THE EFFECT OF WHOLE BODY VIBRATION ON

LOWER BODY RESISTANCE DETRAINING

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DEDICATION

This dissertation is dedicated to all individuals who honor their gifts and have found their niches. And while dedicated to their own personal growth, help to improve their communities and thereby all of humankind.

"Your visions will become clear only when you can look into your own heart. Who looks outside dreams; who looks inside, awakes."-Carl Jung

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ABSTRACT

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THE EFFECT OF WHOLE BODY VIBRATION ON
LOWER BODY RESISTANCE DETRAINING

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This study explored the effect of whole body vibration (WBV) with magnitudes between 2.56 g and 7.68 g on detraining of the 5-repetition maximum (5RM) squat, extensors and flexors of the knee and the flexors and extensors of the ankle. All participants were trained using a lower body resistance lifting program. Exercises performed included the squat, hang cleans, knee extensions, hamstring curls, toe presses and dorsiflexion exercises. All participants were trained one to three times per week for 6 weeks. At the end of the program (Week 6), they were randomized onto either a control group which performed no further training or a WBV group which performed a progressive static WBV program. Data was collected at week 0 at the commencement of the resistance training program; Week 6; Week 8; Week 10; and Week 12 at the end of the detraining period. Data were analyzed using a two-way (condition vs. time) factorial analysis of variance (ANOVA) for the squat, and a two way (condition vs. time) factorial MANOVA for the plantar flexion, dorsiflexion and knee flexion variables. The interaction null hypothesis for condition and time was rejected for the 5RM squat. The means for the control group (in pounds) were 89.5 $\pm$ 59.7, 148 $\pm$ 46.9, 143 $\pm$ 47.3, 135.5 $\pm$ 47.34 and 132 $\pm$ 47.7 for Weeks 0, 6, 8, 10 and 12 respectively, while the respective

WBV group means were 62.5 ± 43.9, 155 ± 22.48, 152.5 ± 28.6, 144 ± 23.8 and 137 ± 28.7. Although the WBV group appeared to maintain strength in the 5RM from Week 6 through Week 8 and the control group had a significantly lower 5 RM in Week 8 from Week 6, there were no differences in 5RM squat between the groups at Week 8. There were no differences between either group at any of the time points for knee flexion torque, dorsiflexion torque or plantar flexion torque. For the resistance training program used in this study, static whole body vibration using accelerations between 2.56 g and 7.68 g does not appear to attenuate detraining of the flexors and extensors of the knee and ankle after 6 weeks.

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CHAPTER I

INTRODUCTION

Exercise is a stimulus that induces physiological adaptations. The type of adaptations that occur depends on the type of exercise that is practiced (categorized as aerobic and anaerobic) and the induction of these adaptations constitutes what is called training. Conversely, cessation of these exercises results in a loss of these adaptations, which is referred to as detraining.

Anaerobic training is defined as exercise that is intermittent and high-intensity in nature (Baechle & Earle, 2009). Anaerobic training includes weight training (otherwise known as resistance training or strength training), interval training, speed training, agility training and plyometric exercise, and is widely reported to increase strength and power. Modes of exercise that are classified as anaerobic or resistance training are well documented to induce adaptations across various physiological systems, most notably the nervous, endocrine, muscular and skeletal systems. Neural adaptations to anaerobic training are responsible for gains in strength from the first 6-10 weeks of training. Muscular adaptations such as hypertrophy are responsible for strength gains after the initial 6-10 weeks (Hortobagyi & Maffiuletti, 2011; Zhou, 2003).

Detraining may be defined as either complete cessation of resistance training exercise, or the marked reduction in any combination of the frequency, intensity or duration of a resistance training protocol that leads to a decrement in performance via loss of physiological adaptations elicited by resistance training (Baechle & Earle, 2009). The rate of detraining may be dependent upon several factors, such as differing levels of training status of participants, types of training protocols employed, age, measurements of different strength and power parameters, as well as the use of different research methodologies (Andersen, Andersen, Magnusson & Aagard, 2005; Lemmer et al., 2000; Melnyck, Rogers & Hurley 2009; Winters & Snow, 2000). A typical example of detraining may occur in the case of injured athletes (Reiman & Lorenz, 2011). Sport specific injuries such as anterior cruciate ligament (ACL) tears impair one's ability to perform anaerobic training with free weights or machines and could therefore result in detraining. There seems to be no consistent period in which detraining occurs, although it has been suggested that short term detraining occurs from 0-4 weeks, resulting in minimal losses in adaptations to resistance training programs. Beyond 4 weeks there is a more rapid increase in the loss of adaptations (Mujika & Padilla, 2000a, 2000b).

