EFFECT OF WHOLE BODY VIBRATION EXERCISE ON MUSCLE ACTIVITY WHEN USING ELASTIC RESISTANCE BANDS IN YOUNG ADULTS

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Education with a major in Exercise Science

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DEDICATION

To my loving wife Kendra
who allowed me to spend so much time on the following document

“Education is a progressive discovery of our ignorance.”
-William James Durant

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ABSTRACT

INTRODUCTION: Whole-body vibration (WBV) has been shown to increase muscle fiber recruitment during isotonic contractions. No prior published studies have used elastic resistance. The main purpose of this study is to investigate the acute effects of a single bout of WBV on electromyography (EMG) activity during exercise when using elastic resistance. **METHOD:** 30 participants (14 male; 16 female) aged 18-30 were recruited for this study. Surface electromyography (sEMG) activity was then determined while participants performed the arm curl and squat using elastic resistance under three conditions: no vibration exposure, during acute vibration exposure, and immediately following acute vibration exposure. Seven muscles of interest were chosen: gastrocnemius, vastus lateralis, vastus medialis, biceps femoris biceps brachii, triceps brachii, and lateral deltoid. Vibration was administered using a vibration platform (Wave®; ProElite, Windsor, ON Canada) at a frequency of 35Hz at 2mm displacement amplitude. **RESULTS:** Results indicate significant increases (.05) in sEMG in all seven muscles of interest between the pre-vibration (control) trial and the vibration trial. Additionally, the vastus medialis, gastrocnemius, biceps brachii and lateral deltoid yielded increased sEMG activity immediately following vibration. **CONCLUSION:** These data suggest sEMG activity is significantly increased during WBV. These data also suggest sEMG activity is significantly increased immediately following WBV in the prime-movers of the squat and arm curl.

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Chapter 1: Introduction

1.1 Introduction

In recent years technological advancement has been at the forefront of the fitness industry. These advancements are occurring at the micro-level through the introduction of smartphones, tablets and other mobile devices complete with their corresponding cloud-based fitness applications. Advancements are also occurring at the macro-level through "high tech" commercially-available fitness equipment. Recent macro-level advancements include pneumatic resistance devices, "zero gravity" treadmills, hypo/hyperbaric chambers.

As the salaries of professional athletes continue to rise there is an increased incentive for the development of performance enhancing devices. For decades athletes have sought out androgen-based performance boosts but this option is becoming less attractive as testing methods are becoming more accurate and penalties are becoming more costly. Athletes are beginning to turn to top notch training facilities outfitted with state-of-the art equipment and highly educated exercise physiologists to find their competitive advantage.

A similar trend is being seen in the general population. The introduction of the previously noted technologies has led to the expectation of technological advancement at the commercial fitness level. One innovative piece of equipment that is becoming popular in the general public as well as among elite athletes is the whole-body vibration (WBV) platform.

WBV platforms are sold commercially by at least three companies: Power Plate, (Irvine, CA) Wave (Windsor, Ontario) and Galileo (Sydney, Australia). Units are marketed as being versatile with benefits including: increased fast twitch muscle fiber utilization (Power Plate), increasing sprint acceleration (Power Plate), increased blood flow (Wave) and increases in bone mineral density (Wave). Many WBV platform manufacturers even provide peer-reviewed literature in which their product has been used.

1.2 Statement the Problems

Research has pointed towards increases in muscular activity during WBV bouts. This has been directly measured using sEMG (Roelants et al., 2006) and assumed during indirect measurements including increased counter-movement jump (CMJ) (Bosco et al., 1998). However, the following topics are less clear:

1. The length of time WBV's neuromuscular benefits last
2. The effects of WBV on muscular activity as measured by sEMG during elastically resisted exercise
3. The factors that determine ones response to WBV
4. What WBV dosage parameters are most beneficial

1.3 Significance of the Study

In the field of exercise science there is a trend toward uniformity of exercise prescription exist. Organizations including the American College of Sports Medicine (ACSM) and the National Strength and Conditioning Association (NSCA) arguably lead the way in this effort. Both of these governing bodies have published literature with exercise prescription guidelines but neither of these organizations have published organizational positions concerning WBV acute training protocols.

Evidence-based practice is important in any health, wellness or medical setting and as the name implies, peer-reviewed evidence is necessary for its development. Further, WBV training research is needed before prescription guidelines can be made. This study explores the specific points explained in the "statement of problems" section and may aid in the development of WBV training prescription guidelines by the major governing bodies.

1.4 Hypotheses

1. It is hypothesized that WBV will increase sEMG activity during and immediately following the vibration bout.
2. It is hypothesized that the increases observed during elastically resisted WBV exercise will be comparable to traditionally weighted WBV exercise (as recorded in previous studies).
3. It is hypothesized that WBV will increase lower extremity sEMG activity more than it will increase upper extremity activity.
4. It is hypothesized that WBV will have less of a neuromuscular effect on participants with higher body mass indexes (BMI).

1.5 Assumptions

It was assumed that recruiting participants from upper level exercise science courses would lead to increased squat biomechanical consistency. This assumption was made because all students at this level have at minimum learned proper weight lifting technique in the classroom setting. It was also assumed that all participants' EMG outputs during the study would be lower than during the maximal voluntary isometric contraction (MVIC) normalizations. This was assumed because a submaximal exercise should never yield higher sEMG activity than maximal exercise. It was also assumed that participants would not become fatigued during the study as fatigue would lead to non-vibration induced increases in sEMG activity during the last sets. This assumption was made because the resistance was extremely low, participants were college-aged and there was a rest period between sets. It was also assumed that decreases in resistance due to elastic deformation were small enough to cause negligible differences in sEMG readings. This was assumed because all bands were pre-stretched one-hundred times to avoid major elastic deformation.

1.6 Limitations

1. Results of this study may have been affected by the manner in which participants were recruited. Because exercise science students were recruited the test pool may have been more physically fit than the general population.
2. Results of this study may also be affected by the age of participants (college-aged).

1.7 Delimitations

The results from this study are limited to college-aged men and women who are habitually active and have at least rudimentary experience performing the arm curl and the squat.

1.8 Definitions

<u>Acute Response</u>: A short-term physiological reaction to a stimulus that is quickly normalized by the removal of the stimuli

<u>Cross-Talk</u>: sEMG activity that is caused by any muscle other than the muscle of interest

<u>Concentric Contraction</u>: A muscular contraction where a muscle produces force to actively shorten causing a decrease in joint angle

Eccentric Contraction: A muscular contraction that produces force as the active lengthening and joint angle enlargement are occurring

Elastic Resistance: A form of resistance that is highly variable depending on the length it is stretched (Table 5)

Electromyography (EMG): A technique for evaluating and recording the electrical activity produced by skeletal muscle

Long-Term Adaptations: A physiological reaction that occurs after many short exposures that occur over an extended amount of time

Maximal Voluntary Contraction (MVC): A maximal contraction that is measured using EMG and used to normalized any sub-maximal contraction (%MVC)

Neuromuscular Junction: The point at which the α-motor neurons and the muscle fibers meet

Isokinetic Contraction: A muscular contraction that causes change in muscle length at a constant rate regardless of power output

Isometric Contraction: A muscular contraction where a muscle produces force without a change in length or joint angle

Whole Body Vibration Training (WBVT): Two varieties of vibration training (VT) can be easily distinguished: strength exercises with superimposed vibratory stimulation (VS exercises) and motor tasks performed under whole body vibration

Chapter 2: REVIEW OF LITERATURE

2.1 Vibration

2.1.1 Introduction

Research exploring the physiological effects caused by vibration dates back to the 1940's. The first readily available research explored how an oscillating hospital bed aided in patient recovery with participants in full body, plaster casts (Whedon et al., 1949). Results suggested that vibration positively affected recovery time and research on vibration has continued to this day.

