09	0.34	0.13	0.81	0.37
P9	2.04	0.23	2.12	0.25	2.49	0.40	3.82	0.34	1.74	0.19	1.66	0.47	0.84	0.11	1.10	0.09	0.76	0.17	1.22	0.12
P10	6.78	0.60	13.56	1.27	0.52	0.25	0.46	0.06	0.65	0.06	0.40	0.22	0.85	0.27	0.53	0.27	0.91	0.11	0.96	0.07
P11	5.98	0.22	6.35	0.49	1.39	0.23	1.71	0.38	1.64	0.23	1.17	0.13	1.25	0.42	1.35	0.44	1.34	0.02	1.69	0.25
P12	6.94	0.69	8.75	0.86	0.88	0.23	1.24	0.07	0.75	0.18	0.82	0.19	0.72	0.15	1.21	0.30	0.65	0.04	0.90	0.07
AVG	**5.68**	**0.52**	**6.55**	**0.57**	**1.14**	**0.32**	**1.42**	**0.34**	**0.95**	**0.19**	**1.27**	**0.30**	**0.75**	**0.19**	**1.19**	**0.36**	**0.77**	**0.20**	**1.14**	**0.35**

Note: EMG muscle activity in the gastrocnemius lateralis (GL). Control data is expressed as a percentage of MVC. VEI data is expressed as the percent change from control.

VM	Control				Increase: Control to 30 HZ				Increase: Control to 35 HZ				Increase: Control to 40 HZ				Increase: Control to 50 HZ			
	Low		High		Low		High		Low		High		Low		High		Low		High	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P1	15.08	1.79	10.17	1.50	1.26	0.57	2.57	0.17	1.39	0.30	2.38	0.19	0.90	0.19	1.51	0.63	0.65	0.20	1.39	0.65
P2	5.15	0.71	4.73	0.64	0.08	0.22	0.27	0.05	0.00	0.18	0.21	0.24	-0.01	0.29	0.03	0.02	-0.14	0.09	-0.12	0.21
P3	5.68	0.71	7.22	0.77	-0.23	0.23	0.47	0.16	-0.19	0.08	0.28	0.08	-0.29	0.21	0.18	0.11	-0.20	0.22	-0.19	0.08
P4	11.57	1.47	11.41	1.56	0.85	0.04	1.76	0.29	1.13	0.14	1.28	0.27	0.70	0.05	0.58	0.20	0.33	0.11	0.34	0.05
P5	4.37	0.52	3.34	0.36	0.04	0.02	0.17	0.07	0.04	0.06	0.32	0.09	-0.04	0.05	0.22	0.13	-0.11	0.01	-0.02	0.10
P6	6.65	0.81	7.69	0.73	-0.04	0.03	0.52	0.09	-0.05	0.08	0.22	0.15	0.02	0.08	0.18	0.06	-0.09	0.06	-0.04	0.03
P7	6.35	0.69	4.42	0.38	0.44	0.15	0.78	0.37	0.29	0.28	0.52	0.15	0.19	0.00	0.36	0.15	0.04	0.11	0.54	0.08
P8	3.97	0.43	4.42	0.36	0.96	0.26	1.24	0.70	1.14	0.39	0.85	0.42	0.57	0.08	0.64	0.20	0.50	0.21	0.41	0.19
P9	8.41	1.12	7.80	1.03	0.04	0.04	1.12	0.15	0.08	0.05	0.54	0.08	0.07	0.00	0.38	0.06	0.07	0.03	0.27	0.27
P10	11.68	1.74	10.73	1.61	0.45	0.06	0.62	0.13	0.37	0.12	0.52	0.08	0.30	0.07	0.48	0.26	0.29	0.10	0.50	0.08
P11	6.18	0.76	7.31	0.86	0.10	0.00	0.00	0.05	-0.01	0.07	0.02	0.13	-0.08	0.22	-0.14	0.05	-0.08	0.05	-0.02	0.29
P12	8.68	0.94	9.61	1.09	0.42	0.05	0.64	0.02	0.46	0.07	0.96	0.49	0.41	0.01	0.81	0.24	0.29	0.14	0.34	0.04
AVG	**7.84**	**0.98**	**7.41**	**0.91**	**0.36**	**0.14**	**0.85**	**0.19**	**0.39**	**0.15**	**0.68**	**0.20**	**0.23**	**0.10**	**0.44**	**0.18**	**0.13**	**0.11**	**0.28**	**0.17**

Note: EMG muscle activity in the vastus medialis (VM).Control data is expressed as a percentage of MVC. VEI data is expressed as the percent change from control.