In cases where the primary mode of training may not be performed due to injury, individuals should consider modes that can minimize detraining, without aggravation of injury. An example of such a mode of training may be whole body vibration. According to Albasini, Krause & Rembitzki, (2010), whole body vibration (WBV) is a relatively new method of exercise which requires the use of an actuator (vibration apparatus) upon a resonator (i.e., the person standing upon the platform of the machine). Intensity of WBV exercise is quantified in multiples of acceleration in the Earth's gravitational field "g", where 1 g = 9.81 ms^{-2}. Acceleration can be changed by manipulating amplitude, which is the maximum vertical displacement from the WBV platform's equilibrium position. Acceleration may also be manipulated by adjusting the platform's frequency, measured in oscillations per second. Acceleration on the platform may be quantified by several mathematical formulae; one such formula is $a = A(2\pi f)^2$ where "a" is the platform's acceleration, "A" is the half of the peak-to-peak amplitude, and "f" is frequency in Hz.

Among the proposed benefits of WBV are increases in muscular force production, as well as its ability to delay deleterious effects associated with bed rest and microgravity, such as atrophy and osteoporosis (Cochrane, et al., 2008; Mikhael, Orr, Amsen, Greene & Singh, 2010). Whole body vibration has been used in order to induce acute and chronic strength gains in various populations (Bazett-Jones, Finch & Dugan, 2008; Cochrane et al., 2008; Mahieu et al., 2006; Mikhael, et al., 2010).

Statement of the Problem

Detraining may occur during times of traumatic knee injury. Selection of a mode of exercise which may delay detraining, yet minimize interference of the injury may be difficult.

Purpose

To determine if a WBV program using progressions of acceleration on the actuator may be used to delay detraining of strength as defined as 5 repetition maximum squat, concentric knee flexion and extension torque.

Null Hypotheses

Main Effects

There will be no significant difference in torque produced by concentric extension or flexion of the knee and ankle between the control and WBV groups.

There will be no significant difference in torque produced by concentric extension or flexion of the knee and ankle between the time periods.

Interaction Effects

There will be no significant differences resulting from the interaction of training group and time.

Assumptions

1. Participants received a maximal training stimulus during both the resistance training and WBV exercise regimens.
2. Participants exerted maximum torque during measurement collection.
3. Participants were free of any physiological limitations which may have affected data collection via the use of a dynamometer.
4. Torque generated using extension and flexion of the knee and ankle as measured by the dynamometer is a valid and reliable measure of strength.

Limitations and Delimitations

1. This study was limited to the examination of flexors and extensors of the knee and ankle joints.

2. This study was limited to the lower body exercises used to increase torque in the resistance training protocol.
3. This study was limited to the population sampled: (18-45 years old; healthy, i.e., no positive response on physical activity readiness questionnaire [PAR-Q]; adults with a body mass index (BMI) less than or equal to 24.9 $kg \cdot m^{-2}$.
4. This study was delimited to the types of exercise used to measure maximal voluntary contractions.
5. This study was delimited to the type of vibration platform used in order to prevent detraining.

Definition of Terms

Acceleration: Rate of change of velocity (unit; ms^{-2}); in vibration, measured in terms of frequency and amplitude by the formula $a= A(2\pi f)^2/2$ where a = acceleration, A = amplitude and f = frequency.

Acceleration upon an apparatus that is not moving in a sinusoidal wave pattern: $a/\sqrt{2}$

Acceleration due to the Earth's gravitational field: 9.81 ms^{-2}.

Actuator: An apparatus that imparts a vibratory stimulus (i.e., the vibration plate).

Amplitude: Displacement of an oscillation from its position of equilibrium in either a positive or negative direction.

Anaerobic training: Exercise that is intermittent and high intensity in nature, (i.e., agility training, interval training, speed training, plyometrics, strength training, resistance training, and weight training).

Detraining: Loss of training induced adaptations resulting from reduction or cessation of resistance exercise. In the present study, the period of detraining was 6 weeks.

Dynamometer: Instrument used to measure force, power or torque. The instrument used in this study was the Biodex System 3 Pro dynamometer.

Force: The product of a body's mass and its acceleration.

Intensity of vibration: Size of the vibration stimulus; quantified by amplitude, duration, frequency or acceleration; often reported as a multiple of acceleration in the Earth's gravitational field or g's. In the present study intensity was controlled by increasing the amplitude of platform displacement, or the frequency of the vibration stimulus.

Muscle Damping: The phenomenon whereby muscles nearer to the vibration plate are absorbing more vibration oscillations than muscles further away.

Muscle spindle: Organ composed of specialized skeletal muscle fibers that induce reflex activity of skeletal muscle upon sensing a stretching stimulus.

Muscular Strength: The ability to move a load. In this experiment muscular strength was measured at the knee and ankle, and was the amount of torque produced when performing isokinetic concentric knee flexion and extension at $60^{o}\ s^{-1}$ and isokinetic concentric ankle flexion and extension at $30^{o}\ s^{-1}$.

Newton: The unit of measurement of force; also expressed as kilogram meter/second^2

Peak-to-peak displacement: Maximum displacement of an oscillation from its position of equilibrium in either a positive or negative direction.