Since the 1970's, the effects of vibration on human performance have been more widely studied. In the realm of sport, mechanical vibration is used as a massage tool and/or for training purposes. Two types of of vibration training (VT) can be easily separated. First, there are strength exercises that utilize superimposed vibratory stimulation. Secondly, routine motor tasks can be performed under whole body vibration as a form of training (Issurin, 2005). Vibration is generally administered either locally via a hand held vibrator (Bongiovanni et al., 1990) or throughout the whole body (WBV) via a vibration platform.

2.1.2 Vibration Platforms

In order to interpret WBV research one must understand the physics of vibration and have at least a rudimentary understanding of how WBV platforms are made. The acceleration that a body experiences during WBV can be estimated from the following equation: $a = A*(2P\ f)^2$ where a is the acceleration experienced expressed as an equivalent of the acceleration of earth's gravity (g), A is the amplitude of displacement, and f is the frequency of vibration in Hz. In most WBV research studies, participants stand on a platform that produces sinusoidal oscillations either in a vertical up and down motion, or that rotates on a center fulcrum producing up and down vertical motion on alternating sides of the fulcrum. These movements result in vibration being transmitted directly to the participant through the legs (Dolny & Reyes, 2008). It is important to note that the dosage of vibration administered will greatly affect the physiological responses and/or chronic adaptations that occur.

2.1.3 Dosages Parameters

Most research exploring the effect of WBV on muscular activity has shown significant increases in sEMG activity during and immediately following WBV training bouts. The degree of significance is based on a long list of variables dealing with dosage parameters. WBV dosage parameters include:

1. Frequency (Hz)- The number of complete oscillations per second
2. Amplitude (mm)- The extent of a vibratory movement measured from the mean position to an extreme
3. Direction of oscillation- The direction the vibration platform vibrates
4. Duration of exercise bout- How long participants were exposed to WBV

Miniscule changes in any of these dosage parameters can lead to large physiological discrepancies (Da Silva-Grigoletto et al., 2011) (Lythgo et al., 2009). Generally, WBV platforms have variable frequency, amplitude and duration settings but fixed direction of oscillation settings (Table 1).

Table 1 Popular WBV Platforms

Galileo; Sport	Power Plate; PR05	Wave; Pro Elite
Frequency: 5-30 (Hz)	Frequency: 25-50 (Hz)	Frequency: 25-50 (Hz)
Amplitude: 1-13 (mm)	Amplitude: 2-4 (mm)	Amplitude: 2-4 (mm)
Direction: vertical sinusoidal	Direction: vertical sinusoidal	Direction: vertical sinusoidal

2.2 Neural Physiology

2.2.1 Theorized Mechanisms During Vibration

Skeletal muscle is a fairly unique tissue type in the sense that it is able to respond to external stimuli. This characteristic is known as excitability. During normal muscular contraction, the nervous system works as a catalyst to initiate muscular contraction. Muscular movement is controlled directly by neural stimulation. There are complex motor movements that begin in the brain, and there are simple reflexes that are controlled completely at the spinal level. Examples of reflex initiated muscle contraction include knee jerk tests and vibration induced contraction. Though reflex initiated muscular contractions are the simplest forms of contraction they still travel through multiple neural subunits including:

1. The receptor (muscle spindle)
2. The gamma afferent neurons (γ -afferent)
3. The gamma efferent (ɣ-efferents)
4. The alpha motor neurons (α motor)
5. The muscle fibers within the motor unit

As previously mentioned muscular contraction is dependent on neural stimulation. Neurons are capable of producing and transmitting electrical signals, from neuron to neuron. The electrical signals are known as action potentials. Action potential development is regulated by the polarity of a neuron. During rest, the polarity of a given neuron is known as its resting membrane potential. Generally, at resting membrane potential the inside of the neuron is negatively charged (-70 mV) compared to the outside. This difference in polarity is caused by the presence and absence of sodium (Na), potassium (K), and chloride (Cl) (Table 2).

Table 2 Concentration Gradient

Ion	Intracellular Concentration	Extracellular Concentration
Na^+	15 mM	150 mM
K^+	150 mM	5 mM
Cl^-	10 mM	110 mM

The difference in ion concentrations from the inside of the cell to the outside of the cell is caused by two variables. First, concentration gradients are regulated by protein pumps that are fuelled by ATP hydrolysis. Secondly, the neurons membrane allows fifty times greater permeability to potassium than sodium. Once ATP hydrolysis opens the membrane's protein gate, there is a change in intracellular polarity from -70 mV to +40 mV that lasts approximately one millisecond. This cascade of events occurs rapidly in a domino-like fashion throughout the nervous system.

2.2.2 Step One: Muscle Spindle

Reflexive neuromuscular excitation, often referred to as “stretch reflex”, unlike voluntary movement, begins in the muscle spindle. As the name suggests, muscle spindles are nervous tissue that wrap around groups of muscle fibers and monitor fiber length. Muscle spindle primary endings (type Ia afferent fibers) are extremely sensitive to even the most minute changes in relative muscle length. Muscle spindle (type II afferents) are less sensitive to minuscule changes in fiber length but are primarily responsible for signaling absolute muscle length. It is important to note that muscle spindles, not Golgi tendon organs (type Ib afferents), which are located in tendons, are primarily responsible for measuring muscular length changes and evoke monosynaptic reflexive response (Fallon & Macefield, 2007).

While a muscle or tendon is being actively vibrated, a reflexive contraction is often observed. This is commonly referred to as “tonic vibration reflex” (Cardinale & Bosco, 2003). It is important to note that tonic vibration reflex is only present during the vibration bout. The deformation of the soft tissue caused by vibration is capable of activating muscle spindles and leading to an engagement of the stretch reflex loop (Cardinale & Bosco, 2003). Thus, the excitatory inflow during vibration stimulation is mainly related to the reflexive activation of α motor-neurons. Increased neuromuscular activity immediately following bouts of WBV can be attributed to a temporary increase in stretch reflex sensitivity. Furthermore, vibration appears to inhibit Ia-inhibitory neurons, thus altering the intra-muscular coordination patterns leading to decreased increased activation rates around the joints stimulated by vibration (Cardinale & Bosco, 2003). These post vibration, physiological changes are short-lived. For example, it has been suggested that WBV increases vertical jump height two minutes post vibration, but no such benefit exists one hour after the WBV dosage is administered (Torvinen, Kannu, et al., 2002).

2.2.3 Step two: Gamma Neurons and Step Three: Motor Neurons

Once the reflex signal has been propitiated by the muscle spindle it begins to travel through the ɣ-afferent neurons, which take the signal all the way to the dorsal grey matter of the spine. The speed of this transmission is highly dependent on the thickness of the myelin which serves as an electrical insulator. Once the stretch reflex has arrived at the dorsal grey matter of the spine it is processed and a motor action potential is developed. This action potential will travel through the α-motor neurons until it reaches the fourth "landmark," the neuro-muscular junction.

2.2.4 Step Four: Neuromuscular Junction

As the name implies, the neuro-muscular junction is the point at which the α-motor neurons and the muscle fibers meet. Though it is called a junction there is no actual anatomical union between the motor neuron and the muscle fibers it innovates (motor unit). Instead of an electrically-induced muscular depolarization the human body depends on biochemical exchanges (exocytosis) in the final stages of the stretch reflex. The space between the neuron and the muscle fibers it innervates is often referred to as the synaptic cleft. The neural transmitter acetylcholine (Ach) is secreted to transmit the action potential. Acetylcholine binds to an Ach-binding site on the exterior of the muscle fiber and muscular depolarization begins. The action potential then travels downs the transverse tubules internally where it comes into contact the Sarcoplasmic Reticulum (SR). The SR secretes calcium, an ion that plays a vital role in muscular contraction. Calcium travels to the actin filament where it binds to troponin which moves tropomyosin off the actin binding site. At this point the myosin head attaches to the actin filament forming what is known as the actin/myosin cross bridge. Adenosine triphosphate (ATP) causes the myosin head to cock and contraction occurs.