VL	Control				Increase: Control to 30 HZ				Increase: Control to 35 HZ				Increase: Control to 40 HZ				Increase: Control to 50 HZ			
	Low		High		Low		High		Low		High		Low		High		Low		High	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P1	13.70	1.58	10.47	1.48	0.35	0.21	1.05	0.17	0.41	0.03	1.04	0.14	0.10	0.01	0.74	0.01	0.16	0.07	0.63	0.27
P2	6.95	0.97	7.52	0.78	-0.03	0.09	0.04	0.02	0.04	0.04	0.06	0.16	-0.08	0.08	-0.04	0.03	-0.09	0.03	-0.08	0.07
P3	9.78	1.08	11.63	1.12	-0.14	0.09	0.11	0.08	-0.13	0.05	0.00	0.02	-0.17	0.05	-0.09	0.04	-0.20	0.09	-0.11	0.05
P4	8.15	1.14	11.39	1.16	1.20	0.08	1.64	0.38	1.45	0.08	1.19	0.54	0.93	0.24	0.58	0.05	0.50	0.20	0.57	0.08
P5	9.28	1.43	7.25	0.97	-0.04	0.02	0.12	0.01	-0.05	0.12	0.25	0.38	-0.13	0.09	0.33	0.32	-0.27	0.03	0.03	0.50
P6	6.24	0.74	7.32	0.84	0.27	0.13	0.69	0.17	0.46	0.17	1.09	0.25	0.49	0.09	0.86	0.11	0.29	0.07	0.26	0.06
P7	12.85	1.35	11.07	1.13	0.78	0.27	1.52	0.39	0.60	0.26	1.16	0.36	0.40	0.34	1.13	0.25	0.58	0.27	1.02	0.47
P8	12.61	1.20	8.78	1.04	0.41	0.12	0.67	0.00	0.24	0.13	0.53	0.08	0.16	0.01	0.26	0.02	0.09	0.05	0.19	0.08
P9	14.22	1.95	14.83	1.99	0.31	0.08	0.42	0.02	0.31	0.13	0.55	0.25	0.14	0.10	0.54	0.11	0.13	0.15	0.18	0.06
P10	12.01	1.81	11.38	1.47	0.77	0.13	0.64	0.07	0.65	0.06	1.08	0.08	0.75	0.10	0.69	0.11	0.59	0.09	0.67	0.06
P11	4.84	0.47	5.67	0.60	0.29	0.06	0.28	0.05	0.18	0.10	0.22	0.04	0.15	0.03	0.26	0.03	0.07	0.10	0.13	0.01
P12	9.80	1.13	11.60	1.56	0.30	0.04	0.29	0.02	0.32	0.05	0.32	0.05	0.24	0.03	0.17	0.04	0.22	0.11	0.16	0.05
AVG	**10.03**	**1.24**	**9.91**	**1.18**	**0.37**	**0.11**	**0.62**	**0.12**	**0.37**	**0.10**	**0.63**	**0.19**	**0.25**	**0.10**	**0.45**	**0.09**	**0.18**	**0.11**	**0.31**	**0.15**

Note: Muscle activity in the vastus lateralis (VL). Control data is expressed as a percentage of MVC. VEI data is expressed as the percent change from control.

APPENDIX E

Four-by-Four Balanced Latin Square

Four-by-Four Balanced Latin Square: Frequency (Hz) Treatment Order

30	35	50	40
35	40	30	50
40	50	35	30
50	30	40	35

APPENDIX F

EMG Specifications and Electrode Attachment Locations & Orientations

EMG System	TeleMyo™ 900 Noraxon Inc., U.S.A
Data Analysis Software	MyoResearch XP Masters Edition 1.04, Noraxon Inc., U.S.A
Sampling Rate	1000 Hz
Smoothing	RMS = 200 ms
Low/High Pass Cut-off Frequencies	10 Hz - 500 Hz
Detection Mode	Differential
Rectification	Full-wave
Transmitting Frequency	905-928 MHz
Per Channel Bandwidth (-3 dB)	10-500 Hz
Overall Gain	2,000 fixed
Differential Input Impedance	>10 MOhm
Baseline Noise	< 1 uV RMS
Common Mode Rejection	Effective 130 dB @ dc (Zero Hz) >100 dB @ 50/60 Hz Min. 85 dB through 10-500 Hz operating range
Surface Electrode	Single Electrode Disposable, gel Ag/AgCl snap electrode (Product #270) Noraxon Inc., U.S.A
Diameter of the circular adhesive area is	3.8 cm (1 ½")
meter of the circular conductive area is	1 cm (7/16")
Inter-electrode distance	2 cm

Electrode Attachment Locations & Orientations (SENIAM Recommendations)

Vastus medialis	Location: electrodes need to be placed at 80% on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament. Orientation: almost perpendicular to the line between the anterior spina iliaca superior and the joint space in front
Vastus lateralis	Location: electrodes need to be placed at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella. Orientation: in the direction of the muscle fibers
Gastrocnemius lateralis	Location: electrodes need to be placed at 1/3 of the line between the head of the fibula and the heel. Orientation: in the direction of the line between the head of the fibula and the heel.
Gastrocnemius medialis	Location: Electrodes need to be placed on the most prominent bulge of the muscle. Orientation: in the direction of the muscle fibers.