Reflex Arc: The combination of a sensory receptor, sensory neuron, integrating neuron, motor neuron and effector organ which facilitates reflex activity.

Resonance: The phenomenon whereby a resonator's amplitude may exceed that of an actuator due to accumulation of mechanical energy, resulting in resonance catastrophe.

Resonator: Term used to describe the entity that experiences a vibratory stimulus from an actuator (i.e., the person standing on the actuator).

Whole-body vibration: Delivery of an oscillating mechanical stimulus from an actuator to a resonator.

Significance of the Study

The objective of this study was to observe the effects of WBV on resistance detraining of the lower body, in order to determine if WBV may be used as a tool to help to maintain strength in the event of an athlete being incapacitated due to traumatic knee injury. Detraining effects may be severe, and may lead to a decrement in performance, and perhaps further injury. Therefore it may be necessary to find other methods of training in the event that conventional methods of training could not be performed due to traumatic knee injury. An example of such an injury would be a tear of the anterior cruciate ligament (ACL).

CHAPTER II

REVIEW OF THE LITERATURE

The purpose of this study was to explore the use of WBV as an intervention to delay lower body resistance detraining in women. In this chapter, theories underlying strength training, knee rehabilitation from traumatic injury, WBV, and its potential use in maintaining strength during the rehabilitation process will be discussed.

Anaerobic Training

Anaerobic training may result in neural adaptations in the central and peripheral divisions of the nervous system. This increase in neural drive results in an ability of agonists to produce force, accompanied by inhibition of inhibitory pathways, such as those produced by golgi tendon organs (Aagaard, et al. 2000). The ability to produce force is mediated by an increase in muscle fiber recruitment, increase in motor neuron firing rate and more efficient discharge patterns and discharge timing. There are two pathways via which the central nervous system adapts to anaerobic training: increase in motor cortex activity (Griffin & Cafarelli, 2007) and an increase in excitability of the corticospinal tracts of the spinal cord (Aagaard, Simonsen, Andersen, Magnusson, & Dhyre-Poulsen, 2002b).

Neuromuscular Response to Anaerobic Training

Motor Unit

A motor unit consists of an alpha motor neuron and the muscle fibers that it innervates (Marieb & Hoehn, 2007). Motor units range in size from a neuron and its four associated muscle fibers to another neuron innervating over several hundred muscles for large, powerful muscles (Marieb & Hoehn, 2007). Increasing a muscle's ability to produce force entails maximal motor unit recruitment and an increase in motor unit firing frequencies. One way to increase a muscle's ability to increase these parameters is via heavy resistance training (Aagaard, Simonsen, Andersen, Magnusson, & Dhyre-Poulsen, 2002a, Aagaard et al., 2002b).

Recruitment of muscle fibers is governed by the size principle (Henneman, Somjen & Carpenter 1965; Marieb & Hoehn, 2009). The size principle postulates that in order to recruit large powerful fibers/motor units, smaller ones must first be recruited. All muscles contain a distribution of type I muscle fibers as well as type II muscle fibers. Type I fibers tend to be relatively small and have lower thresholds, and type II fibers tend to be larger and have higher thresholds of firing. Therefore in order to move a heavy load, type I fibers are sequentially recruited before type II fibers. Large type II fibers are thus recruited for heavy lifting or explosive movements. Maximal loads would require the use of the highest possible ability to recruit all muscle fibers in order to generate movement against the load. Additionally, when a motor unit is activated, subsequent recruitment requires less activation in order to do so (Baechle & Earle, 2009)

It is suggested that there are situations that take exception to the size principle. During situations where powerful ballistic movements or changes in direction of force are needed (such as those found in plyometrics) trained individuals may be able to selectively recruit power-generating fast twitch fibers without using smaller units (Baechle & Earle, 2009). The advantage of this ability is that individuals would not have to take the time to recruit all the muscles of the slow twitch pool in order to generate the force in order to execute ballistic movements such as throwing shot put. Thus selective recruitment would reduce the amount of time needed in order to generate large amounts of force.

Evidence suggests that hypertrophy may also affect recruitment patterns (Van Cutsem, Duchataeu & Hainaut, 1998). When a muscle increases in size, it does not need as much neural activation in order to lift a particular load. Changes in rate and sequence may also be relevant to the muscle's size. Larger muscles seem to rely more on recruitment, whereas smaller ones may rely on an increased rate of firing (Baechle & Earle, 2009). High firing rates are critical to the production of force by a muscle and are also improved by resistance training. Resistance training may also improve synchronous firing by motor units. Anaerobic training may also enhance the stretch reflex, which may be an adaptation to enhance the rate of force development as well as total force generated (Aagaard et al., 2002a).