2.2.5 Proposed Alternative Mechanisms

In addition to the neural mechanisms, it has been suggested that WBV exercise increases testosterone and human growth hormone (HGH) levels in healthy young individuals after a single bout of 10 min. Testosterone and HGH are both androgenic aids and could cause an increase in strength and power output independent of neuromuscular response (Bosco et al., 2000). Equally noteworthy is how vibration affects cortisol levels. The role of cortisol is largely antagonistic to that of testosterone and, consequently, the testosterone-to-cortisol ratio has been used as a measure of the body's anabolic–-catabolic status (Kraemer et al., 2001). The literature suggests that an increase in testosterone marked with a corresponding increase in cortisol could nullify any strength or power benefits. The results of the (Bosco et al., 2000) study are called into question by the work of other researchers who found no increase in testosterone levels post vibration (Di Loreto et al., 2004) (Cardinale & Rittweger, 2006). In Bosco's defense, these studies do utilize lower vibration dosages than his study (27 and 30 Hz respectively). Another possible mechanism that could explain increased strength and/or power without the utilization of the stretch reflex is an increase in localized blood flow (Issurin, 2005). One study displayed this phenomenon by having twenty healthy adults exercise and then stand on a vibration platform for nine minutes (26 Hz amplitude not reported). Lower-body blood flow measurements were taken before and after vibration using Doppler Sonography and Doppler Ultrasound. The mean blood flow velocity in the popliteal artery increased from 6.5 to 13.0 cm$*s^{-1}$ and its resistive index was significantly reduced (Kerschan-Schindl et al., 2001b). These results indicate that low-frequency vibration does increase localized blood flow and this could theoretically improve performance.

2.3 EMG

2.3.1 Overview

The first documented EMG related study dates back to 1666 which showed that electric eel skeletal muscle had the ability to produce electrical activity (Galvani, 1791). EMG technology has obviously improved drastically since then, as has our understanding of EMG data acquisition and signal processing techniques. Uniformity of EMG data collection and signal processing is extremely important for the sake of repeatability and one major sEMG governing body has been formed (SENIAM) for this purpose.

2.3.2 SENIAM

The SENIAM (surface EMG for non-invasive assessment of muscle) project was organized as a European concerted effort. The purposes behind the project include: the integration of basic and applied research into sEMG practice and the development of bipartisan working relationships to further the inexact science of sEMG. Initially, three major scientific topics were addressed (Merletti & Hermens, 2000):

1. sEMG sensors and sensor placement protocols
2. sEMG signal processing
3. sEMG modeling

2.3.3 Surface EMG

sEMG utilizes surface electrodes, connected to a transmitter which amplifies the electrical activity produced at the myoneural junction and transmits this signal to a computer where it is graphically and numerically recorded (Krol et al., 2011). sEMG electrodes are generally composed of Ag/AgCl and require a gelled medium for optimal electrical conductivity. The surfaces of electrodes are designed to be extremely sticky to create optimal skin surface contact. Premade disposable and reusable electrodes are both readily available and utilized both in research and the clinical setting. Generally, disposable electrodes come pre-gelled and ready for use. Uneven distribution gel could potentially be a limitation when using reusable electrodes.

Every muscle of interest requires two monopolar electrodes or one bipolar electrode for effective signal acquisition. Clinicians also utilize a ground lead to normalize any electrical "cross talk". Cross-talk is the term given to electrical activity that comes from any place other than the muscle of interest. Cross-talk can come from adjacent muscles, cardiac activity and brain activity. While some crosstalk is unavoidable, it can be managed by proper electrode placement. For example, it has been shown that having a small inter electrode distance (IED) leads to lower cross-talk levels (Farina et al., 2002).

Electrode placement and orientation are extremely important when using sEMG to quantify muscle activity. (IED) is expressed in either centimeters (cm) or millimeters (mm) and represents the distance from the center of the negative electrode to the center of the positive electrode. Generally, a premade electrodes have either a 10 mm or 20 mm IED is utilized to limit the pickup area of the electrodes (Krol et al., 2011).

2.3.4 Intramuscular (Needle) EMG

iEMG is less prevalent in exercise physiology laboratories doe to its more invasive and less practical during exercise testing. iEMG does have inherent advantages including less cross talk (Chapman et al., 2010). As one researcher writes, this (sEMG) advancement has widespread appeal among researchers and clinicians because of the ease of use, reduced risk of infection, and the greater number of motor unit action potential trains obtained compared to needle sensor techniques (Zaheer et al., 2012)

2.3.5 Normalization of Data

sEMG data must be normalized in order for comparison between trials and between participants to be valid. Over the past centuries there have been at least eight different methods to accomplish this task (Burden, 2010). Despite the endorsement of both SENIAM and the Journal of Electromyography and Kinesiology the technique to measure maximal voluntary isometric contractions (MVIC) still receives criticism (Burden, 2010). Most often critics point out that studies often yield sEMG results greater than 100% of MVIC (Burden, 2010). According to (Burden, 2010), maximal voluntary contractions (MVC) are the best way to normalize data. Multiple contraction types have been used during MVC's, but the EMG from an isometric MVC is endorsed as the gold standard reference value normalization reference value (Burden, 2010).

Another study looked at sEMG's various normalization techniques repeatability in runners (Albertus-Kajee et al., 2011). Researchers found that having athletes perform MVIC's or maximal sprints were both viable forms of normalization according to their intraclass coefficient correlations (average ICC > 0.80).

Another study examined three different sEMG normalization methods (Bolgla & Uhl, 2007). The methods were MVIC, mean dynamic and peak dynamic activity. Participants (n=13) performed three open kinetic chain and three closed kinetic chain hip abductor exercises that were normalized using each of the three methods. ICC's were calculated for each of the normalization techniques. This study found that the MVIC normalization protocol offered the highest reliability (MVIC ICCs exceeded 0.93 for all exercises).

2.3.6 Vibration Induced Artifact

The validity of sEMG data recording during whole body vibration exercise is controversial. Some authors attribute much of the increased EMG activity to vibration induced artifact (Abercromby et al., 2007). Even those who believe in vibration's EMG-enhancing properties have a difficult time dismissing the possibility of vibration induced artifact. Recently researchers have developed have developed ways to distinguish between vibration-induced artifact and stimulated myoneural response. Several studies have used frequency filters to nullify vibrations induced artifact (Abercromby et al., 2007; Roelants et al., 2006) (Hazell et al., 2007).

2.3.7 Disregard for Concept of Vibration Induced Artifact

One recent study used a three trial, repeated measures protocol to measure how much, if any, vibration induced artifact skews results (Ritzmann et al., 2010). The first method used "dummy electrodes" that were placed on top of specialized, non-conductive tape, 2 mm parallel to the normative electrodes. The specialized tape allowed vibration induced artifacts to be read but nullified all true EMG data. The difference in EMG activity indicated that vibration induced artifact was responsible for only 7 ± 2% of the increased activity of the soleus muscle. This test is especially compelling when one considers that the soleus is one of the closest muscles to the source of vibration. If vibration induced artifact is a limitation, then activity should be highest in the lower leg.

The second method used involved analyses of latencies. Researchers found that the number of peaks per second as measured by EMG correlated directly with the frequency of vibration prescribed ($p < .001$). In contrast, the latency of the dummy electrodes was sporadic, with a large standard deviation (SD 17 ± 18 ms). This not only suggests that increased electrical activity is caused by stretch reflex, not artifact, but that the leading method of artifact cancelation, the notch filter, only nullifies "true" electrical output.

The third experiment's methodology is based on a study that suggests compression applied with a blood pressure cuff has the ability to dampen the effects of the stretch reflex (Ritzmann et al., 2010). Researchers mechanically compressed the muscle belly of the soleus and had participants exercise on an ankle ergometer with and without vibration. There was no difference between the two trials ($p<.05$) which suggests that the stretch reflex is the leading reason for increased electrical activity during WBV.