Neuromuscular Junction

Animal studies have demonstrated that exercise may elicit adaptations of the neuromuscular junction. One study reported increased acetylcholine receptors as well as end plate area after 7 weeks of resistance training. Using the soleus muscle of rodents, Deschenes et al. (1993), demonstrated that the neuromuscular junction increased in area in relatively high and low intensity exercise. However there was more nerve terminal branching, and more irregular shaped and dispersed synapses in the high intensity exercise group. There was increased dendrite restructuring, increased protein synthesis and transport, and enhanced neuromuscular transmission dynamics in α-motoneurons of rats subjected to exercise as well (Gardiner, Dai & Heckman, 2006).

Neural Signaling and Time Taken to Achieve Strength Gains

It has been shown that resistance training can improve neural signaling in the untrained before hypertrophy begins (Aagaard et al., 2002a; Zhou, 2003). Furthermore, it is shown that the hypertrophy and electromyography (EMG) signaling share an inverse relationship (i.e., as muscle size increases neural signaling decreases; Baechle & Earle, 2009). An explanation of this is that early in the training program (about 6-10 weeks) increases in neural adaptations are occurring (Hortobagyi & Maffiuletti, 2011; Zhou, 2003). If training continues after this period, muscle hypertrophy contributes more to improved strength gains. Evidence also suggests that if the individual seeks to improve strength gains then one must introduce variation and progressive overload in the training regimen. Thus anaerobic training appears to improve neural output.

Bilateral Deficit and Cross Education

Studies have suggested that EMG is higher in either limb contracting unilaterally than when they contract bilaterally and there is less of an EMG deficit between limbs with bilateral resistance training (Oda & Moritani, 1994). EMG studies have indicated that training one limb can result in an increase in strength in the untrained limb (Lee & Carroll, 2007; Zhou, 2003). The increase in strength is accompanied by a greater magnitude of neural activity recorded by the EMG in the untrained limb. Both of these findings suggest an improvement in neural pathways as a consequence of resistance training. Antagonist co-contraction is a mechanism moderated by the golgi tendon organ and is used to decrease the risk of injury by an agonist that produces too much force. In untrained individuals, antagonist co-contraction is higher especially if the individual is unfamiliar with a particular task. However, if the goal is to improve an agonist's ability to produce force, then too much antagonist activity may prevent this from happening. Therefore some studies propose that reduced antagonist co-contraction is an adaptation to resistance training (Hakkinen et al., 1998).

Finally, resistance training may have a residual effect that could be partly neural in nature. When a participant returns to training strength re-attainment is somewhat high when compared to the original untrained state. Andersen, Andersen, Magnusson and Aagaard, (2005) subjected 13 sedentary males to 3 months of heavy resistance training. After training, significant increases were observed in muscle cross sectional area, moment of force during slow eccentric, slow concentric, fast eccentric and fast concentric contractions, and EMG during slow and fast eccentric, and slow concentric contraction conditions. The authors reported that maximal muscle strength and EMG remained preserved during eccentric contractions after 3 months of detraining, although concentric contractions were not.

Skeletal Muscle Response to Anaerobic Training

Just as resistance training appears to elicit changes in the central and peripheral nervous system in order to adapt to force production, this discussion now turns into adaptations to skeletal muscle. The simplest organization of muscle fiber type from most glycolytic/least oxidative to least glycolytic/most oxidative is type IIb, type IIa, and type I fibers. Myosin ATP-ase staining has found up to seven fiber types: I, IC, IIC, IIAC, IIA and IIB, with type I being the most oxidative and type IIB being the most glycolytic. The size principle postulates that all fibers belonging to small motor units, generally type I, must be recruited in a maximal contraction before larger motor units i.e., type II (Henneman, Somjen & Carpenter 1965). This is because small motor units have smaller firing thresholds than large motor units. Thus both fiber types increase in cross sectional area in response to heavy resistance training, although it has been shown that type II fibers increase in cross sectional area more so than type I fibers (Baechle & Earle, 2009). Since type II fibers tend to generate more force, an individual who has a genetic predisposition to more type II fibers has the potential to induce hypertrophy and thus reap greater gains in increasing muscle mass (Baechle & Earle).

Mechanism of Muscular Contraction

The basic functional unit of skeletal muscle is the sarcomere (Scott, Stevens & Binder-Macleod, 2001; Marieb & Hoehn, 2007). Within the sarcomere are contractile proteins called actin and myosin (Marieb & Hoehn, 2007). Actin filaments are called thin filaments while myosin filaments are referred to as thick filaments. The thin filament is made of actin and its two regulatory polypeptides, troponin and tropomyosin. The myosin filament is composed of six peptide chains: two are heavy chains and four are light chains. Of the four light chains, two are alkali chains and the other two are regulatory chains. Each heavy chain therefore has its own alkali and regulatory chains. The myosin heads that interact with actin (thus producing a muscular contraction) are located within the heavy chains. Each myosin head contains a site that serves to bind adenosine triphosphate (ATP). The binding site also contains adenosine triphosphatase (ATP-ase), which splits ATP into adenosine diphosphate (ADP) and a phosphate group, releasing energy used in order to facilitate muscular contraction.

When a motor neuron secretes acetylcholine, an action potential occurs which causes the release of calcium from the sarcoplasmic reticulum. The calcium binds to troponin, specifically troponin-C), which removes tropomyosin, thus exposing a myosin binding site on the actin molecule. As long as ATP is present, the myosin head will grab and pull the actin filament. Cross-bridge cycling is the process via which myosin heads attach successively to actin binding sites (i.e., cross bridge formation), pulling the actin filament closer to the center of the sarcomere. In other words, a myosin head binds to actin at an exposed binding site of the latter, releases, and then reattaches to another actin location until there is complete overlap of myosin and actin filaments (Scott et al., 2001).

Cross bridge cycling rates are determined by the rate that the myosin head's ATPase can hydrolyze ATP (Scott et al., 2001).

Muscle Fiber Types

There are several ways in which to classify muscle fibers. The simplest way is to classify them as fast or slow based on speeds of shortening (Scott, Stevens & Binder-Macleod, 2001). Classically this was associated with physical differences; slow fibers were red and fast muscle fibers, white. Greater myoglobin content and capillary numbers account for the red color of slow fibers and are thus more oxidative in nature when compared with white fibers. Myosin ATP-ase activity and speed of muscle shortening are also correlated. Myosin ATP-ase staining first identified three muscle types: I (slow oxidative), II (fast oxidative) and IIB [fast glycolytic]. More recently, the technique has identified up to seven fiber types. From most oxidative to most glycolytic these types are called I, IC, IIC, IIAC, IIA and IIB. For the next discussion, however, the classification of type I and type II should be sufficient.

Type I Muscle Fibers

Type I muscle fibers are oxidative in nature, (i.e., specialized to use substrate in the presence of high amounts of oxygen; Marieb & Hoehn, 2007). They are usually red in color due to increased myoglobin content, relatively small in size compared to type II muscle fibers and are specialized for long term endurance activity (Marieb & Hoehn, 2007). In addition, they have small α-motorneurons, a long contraction time, a large number of mitochondria (and thus better adapted to use trigylcerides as a fuel substrate), relatively thin muscle fibers in order to allow for more efficient oxygen diffusion, and are highly vascularized in order to furthermore increase oxygen delivery and transport and carbon dioxide/waste product removal (Marieb & Hoehn, 2007). Therefore, these muscle fibers are well adapted to performing for relatively long periods of time (i.e., many hours).

In an individual the factors that determine an increased phenotypic expression of type I fibers include heredity and environmental stimuli, (i.e., exercise). Modes of exercise that increase expression of type I muscle fibers include long duration and distance running such as marathon, swimming, cross country skiing, distance biking or combinations of the above (Baechle & Earle, 2009).

Type II Muscle Fibers

Type II muscle fibers are glycolytic in nature, and are more suited for force production (Marieb & Hoehn, 2007). They are larger in size with large α-motorneuons and have short, fast contraction times. The muscle fibers are larger than type I fibers, have a relatively small number of mitochondria, and are relatively white (type IIb or "pink") in color due to having less myoglobin than Type I muscle fibers.

Skeletal Muscle Organization

The functional unit of contraction is the sarcomere (Marieb & Hoehn, 2007). Sarcomeres are arranged in series to create myobrils, which are specialized organelles that occupy most of the fiber's volume. Myofibrils are arranged in parallel to create a multinucleated muscle fiber, which is the actual cell of skeletal muscle tissue. Muscle fibers in turn are arranged in parallel to create the muscle fascicles, which in turn are also arranged in parallel to create an entire muscle.

Response to Anaerobic Training

There are two means via which skeletal muscle is able to grow. Hypertrophy describes the increase in cross sectional area of myofibrils, while hyperplasia describes an increase in the number of muscle fibers.

Mechanisms of Hypertrophy

Resistance training increases expression of insulin-like growth factor (IGF-1). IGF-1 indirectly phosphorylates Akt, via phosphatidylinositol-3-kinase (PI3K) and phosphoinositide-dependent kinase 1 (PDK1), which is able to induce hypertrophy via several pathways. Akt is able to phosphorylate and activate the mammalian target of rapamycin (mTORC)-1 pathway, which in turn activates S6 kinase, which results in the protein synthesis necessary for muscle growth (Schiaffino & Mammucari, 2011).

Akt is also able to phosphorylate glycogen synthase kinase-3β (GSK3β), which inhibits eukaryotic translation initiation factor 2B (eIF2B), which can inhibits protein synthesis (Schiaffino & Mammucari, 2011). The latter results in phosphorylation of GSK3β thus inactivates eIF2B which also leads to hypertrophy. In summary, Akt's downregulation of eIF2B and upregulation of mTORC result in protein synthesis that leads to hypertrophy, as does Akt's inhibition of proteins that lead to atrophy, such as those of the Foxo family (Schiaffino & Mammucari, 2011).