The (Ritzman et al., 2010) study, if repeatable, could change the way signal processing is accomplished during WBV sEMG studies. This is the only study that encourages complete disregard of signal processing countermeasures when collecting WBV sEMG data. Though this study is compelling it should be noted that this is the only study of its kind. Future research should further explore this topic.

2.3.8 Acute Responses

Several acute responses to vibration have been observed including: increased blood flow (Kerschan-Schindl et al., 2001a) (Lythgo et al., 2009), increased VO_2, (Cardinale et al., 2007) increased counter-movement jump (CMJ) (Cochrane et al., 2004) and increased muscular activity.

2.3.9 Long Term Adaptations

Long term adaptations have been observed with WBV training programs (Table 3). Suggested chronic adaptations include: reversal of microgravity and disuse muscle wasting, a significant increase in isometric, dynamic, and explosive strength of knee extensor muscles in healthy, untrained, young adults (Cardinale & Wakeling, 2005), increased vertical leap in college aged, female athletes (Fagnani et al., 2006) and an increase in vertical leap in college aged males (Christophe Delecluse et al., 2003).

Table 3 Long Term Adaptations to WBV

Author; N	Dosage	Duration	Results
(Bosco et al., 1998) n=14	26 Hz, 10 mm	5x90 sec 10 days	Vibration increased mean jump height (5 sec post) by 12%
(Di Giminiani et al., 2009) n=30	20-50 Hz 2mm 30Hz, 2mm	10x1 min 3x/wk, 8wks	The group with variable dosage increased the most significantly (11% compared to fixed vibration (3%) and control (2%)
(Annino et al., 2007) n=22	30 Hz, 5mm	5x40s 3/wk, 8wks	VT increased CMJ height (6.3%). It also increased leg press power by (8-18%) and velocity by (8-26%) at loads of 50,70,100 kg
(Cochrane et al., 2004) n=26	26 Hz, 11mm	5x2min 9 days	No significant changes in CMJ following VT
(C. Delecluse et al., 2005) n=25	35-40 Hz, 1.7-2.5mm 0 Hz, 0mm	6x30-60s 3xwk, 5wks	No significant changes in CMJ following VT
(Fagnani et al., 2006) n=13	35 Hz, 4mm	3-4x20-60s 3/wk, 8 wks	VT significantly increased CMJ (8.7%)
(Ronnestad, 2004) n=7	40 Hz, NR amplitude	3x1oRM 2-3xwk, 5 wks	Both the VT and conventional training group increased CMJ (32.4% and 24% respectively). VT didn't have a statistically significant

			effect
(de Ruiter, Van Raak, et al., 2003) n=10	30 Hz, 8mm	3/wk, 11wks	VT did not significantly alter vertical jump height
(Christophe Delecluse et al., 2003) n=18	35-40 Hz, 2.5-5mm	1-3x2-6x30-60s 3x/wk, 12wks	VT significantly increased vertical jump height (7.6%)
(Roelants et al., 2004) n=24	35-40 Hz, 2.5-5mm	3x/wk, 24 wks	There was no significant difference in isometric and dynamic knee extensors following VT regime
(Torvinen, Kannus, et al., 2002) n=56	25-30 Hz, 2mm gradually increasing to 25-35 Hz, 2mm after 2 mths	3-5x/wk, 4 mth's	Both the 2 month and 4 month test showed significant increase in CMJ (10.2% and 8.5%) compared to control group
(Torvinen et al., 2003) n= 56	25-30 Hz, 2mm gradually increasing to 25-35 Hz, 2mm after 4 mths	3-5x/wk, 8 mth's	VT increased CMJ height (7.8%) compared to control group

2.4 Effects of vibration on muscle activity

2.4.1 Introduction

As previously mentioned, the effect of vibration on muscle fiber recruitment is a prevalent research topic in human performance, physical therapy and human factors engineering research. Researchers have addressed how vibration affects muscle fiber activity from many angles. The most logical way to categorize the different approaches of measuring the effects of WBV on muscular activity is to distinguish direct measurements from indirect measurements. Direct measurement of muscular activity requires either surface electromyography (sEMG) or intramuscular electromyography (iEMG). Indirect measurements monitor strength and power in an attempt to quantify neuromuscular activity. This line of reasoning has one large limitation. The limitation being the assumption that any increase in strength or power is due to increased neuromuscular activity.

2.4.2 Direct Measurements

As previously mentioned, the direct measurement of muscular activity utilizes sEMG or iEMG technology. Generally, sEMG is used because it is less invasive. In one study researchers recruited ten recreationally active college students (n=10, age 24.4 $\pm$ 2.0) and put the participants through a familiarization protocol to introduce participants to WBV (Hazell et al., 2007). After completion of the familiarization period, participants were randomly exposed to ten WBV conditions comprising five frequencies (25, 30, 35, 40, 45 Hz) for forty-five seconds each. sEMG data suggested a significant increase (p<.05) in sEMG activity including a (2.9%-6.7%) increase in vastus lateralis (VL) and a (.08%-1.2%) increase in biceps femoris (BF). Researchers also noted that higher recruitment was observed at 4mm amplitude than 2mm amplitude and that the higher frequency dosages (35, 40, 45 Hz) produced greater electrical activity.

Another study explored the effect of vibration on MF recruitment using sEMG during different squat exercises (Roelants et al., 2006). Fifteen men (age 21.2 $\pm$ .8) took part in a repeated measures study including one non-vibration, control trial and one vibration (35 Hz) trial. Each trial included three common variations of the squat exercise: high squat, low squat and one legged squat. Muscle activity was recorded using sEMG in the following muscles: rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) and gastrocnemius (GSN). WBV caused a significant overall increase of electrical activity expressed as root-mean-squared (p<.05) (Table 4).

Table 4 WBV and Variouse Squat Protocols

High Squat	Low Squat	One Legged Squat
+115.1 $\pm$16.3%	+49.1 $\pm$ 6.7%	+151.4 $\pm$ 19.5%

The following table contains a more exhaustive list of studies that have examined the effect of vibration on sEMG activity. Basic information including the author(s), number of participants, dosage parameters, duration of WBV exposure and a brief synopsis of the results are provided (Table 5).

Table 5 WBV effect on sEMG

Author; N	Dosage	Duration	Results
(Abercromby et al., 2007) n=16	30 Hz, 4mm	30 Seconds	Significant increase in knee extensor sEMG activity
(Cardinale & Lim, 2003) n=16	30, 40, 50 Hz 10mm	4x60 sec	30 Hz displayed the largest increase in sEMG of VL
(Cormie et al., 2006) n=9	30 Hz, 2mm	30 sec	No significant change in sEMG IF, 5 15 or 30 minutes following
(Torvinen, Kannu, et al., 2002) n=16	25, 30, 35, 40 Hz, 2mm (increased 5 Hz every min)	4 min	EMGrms increased 4.5% in gluteus medius from minute 1 to 4 (p=.017)
(Hazell et al., 2007) n=10	25, 30, 35, 40, 45 Hz 2,4 mm	45 sec	The higher WBV amplitude (4 mm) and frequencies (35, 40, 45 Hz) resulted in the greatest increases in EMG activity.
(M. Roelants et al., 2006) n=15	35 Hz, amplitude not specified	Not specified	WBV resulted in an increased activation of the leg muscles. During WBV, leg muscle activity varied between 12.6% and 82.4% of MVC values.

2.4.3 Indirect Measurement

Indirect measurement of muscular activity can be accomplished using other data including vertical jump height (Christophe Delecluse et al., 2003), isokinetic dynamometer torque values (de Ruiter, van der Linden, et al., 2003) and metabolic testing (Cardinale et al., 2007). It is important to note that increased power and/or strength is not always indicative of an increase in sEMG activity (Bosco et al., 1999). Often, indirect measurements are utilized because sEMG units are expensive and sEMG sensor placement and signal processing protocols are complex and time-consuming.