Hypertrophy begins if a program is extended past the 6-10 week period during which neural adaptations are elicited by resistance training. There are changes observed in protein synthesis before that time, such as increases in type II myosin heavy chain production. One study suggests that protein synthesis may be better induced by a high volume low load resistance training protocol than a protocol using heavy loads with low volume (Burd, et.al, 2010), although fiber type number or growth were not measured. Hypertrophy involves a net accrual of contractile proteins in a sarcomere and consequently the myofibril. The contractile proteins are thus named because they associate with each other in the presence of calcium in order to cause a muscular contraction. These proteins are called actin and myosin. Thus, there is also an accrual of associated proteins, such as titin, in proportion to actin and myosin accrual. The cross sectional area of the myofibril increases because actin, myosin and other structurally related proteins are added to the periphery of the myofibril. Also, the number of myofibrils within a muscle fiber is increased. Thus cumulatively, an increase in cross sectional area of myofibrils would lead to an increase in the cross sectional area of fascicles and ultimately to the entire muscle.

A potent stimulus for hypertrophy is microtrauma (Baechle & Earle, 2009). Microtrauma is the process of muscle fiber tearing that occurs during intensive weight training. Repair results in a process of remodeling that is administered by the endocrine and immune systems, and is also dependent on hydration status and contractile and noncontractile protein synthesis.

Genetic response to increased loads may also contribute to hypertrophy. Genes that code proteins such as Ankrd2, myogenin, and myoD are upregulated by resistance training, while factors such as myostatin are inhibited (Costa et al, 2007; Kemp et al, 2000). Protein synthesis may be increased up to 48 hr after exercise and is dependent upon such factors as the load used, ingestion of nutrients specifically carbohydrate and protein, as well as the timing of nutrient ingestion (Baty et al., 2007; Coffey et al., 2007), and the endocrine response to resistance training (Smilios, Pilianidis, Karamouzis & Tokmakidis, 2003). Other adaptations and concomitant facilitators of hypertrophy include sarcoplasmic reticulum and transverse tubule density, cytoplasmic density, myofibrillar volume, increase in angle of pennation and cytoplasmic density (Luthi et al., 1986; MacDougall, Sale, Elder & Sutton, 1982; Maughn, Watson & Weir, 1984; McCall, Byrnes, Dickinson, Pattany & Fleck, 1996).

Hyperplasia

Whereas hypertrophy entails the enlargement of myofibers, hyperplasia is defined as an increase in myofiber number via longitudinal splitting. This has shown to be a factor leading to improved strength in animal studies, but whether or not it plays a role in strength gains in humans is controversial. Some studies suggest that hyperplasia may be an adaptation of strength training in humans (McCall et al., 1996), but other studies do not agree (MacDougall, Sale, Alway & Sutton, 1984). It may be that the potential for hyperplasia is genetically regulated and differences may exist between individuals. Although hyperplasia may indeed play a role, the respective roles of hypertrophy and hyperplasia in the response to mechanical loading are not fully known (D'Antona et al., 2006). More research into this phenomenon needs to be conducted.

Anaerobic Training and Detraining Studies

Detraining is defined as the loss of training induced adaptations due to either a reduction in, or complete cessation of training, and is associated with atrophy, loss of muscular strength and a reduction in neural drive (Andersen et al, 2005). Time periods "needed" in order to elicit detraining in strength and power parameters appear to be inconsistent across studies.

For example, Garcia-Pallares, Carrasco, Diaz and Sanchez-Medina (2009) investigated the effect of detraining in highly competitive kayakers (including 10 world championship finalists and two Olympic gold medalists). Fourteen participants were equally divided into a reduced training group and a training cessation group at the end of their competitive season. The training cessation group stopped training entirely, while the reduced training group was subjected to an intervention that included 3 sets of 10 repetitions with the respective athlete's 12 repetition max load in the bench press exercise, a prone bench pull and squats with a rest period of 3 min between sets. The detraining period lasted for 5 weeks. Paddling power at VO_2 max and paddling speed at VO_2 max were significantly reduced in the training cessation group compared to the reduced training group.

Another study investigated the neuromuscular response to 3 months of training followed by 3 months of detraining in 13 young sedentary males (Andersen et al, 2005).

The training program consisted of 4-5 sets of incline leg press, hack squats, hamstring curls and isolated knee extension, that were completed 38 times over a 3 month period. Each repetition was performed in a controlled manner during the concentric and eccentric phases of the movement. During the early phase of the program (Sessions 1-15), the programs consisted of 10-12 repetition maximum loads performed for 4 sets. Sessions 16-25 were designated as the middle phase, and consisted of 8-10 repetition maximum loads for 4 sets, while the late phase, Sessions 26-38, was heavily loaded and consisted of 6-8 repetition maximum loads for 5 sets.