2.4.4 Indirect Studies

There have also been studies that measure the effects of vibration on muscle activity using indirect measurement methods. One team of researchers studied the short-term effects of WBV on maximal voluntary isometric knee extensor force (de Ruiter, van der Linden, et al., 2003). The study featured twelve participants with a mean age of 23 ± 4.2 years. Baseline power output was measured with both the hip and knee at 90° using an isokinetic dynamometer. Participants returned one week later and underwent five, one-minute bouts of WBV (30Hz, 8mm amplitude) with two minutes rest between sets. Power outputs were again measured using an isokinetic dynamometer at 1.5, 30, 60 and 90 minutes post vibration. Results suggested that vibration does not have a significant effect on muscular activity (1.5, 30, 60 or 90 min) post exercise. It is important to note that de Ruiter's study design did not measure knee extensor strength during or immediately following vibration. It has been shown repeatedly that WBV increases sEMG activity during and immediately following its termination.

2.5 Elastic Resistance

2.5.1 Introduction

Elastic resistance has been used as a strength training and rehabilitation aide for over one-hundred years. Exercise utilizing elastic resistance is popular because of its low cost, simplicity, portability and versatility. Elastic resistance is extremely popular among athletes and rehabilitation patients. Elastic resistance is unique in the sense that its resistive properties are dependent on the length to which it is stretched.

2.5.2 Elastic Properties (Hooks Law)

Hooks law suggests that the resistance (F) of a given elastomer is equal to the resistance value (k) multiplied by the change in length (s). The resistance value of an elastomer is constant and a product of the thickness and composition of an elastomer. Elastomers, unlike many other materials have a near-linear stress/strain behavior (Thomas et al., 2005) (Hintermeister et al., 1998). This makes possible the prediction of resistance during elastic exercise (Page & Ellenbecker, 2003) (Table 6).

Table 6 Force-Elongation for Thera-Bands (Force in Pounds)

Elongation (%)	Yellow	Red	Green	Blue	Black	Silver	Gold
25	1.1	1.5	2.0	2.8	3.6	5.0	7.9
50	1.8	2.6	3.2	4.6	6.3	8.5	13.9
75	2.4	3.3	4.2	5.9	8.1	11.1	18.1
100	2.9	3.9	5.0	7.1	9.7	13.2	21.6
125	3.4	4.4	5.7	8.1	11.0	15.2	24.6
150	3.9	4.9	6.5	9.1	12.3	17.1	27.5
175	4.3	5.4	7.2	10.1	13.5	18.9	30.3
200	4.8	5.9	7.9	11.1	14.8	21.0	33.4
225	5.3	6.4	8.8	12.1	16.2	23.0	36.6
250	5.8	7.0	9.6	13.3	17.6	25.3	40.1

2.5.3 Loss of Elastic Properties

Prolonged use of the same elastic band is known as cyclical loading and causes breakdown of the elastomers elastic properties. One study suggests that stretching an elastic band twice its resting length five-hundred times can cause a 5-12% decrease in elastic resistance (Simoneau et al., 2001). Research has also suggested that most of the loss of elasticity occurs in the first fifty repetitions of exercise (Patterson et al., 2001). These studies suggest that research studies utilizing elastic resistance should keep elastic deformation in mind when designing the methods section of a study.

2.5.4 Comparison between Elastic Resistance and Weighted Resistance

At least one study has suggested that when properly prescribed there is little difference in EMG activity during dumbbell weighted exercise versus elastically-resisted exercise (Anderson & Kippelen, 2005). This same phenomenon is observed when comparing Borg's rate of perceived exertion with dumbbell training versus elastically-resisted training. There is one primary difference between elastic resistance and dumbbell or barbell weighted resistance. Elastic resistance is variable whereas weighted resistance is constant. In order to lessen the variability of elastic resistance, participants should begin repetitions with approximately 125% elongation. The following chart produced by Thera-Band, one of the leading elastic workout band producers, can be used as a practical conversion chart (Page & Ellenbecker, 2003) (Table 7).

Table 7 Standard Elongation Values

Color	**Elastic Tubing Range (Kg's at 100-150% elongation)**	**Dumbbells (kg)**
Red	2.0-2.2	2.o
Green	2.6-3.0	3.0
Blue	3.7-4.1	4.0
Black	5.0-5.6	5.0
Blue+Red	5.7-6.3	6.25
Silver	6.9-7.8	7.5

2.5.5 Purpose

The purpose of this study was to examine the effect of WBV on muscle activity during and immediately following the removal of the stimuli. Possible cohorts that would benefit from this research include:

1. Post-operative rehabilitation participants
2. Older adults who are already using elastic resistance as a form of exercise
3. Elite athletes who use WBV training in conjunction with their conventional speed and agility workouts.

2.5.6 Hypotheses

1. It is hypothesized that WBV will increase sEMG activity during and immediately following the vibration bout.
2. It is hypothesized that the increases observed during elastically resisted WBV exercise will be comparable to traditionally weighted WBV exercise (as recorded in previous studies).
3. It is hypothesized that WBV will increase lower extremity sEMG activity more than it will increase upper extremity activity.
4. It is hypothesized that WBV will have less of a neuromuscular effect on participants with higher body mass indexes (BMI).

Chapter 3 METHODS

3.1 Participants

Thirty undergraduate college students (14 male, 16 female) from Wichita State University's Department of Human Performance Studies were recruited for this study. Their average age height and weight were (23.1 yrs±5.2 1.7m±0.09 69.5 kg±9.3) respectively. Contraindications for participation included: having a pace maker, active cancer, deep vein thrombosis, recent operative wounds, recent joint implants, kidney stones, tumors, epilepsy, acute and severe migraine headaches, acute infections, current diagnosis of cardiovascular disease, severe diabetes, allergies to latex, pregnancy. An informed consent form was obtained from each participant prior to their participation in the experiment. All facets of the experiment were reviewed and approved by the Institutional Review Board of Wichita State University.

3.2 Procedures

Participants were recruited from upper-level undergraduate exercise science classes. Exercise science students were chosen to negate the need for a highly-involved squat and biceps curl familiarization. Upon entering the laboratory, students were asked to carefully read the consent form. After volunteers read the consent form they were once again verbally reminded of the contraindications. Volunteers were then weighed and standing height was measured. Both height and weight were measured with the participant's shoes on. This was done because Wave ProElite WBV platforms take the participants weight into account when administering WBV. Shoes were worn during WBV bouts, so participants were weighed and measured in their shoes. Participants were then asked to lie down on their back to begin the electrode placement process.

3.2.1 Electrode Placement

sEMG electrode placement protocols were based on Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) website. Initially, each sensor location was measured and marked using a skin marker. Once all electrode locations were marked they were prepped for electrode placement. All participants who had hair on the electrode sites were provided a razor and asked to shave. Once all hair was removed from the electrode site, the sites were cleaned and braised using an alcohol prep pad. This process served a two-fold purpose. First, the alcohol prep pad removed surface oils that could disrupt the medium between the adhesive and the skin. Second, the abrasion removed dead skin cells that may hamper the electrical conductivity or the adhesion of the electrode to the skin. To ensure uniformity of sensor location, each electrode was double-checked by another researcher. Noraxon disposable, dual electrodes (product number #272) were used for this study (Noraxon; Dual Electrodes, Scottsdale, AZ). The electrodes were pre-gelled and featured an Ag/AgCl snap. Disposable electrodes were used because of their superior adhesiveness and uniformity of conduction gel volume. The inter-electrode distance (IED) was pre-set by the manufacturer at 20mm to limit cross talk.

3.2.2 Electrode Insulation

All electrodes were lightly wrapped using pre-wrap. This effort served two purposes. First, the pre-wrap “carried” much of the weight of the wires leading to better electrode adhesion and less artifact from swinging wires. Secondarily, the pre-wrap served as a medium between the electrodes and any lose clothing that might rub on the electrodes causing artifact. Maintaining proper adhesion between the electrode and the skin was important because if an electrode became even partially detached, normalization had to be repeated. If an electrode were to become detached during or after the vibration bouts then normalization would be skewed by the vibration administered and the participant's data would be considered worthless.