After training, moment of force in the knee extensors was reported to increase in the slow concentric (19%) and eccentric (50%), as well as fast concentric (11%) and eccentric (25%) contractions. There were also increases in EMG activity during both slow concentric conditions and the eccentric condition. Moderate to strong correlations were also found between EMG and increases in moment of force (R^2 = .33 - .77). Muscle cross sectional area increased by 10%. After detraining, maximal muscle strength and EMG were preserved during eccentric contraction, but not concentric contraction.

In another study (Andersen et al., 2005), 14 young sedentary males showed improvements in isokinetic muscle strength at slow and medium velocities, electromyography and muscle cross sectional area of the quadriceps and hamstrings after 3 months of resistance training. The training program was 38 weeks long and consisted of three phases. The early phase of the program consisted of 10-12 repetition maximum loads performed for 4 sets, the middle phase, and consisted of 8-10 repetition maximum loads for 4 sets, and the late phase was heavily loaded, and consisted of 6-8 repetition maximum loads for 5 sets. After 3 more months of detraining the gains were lost; however maximal unloaded knee extension velocity and power increased significantly. Additionally, muscle biopsies taken showed a decrease in type IIx in favor of type IIa isoforms during training, whereas type IIx isoforms increased during detraining in favor of type IIa. As a result it was concluded that training followed by detraining resulted in a phenotypic shift toward more fast twitch muscle isoforms, which would result in increased knee extension velocity and power. However, this fiber type transition is ultimately overtaken by decreases in neural drive and atrophy.

A 6-month detraining protocol was administered after a 12-month progressive plyometric and lower body resistance training program in 29 premenopausal women (Winters & Snow, 2000). This exercise group was compared to a control group of 22 women who remained untrained for the duration of the study, and both groups shared similar baseline values.

The training program consisted of 9 sets of 10-12 repetitions of lower body resistance exercises and 9 sets of 10-12 jumps performed in the following manner. The jumping program consisted of two-footed jumps off of the ground, two-footed jumps onto and off of a 12-inch high box, 2-footed side to side hops and 1-footed hops. Resistance training was performed after the jumping program and consisted of wide stance squats to 90^{o} of knee flexion, forward side and backward lunges to 90^{o} of knee flexion and calf raises performed to slightly less than 90^{o} of plantar flexion.

Significant improvements were observed in the exercise group after the 12 month training period; knee extensor strength, hip abductor strength and leg power increased by 17, 27 and 28% respectively. Controls were also reported to increase both hip abductor strength and leg power by 18%, but knee extensor strength and maximal leg power was significantly higher in the exercising group.

Over the 6-month detraining period, knee extensor strength, hip abductor strength and leg power decreased by 8, 8 and 18% respectively. For the control group, changes in strength showed no difference between the training and detraining periods, however power was reported to decline. At the end of the detraining periods the investigators reported no differences in any of the strength and power parameters between the groups (Winters & Snow, 2000).

Melnyck, Rogers and Hurley (2009) investigated the effects of 9 weeks of strength training followed by 31 weeks of detraining on the quadriceps of young and older participants of both genders. The size of the proximal, middle and distal portions of the quadriceps femoris muscle group was measured via magnetic resonance imaging (MRI) in 10 young (i.e., 20-30 years old) women and 11 young men as well as 11 older women (i.e., 65-75 years old) and 11 older men at three time periods: pretraining, immediately after strength training and after 31 weeks of detraining. Additionally, each participant was assessed by comparing a control (i.e., untrained) limb with a trained limb; in summary the untrained and trained limbs were compared within and between all 4 groups. The training program consisted of unilateral knee extension for 5 sets on a Keiser

K-300 exercise machine for a total of 9 weeks. The first set was considered to be a warm-up and was performed at 5 repetitions at 50% of the 1 repetition maximum value. The second set consisted of 5 repetitions at the participant's 5-repetition maximum value which was also previously obtained. The third set consisted of a total of 10 repetitions. Like the second set, this set also consisted of 4-5 repetitions at the participant's 5-repetition maximum value. However the rest of the set was completed by continually reducing the load just enough for the participant to complete one or two more repetitions, until 5 more repetitions were completed. The fourth and fifth sets were performed similarly to the second set; however, the total number of repetitions was increased. The fourth set consisted of 4-5 repetitions at the 5-repetition maximum value followed by 10 more repetitions for a total of 15 repetitions and the fifth set consisted of 4-5 repetitions at the 5-repetition maximum value followed by 15 more repetitions for a total of 20 repetitions.

It was reported that men had greater differences between the trained and untrained legs when compared with the women, and the differences were also greater at baseline than after detraining in young men in the proximal and middle regions; no other differences were detected with groups. It was concluded that gender, not age influenced changes in regional cross-sectional area after strength training (Melnyck, et al., 2009).

In contrast, another study that subjected young and elderly males and females to the same type of program found that young subjects experienced greater gains in strength parameters (1 repetition maximum) than the elderly. The elderly had greater declines in strength (14%) than the young group (8%). In contrast to the kayaker study, the strength loss for both groups occurred during the 12th and 31st week of detraining for both groups (Lemmer et al., 2000).