3.2.3 Muscles of Interest

Muscles of interest for this study were:

1. Vastus Lateralis (VL) Prime mover
2. Vastus Medialis (VM) Prime mover
3. Biceps Femoris (BF)Protagonist
4. Medial Gastrocnemius (GST)Protagonist
5. Medial Deltoid (MD)Stabilizer
6. Biceps Brachii (BB) Prime mover
7. Triceps Long Head (TR) Antagonist

These muscles were chosen because each is involved, either as the prime mover, protagonist or antagonistic level during either the squat or the arm curl.

3.2.4 sEMG System

Once electrodes were properly placed, leads were attached to each electrode and connected to the sEMG transmitter belt (Noraxon; TeleMyo 2400T G2, Scottsdale, AZ). Each participant's name, sex, date of birth, height and weight were entered into the sEMG data collection/signal processing software program (Noraxon; MR-XP 1.07 Master Edition, Scottsdale, AZ). Once it was evident that the laptop was graphically and numerically recording the data, participants began the normalization tests.

3.2.5 Normalization

Participants were taken through maximal voluntary isometric contractions (MVIC) for each muscle of interest according to SENIAM manual muscle testing guidelines (Table 8). Each MVIC was performed twice and the higher mean value was used for normalization purposes. Each muscle of interest was measured using a unique test and saved as a unique file for analysis, with the exception of VM and VL. VM and VL MVICs were attained at the same time and saved in the same file because the function of both muscles is primarily knee extension.

Table 8 SENIAM MVC Guidelines

Muscle	Resistance	SENIAM Guidelines
VL	Manual	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.
VM	Manual	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.
BF	Manual	Press against the leg proximal to the ankle in the direction of knee extension.
GST	Isk Dyn*	Plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward. For maximum pressure in this position it is necessary to apply pressure against the forefoot as well as against the calcaneus.
MD	Manual	The arm should be abducted without rotation. When placing the shoulder in test position, the elbow should be flexed to indicate the neutral position of rotation but may be extended after the shoulder position is established in order to use the extended extremity for a longer lever. Pressure needs to be applied against the dorsal surface of the distal end of the humerus if the elbow is flexed or against the forearm if the elbow is extended.
BB	Manual	Place one hand under the elbow to cushion it from table pressure and flex the elbow slightly below or at a right angle, with the forearm in supination. Press against the forearm in the direction of extension.
TR	Manual	Extend the elbow while applying pressure to the forearm in the direction of flexion.

*MVC acquired using isometric test on isokinetic dynamometer

Prior to normalization, participants were informed of the upcoming MVIC's protocols using simple verbal and kinesthetic queues.

3.2.6 Warm Up

Once participants completed MVICs they were asked to perform a basic warm-up which also served as a normalization period. Participants were given a yellow (light resistance) elastic band (Hygenic Thera-Band, Corp, Akron, OH) and asked to perform eight repetitions of squat and eight repetitions of arm curl. Participants performed all exercise tasks to the beat of a metronome set at sixty beats per minute. This measure was taken to assure uniformity between each eccentric and concentric phases (1 sec each). Each participant was given three coaching queues during the warm-up phase:

1. “Each beat of the metronome should correspond with you being at either the top or the bottom of a repetition”
2. “Keep your arms elongated throughout out the entire squat to assure consistency of elastic resistance”
3. “During your squats go as low as you can but not lower than parallel”
4. “Try to maintain uniformity of squat depth”

Once participants began squatting, they were given no feedback unless their action would cause the validity of the data to be questioned. No further feedback was given to avoid confusion. Once participants had completed their two warm-up sets they were informed of the protocol for the up-coming six sets.

3.2.7 Data Collection Sets

Each participant was asked to stand with their feet shoulder-width on the WBV platform with the arches of their feet on the white line that was previously marked as the midline of the platform. Once participants were in their squatting stance, they were asked to remain with their feet in that position for the remainder of the test. Three measurements were then taken:

1. Stance Width: The measurement from the most lateral projection of a participant’s left foot to the most lateral projection of the right foot.
2. Ground to Hand: Anatomical position with hand balled into a fist
3. Ground to Hand: Hand in the position of a completed biceps curl (elbow flexion)

These measurements were taken to control the amount of resistance each participant would experience during exercise. A green (medium) elastic band was used for all six sets.

3.2.8 Level of Resistance

During the squatting sets, participants had the band under their feet and experienced two hundred percent elongation of the band in each hand. Total resistance was variable throughout the repetition but at the top of each squat, participants experienced four hundred percent elongation (15.8 lbs). The maximal elongation during arm curl repetitions was one hundred percent (5.0 lbs). Research suggests that stretching an elastic band twice its resting length five-hundred times can cause a 5-12% decrease in elastic resistance (Simoneau, Bereda, Sobush, & Starsky, 2001). Research has also suggested that most elasticity loss occurs in the first fifty repetitions of exercise (Patterson, Stegink Jansen, Hogan, & Nassif, 2001). In order to reduce the limitation of decreased resistance, which would in turn lead to decreased sEMG outputs, counter-measures were put in place.

3.2.9 Loss of Resistance Counter-Measures

In order to counteract the reduced resistance due to elastic deformation each band was pre-stretched fifty times prior to use. This measure counteracted the previously mentioned limitation which indicated that most elastic deformation occurs in the first 50 repetitions (Patterson et al., 2001). Additionally, bands were switched-out every 10 participants to avoid long term elastic deformation and or tearing.

3.2.10 Pre Vibration Sets

The first sets of elastically-resisted squats and arm curls were performed on the WBV platform but did not include vibration. All sets were performed on the WBV platform to avoid the need to account for the change in stability from surface to surface. Each set of each protocol included ten repetitions performed at a pace of thirty repetitions per minute.

3.2.11 Vibrations Sets

The next two sets were performed during WBV. The vibration was administered at 35 Hz frequency and 2 mm amplitude. Participants received ten seconds of vibration prior to beginning their sets of exercise. The WBV platform administered this same dosage for the entirety of the two sets.

3.2.12 Immediately Following Vibration Sets

The next two sets were performed immediately following the WBV platform being turned off. Even with this being the case, only one true "immediately following vibration" set was attained because participants could only perform one exercise at a time. For this reason, every other participant performed squat/arm curl first. Furthermore, the order of exercises from trial to trial was kept constant. For example, if one participant performed squats before arm curls for the pre-vibration set then they would do the same for the vibration and post-vibration sets. The next participant performed all sets in the opposite order.

3.2.13 Signal Processing

Signal processing was completed using Noraxon's Myo-Research XP Master Edition. The following steps were performed:

1. Each of the two MVCs were separated for each muscle of interest. Each MVC was saved as a unique file. This step created a total of twelve unique files.
2. All activity prior to the first time stamp and following the final time stamp was deleted for each subject and each condition. Because each condition featured two exercises (arm curl and squat). This lead to the creation of six more unique files.
3. All eighteen files were then processed using the following operations:
    - Rectification: |mV| makes all deflections positive
    - Smoothing: 150 moving slide (averages alldata points with the 75 points prior and the 75 points immediately following)
    - Filtering: Bandpass with a low-pass at 80 Hz and a high-pass at 450 Hz (filters out extremely small deflections, electrical sockets (50 Hz), and extremely large deflections)

    This step led to the creation of eighteen new files that were saved with a unique file ending to avoid confusion.

3.2.14 Database Management

1. Once all thirty participants' data were processed it was exported into Microsoft Excel. The MVC with the highest mean mV value was selected as the "true" MVC.
2. Once all sEMG mV data were in Microsoft Excel, %MVC values were calculated using the following formula [(mean mV/mean MVC)*100]

3. Once all sEMG data was in the spread sheet, participants' demographic data were entered. The following data were included:
    - Trial Group (1=arm curl first, 2= squat first)
    - Gender (1= male, 2= female)
    - Height (kg)
    - Weight (m)
    - BMI: calculated in excel (kg/m^2)
    - Age (years)

3.2.15 Data Analysis and Statistical Methods

Data analysis was completed using SPSS (SPSS Inc., Version 18, Chicago, Illinois). All sEMG data were imported into SPSS in %MVC form. It is important to note than any participant who had %MVC data higher than 100% for all three conditions were excluded from analysis. This exclusion was on a muscle by muscle basis. For example, one participant's VLO data may have been excluded but the same participants VMO data included in statistical analysis.

Within subject variance was measured using repeated measures ANOVAs. Participants BMI were entered as a covariate to explore body mass effect. Follow-up post-hoc analyses (LSD) were used to determine the nature of any main effects differences. A probability value of less than 0.05 was considered statistically significant and less than 0.10 was considered clinically significant. This same syntax was run for each of the muscles of interest.

Chapter 4: Results

4.1 Introduction

The number of data used for analysis was less than the number of data collected. As previously mentioned any participant who exceeded 100%MVC during one of the sub-maximal conditions had that muscles data excluded from analysis. The following table (Table 9) illustrates how many data were excluded from analysis.

Table 9 Percent Changes

Muscle	Pre-Vibration	During Vibration	Post-Vibration
V. Medialis	57.20±22.5 (n=21)	59.63±23.4	58.40±23.0
V. Lateralis	45.96±18.2 (n=27)	48.61±19.2	44.5±17.6
Gastrocnemius	32.89±16.0 (n=29)	43.27±21.1	36.42±17.8
Biceps Femoris	18.87±10.4 (n=30)	19.52±10.8	18.81±10.4
Triceps Bra.	25.43±20.0 (n=30)	27.51±21.6	23.70±23.7
Biceps Bra.	46.63±26.6 (n=25)	47.94±27.3	47.17±26.9
Deltoid	2.67±1.3 (n=30)	4.11±2.0	3.34±1.6

4.2 Significant Differences Between Trials

Repeated-measures ANOVA were used to observe within-subject main-effects between conditions. ($p<.05$). Each ANOVA featured three levels to analyze all three conditions at once. Means were calculated across the participant pool for each of the three conditions.

Statistically significant increases in sEMG (%MVC) were observed in all seven muscles of interest between the pre-vibration (control) trial and the vibration trial (Table 9). The most noticeable increases were found in the lower-body muscles. For example, the gastrocnemius muscle saw an average increase of 31.55% of MVC. The prime movers of the squat (VMO and VLO) saw a 4.24% and 5.76% increase respectively. The biceps femoris' sEMG activity increased an average of 3.44%.

As previously mentioned vibration increased sEMG activity in the upper extremity muscles as well (Table 9). The prime-mover of the arm curl, the biceps brachii, saw an average increase of 2.8% (Table 9) from the control condition to the vibration condition. The antagonist muscle, the triceps brachii, saw an average increase of 8.17%.

4.2.1 Vastus Lateralis

Results indicate that sEMG activity was increased during vibration but not immediately following vibration (Table 10). Results indicate BMI has no main-effect on sEMG activity during or immediately following vibration (Table 11).

Pairwise Comparisons

Table 10 Vastus Lateralis sEMG Pairwise Comparison

(I) vibration	(J) vibration	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Pre	Vib	-2.651*	.213	.000	-3.090	-2.213
	Post	1.446*	.116	.000	1.207	1.685
Vib	Pre	2.651*	.213	.000	2.213	3.090
	Post	4.097*	.329	.000	3.420	4.775
Vib	Pre	-1.446*	.116	.000	-1.685	-1.207
	Post	-4.097*	.329	.000	-4.775	-3.420

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Table 11 Vastus Lateralis BMI Pairwise Comparison

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
lowbmi	Highbmi	-.696	7.459	.926	-16.059	14.667
highbmi	Lowbmi	.696	7.459	.926	-14.667	16.059

Based on estimated marginal means

4.2.2 Vastus Medialis

Results indicate that sEMG activity was increased during and immediately following vibration (Table 12). Results indicate BMI has no main-effect on sEMG activity during or immediately following vibration (Table 13).

Pairwise Comparisons

Table 12 Vastus Medialis sEMG Pairwise Comparison

(I) vibration	(J) vibration	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Pre	Vib	-2.356*	.215	.000	-2.812	-1.900
	Post	-1.167*	.107	.000	-1.393	-.941
Vib	Pre	2.356*	.215	.000	1.900	2.812
	Post	1.189*	.109	.000	.959	1.419
Post	Pre	1.167*	.107	.000	.941	1.393
	-Vib	-1.189*	.109	.000	-1.419	-.959

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Table 13 Vastus Medialis BMI Pairwise Comparison

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
lowbmi	highbmi	15.952	10.364	.143	-6.019	37.922
highbmi	lowbmi	-15.952	10.364	.143	-37.922	6.019

Based on estimated marginal means

4.2.3 Biceps Femoris

Results indicate that sEMG activity was increased during and immediately following vibration (Table 14). Results indicate BMI has no main-effect on sEMG activity during or immediately following vibration (Table 15).

Pairwise Comparisons

Table 14 Biceps Femoris sEMG Pairwise Comparison

(I) vibration	(J) vibration	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Pre	Vib	-.658*	.069	.000	-.800	-.516
	Post	.061*	.006	.000	.048	.074
Vib	Pre	.658*	.069	.000	.516	.800
	Post	.719*	.076	.000	.564	.873
Post	Pre	-.061*	.006	.000	-.074	-.048
	Vib	-.719*	.076	.000	-.873	-.564

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Table 15 Biceps Femoris BMI Pairwise Comparison

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
lowbmi	Highbmi	-2.885	4.109	.488	-11.302	5.532
highbmi	Lowbmi	2.885	4.109	.488	-5.532	11.302

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4.2.4 Gastrocnemius

Results indicate that sEMG activity was increased during and immediately following vibration (Table 16). Results indicate BMI has no main-effect on sEMG activity during or immediately following vibration (Table 17).

Pairwise Comparisons

Table 16 Gastrocnemius sEMG Pairwise Comparison

(I) vibration	(J) vibration	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Pre	Vib	-10.807*	.973	.000	-12.804	-8.809
	Post	-3.676*	.331	.000	-4.355	-2.996
Vib	Pre	10.807*	.973	.000	8.809	12.804
	Post	7.131*	.642	.000	5.813	8.449
Post	Pre	3.676*	.331	.000	2.996	4.355
	Vib	-7.131*	.642	.000	-8.449	-5.813

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments)

Pairwise Comparisons

Table 17 Gastrocnemius BMI Pairwise Comparison

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
lowbmi	highbmi	-9.846	7.035	.173	-24.279	4.588
highbmi	lowbmi	9.846	7.035	.173	-4.588	24.279

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4.2.5 Deltoid

Results indicate that sEMG activity was increased during and immediately following vibration (Table 18). Results indicate BMI had a significant main-effect on sEMG activity during or immediately following vibration (Table 19). These data suggest that participants with above average BMI's had significantly lower sEMG increases during and immediately following WBV.

Pairwise Comparisons

Table 18 Deltoid sEMG Pairwise Comparison

		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Pre	Vib	-.728*	.054	.000	-.838	-.618
	Post	-1.563*	.116	.000	-1.800	-1.326
Vib	Pre	.728*	.054	.000	.618	.838
	Post	-.835*	.062	.000	-.961	-.708
Post	Pre	1.563*	.116	.000	1.326	1.800
	Vib	.835*	.062	.000	.708	.961

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Table 19 Deltoid BMI Pairwise Function

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Lowbmi	highbmi	-1.772*	.543	.003	-2.885	-.659
highbmi	lowbmi	1.772*	.543	.003	.659	2.885

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

Pairwise Comparisons

Table 19 Deltoid BMI Pairwise Function

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Lowbmi	highbmi	-1.772*	.543	.003	-2.885	-.659
highbmi	lowbmi	1.772*	.543	.003	.659	2.885

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

BMI Means

Table 20 Deltoid BMI Means

bmigroup	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
lowbmi	46.485	6.307	33.438	59.532
highbmi	49.674	11.224	26.456	72.892

4.2.6 Biceps Brachii

Results indicate that sEMG activity was increased during and immediately following vibration (Table 21). Results indicate BMI has no main-effect on sEMG activity during or immediately following vibration (Table 22).

Pairwise Comparisons

Table 21 Biceps Brachii sEMG Pairwise Comparison

(I) vibration	(J) vibration	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Pre	Vib	-1.334*	.179	.000	-1.704	-.965
	Post	-.553*	.074	.000	-.706	-.400
Vib	Pre	1.334*	.179	.000	.965	1.704
	Post	.781*	.105	.000	.565	.997
Post	Pre	.553*	.074	.000	.400	.706
	Vib	-.781*	.105	.000	-.997	-.565

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Table 22 Biceps Brachii BMI Pairwise Comparison

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Lowbmi	Highbmi	-3.189	12.874	.807	-29.822	23.444
highbmi	Lowbmi	3.189	12.874	.807	-23.444	29.822

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4.2.7 Triceps Brachii

Results indicate that sEMG activity was increased during and immediately following vibration (Table 23). Results indicate BMI has no main-effect on sEMG activity during or immediately following vibration (Table 24).

Pairwise Comparisons

Table 23 Triceps Brachii sEMG Pairwise Comparison

(I) vibration	(J) vibration	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Pre	Vib	-2.222*	.311	.000	-2.860	-1.585
	Post	1.852*	.259	.000	1.321	2.383
Vib	Pre	2.222*	.311	.000	1.585	2.860
	Post	4.074*	.571	.000	2.905	5.243
Post	Pre	-1.852*	.259	.000	-2.383	-1.321
	Vib	-4.074*	.571	.000	-5.243	-2.905

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Pairwise Comparisons

Table 24 Triceps Brachii BMI Pairwise Comparison

(I) bmigroup	(J) bmigroup	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
lowbmi	highbmi	-10.548	7.646	.179	-26.210	5.114
highbmi	lowbmi	10.548	7.646	.179	-5.114	26.210

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 25 Percent Change from Control

Muscle	Vibration	Post-Vibration
V. Medialis	4.24%	2.09%
V. Lateralis	5.76%	-3.17%
Gastrocnemius	31.55%	10.73%
Biceps Femoris	3.44%	-0.31%
Triceps Bra.	8.17%	-6.80%
Biceps Bra.	2.80%	1.16%
Deltoid	53.93%	25.09%

Chapter 5: Discussion

5.1 Introduction

In conclusion, results indicate increased sEMG activity during and immediately following WBV. The increases in sEMG activity are generally larger in the lower extremity muscles, closest to the source of vibration. Our data also indicate that BMI does not have a significant effect on WBV's neurological enhancement properties.

5.2 Hypotheses Revisited

5.2.1 Hypothesis One

As previously stated, it was hypothesized that WBV would increase sEMG activity during and immediately following the vibration bout. Data from the present study is consistent with the first clause of this hypothesis. WBV increased sEMG activity in every muscle of interest during the arm curl and the squat.

The second clause of the first hypothesize stated that sEMG activity should stay elevated immediately following vibration. Post vibration sEMG increases were not observed in the following muscles:

1. Triceps Brachii
2. Biceps Femoris
3. Vastus Lateralis

The data of these three muscles are inconsistent with previously conducted research (Tables 4&6). One possible reason for this discrepancy is the alteration of squat and arm curl bio-mechanics caused by the combination of WBV and elastic resistance.

5.2.2 Hypothesis Two

Hypothesis two predicted that the increases observed during elastically resisted WBV exercise would be comparable to traditionally resisted WBV exercise (as recorded in previous studies). The data of the present study were generally consistent with previously conducted WBV research utilizing traditionally weighted resistance (Tables 4&6). Examples of the correlation include:

1. Increased sEMG activity during WBV
2. Higher increases in sEMG activity in the muscles closest to the WBV source

5.2.3 Hypothesis Three

Hypothesis three predicted that WBV would increase lower extremity sEMG activity more than it would increase upper extremity activity. This hypothesis was confirmed by this study with two exceptions (Table 11). Our research suggested a thirty-one percent increase in sEMG in the gastrocnemius during squatting with WBV. The gastrocnemius' sEMG increases were far higher than any other muscle. Additionally, the percent increase was higher in the vastus lateralis and vastus medialis compared to the biceps femoris which is considerably higher up the kinetic chain. There were however two outliers to this trend. There was a fifty-four percent increase in sEMG activity in the deltoid and an eight percent increase in the triceps brachii during the WBV bout. It is important to remember that the deltoid was not involved as a prime-mover or antagonist during the arm curl. Additionally, the triceps serves only as an antagonistic muscle so these data should be taken more lightly than the other muscles of interest.

One possible reason for the large sEMG increase in these muscles could be the increased need for shoulder-girdle stability during WBV.

5.2.4 Hypothesis Four

Hypothesis four predicted a decreased main-effect of WBV and sEMG activity in individuals with above average BMI's compared to those with bellow average BMI's. This hypothesis was incorrect. The only muscle that produced such a trend was the deltoid. As previously mentioned, the deltoid due to its negligible sEMG activity during the biceps curl is not enough evidence to suggest a significant correlation between BMI and sEMG.

5.3 Research Problems Revisited

As previously mentioned there are several unknown facets of WBV training. These include the following:

1. The length of time WBV's neuromuscular benefits last
2. The effects of WBV on muscular activity as measured by sEMG during elastically resisted exercise
3. The factors that determine ones response to WBV
4. What WBV dosage parameters are most beneficial

5.3.1 Research Question One

The present studies data does not completely answer research problem number one but it does shed some light on the subject. The data suggested that all prime-movers had significant increases in sEMG activity immediately following WBV which suggests WBV benefits are not limited to the time of exposure.

5.3.2 Research Question Two

The data collected during this study does provide evidence that will aid in answering question number two. sEMG activity during elastically resisted exercise behaved in the same fashion as sEMG activity during traditionally weighted exercise (Table 6). sEMG activity was increased across the board during WBV. Also, the fact that immediately following WBV data were inconclusive is consistent with previously conducted research (Table 6).

5.3.3 Research Question Three

The study at hand examined one possible within-subject factor that could affect participants' responses to WBV. BMI was run in each repeated measures ANOVA as a factor. Results indicate that the deltoid is the only muscle in-which BMI affects sEMG percent-change with the introduction of WBV. As previously mentioned the deltoid acts only as a stabilizing muscle so its sEMG outputs do not carry as much weight as other muscles of interest.

5.3.4 Research Question Four

Research question four aims at learning which WBV dosage parameters are most effective at increasing sEMG activity. Data from the present study indicate that the following dose causes increased sEMG activity:

- 30 second exposure
- 35 Hz frequency
- 2 mm amplitude

Further research is needed to determine if the previously described WBV dosage is the most effective at increasing sEMG activity.

5.4 Conclusion

In conclusion, it appears that muscle activity as measured by sEMG, is increased during and immediately following elastically resisted WBV training. These data are potentially useful for multiple cohorts including the elderly and physical therapy patients. Additionally, it appears that elastically resisted WBV responses are similar to that of traditionally resisted WBV responses. The current study also suggests there is no difference in sEMG activity between slightly overweight and slightly overweight participants.

5.5 Future Considerations

Future research should explore the effects of elastically resisted WBV training as a rehabilitation tool in older adults and post injury patients. Additionally, further research exploring dosage parameters effectiveness should be explored. Long-term studies would also be beneficial for observation of long-term effects.

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