Based upon different studies, it appears that the rate of detraining may be dependent upon several factors, such as differing levels of training status of participants (beginning or advanced), types of training protocols employed, age, measurements of different strength and power parameters, as well as the use of different research methodologies. However, two articles written by the same authors suggest that detraining due to a short term insufficient stimulus results in minor losses in strength, where short term is defined as 4 weeks long. Beyond 4 weeks, adaptations induced by resistance training will decline more rapidly (Mujika & Padilla, 2000a, 2000b).

Methods of Training used to Rehabilitate Knee Injuries

Knee injury types prevalent in sports include complete ligament tears, contusions, dislocations, fractures, hyperextension, incomplete ligament tears, inflammation, tendinitis, torn cartilage (Ingram et.al, 2008). According to Webb and Corry (2000), ligament injury tends to be the most frequent type of injury (40% of all injuries), with anterior cruciate ligament (ACL) injuries being the most common (46%) of ligament injuries. Medial collateral ligament (MCL) injury was the second most prevalent type (29%), with combined ACL and MCL being the third most prevalent type (13%).

An example of a situation in which atrophy occurs is with traumatic knee injury such as tearing of the ACL. Anterior cruciate ligament injuries occur more frequently in female athletes playing basketball and soccer when compared to males (Agel, Arendt & Bershadsky, 2005). Rehabilitation programs following surgery to repair anterior cruciate ligament tears once aimed to return the athlete to activity within 9-12 months. However in 1986, accelerated programs were implemented which decreased the incidence of patellofemoral joint symptoms, facilitated an earlier return to regular activity, and improved patient compliance.

Shelbourne and Nitz (1992) began to treat ACL deficient knees with a modified Jones patellar tendon-bone graft technique in 1982. Following surgery, the knee was immobilized and full weight bearing activities were not permitted until after 6-8 weeks of rehabilitation. In 1983 the authors discarded immobilization with immediate, continuous passive motion, a modified version of which was continued through 1984-85. The investigators then noticed that patients who were noncompliant (i.e., progressed on their own as opposed to the physician's instructions) returned to normal function while achieving knee stability sooner than patients who complied with the regimen. Henceforth, the investigators advanced the rehabilitation schedule and allowed early weight bearing to the patient's tolerance, and providing that objective goals other than time after surgery were met, eventually permitted the patients to return to activity sooner (Shelbourne & Nitz, 1992).

Analysis of data over subsequent years confirmed that the accelerated program allowed patients to achieve full range of motion more quickly and completely, decrease patellofemoral joint symptoms, and to attenuate atrophy or to reverse it sooner. Thus by

1986, accelerated rehabilitation programs replaced what was considered to be "traditional" rehabilitation programs circa 1983. DeCarlo and colleagues (1992) also found that isokinetic quadriceps and hamstring strength improved at 3, 6 and 12 months using the accelerated model as opposed to the traditional one.

One of the objective criteria used to determine readiness to return to activity is muscular strength in the ACL reconstructed leg and thus an important aspect of rehabilitation of the ACL repaired knee is anaerobic training. Recall that anaerobic training includes strength/weight training, plyometrics and agility training, which are found in both traditional and accelerated rehabilitation models, but are emphasized in the accelerated model. Additionally, Hewett and colleagues (1999) found that athletes of both genders who engaged in plyometric training followed by weight training had a lower incidence of knee injury than athletes who did not.

Few studies have observed the effect of WBV or other types of vibration stimuli on the performance of the ACL reconstructed leg. One study observed the effect of WBV on strength and balance of the ACL reconstructed knee (Brunetti et al., 2006). There were thirty participants, all of which were engaged in an accelerated rehabilitation program, which was supervised by a physical therapist. Fifteen were randomized into a control "sham vibration" group, while the other half were actually subjected to the experimental stimulus.

The program consisted of straight leg raises for 20 repetitions three times daily, cryotherapy and ankle flexion and extension. They also wore a brace locked at 0^{o} and they walked with crutches without bearing weight on the ACL repaired limb. On the 9^{th} day, the participants removed the brace and performed active and passive flexion of the operated knee up to 90^{o}; active and passive stretching of the flexor for five repetitions four times daily; active and passive knee flexion for 15 repetitions four times daily; straight leg raises for 30 repetitions four times daily; and cryotherapy. Independent ambulation was allowed after 21 days, and they performed straight leg raises with increasing weights.

After 40 days they performed proprioceptive exercises four times daily, and after 60 days they began linear running, progressively increasing in difficulty with changes in direction. After 90 days they returned to light sport activity.

The vibration stimulus used was a CRO SYSTEM transducer which generates a stimulus of one hundred Hz with peak-to-peak amplitude of 5-15 μm and a force between 4-6 N; note that the resonator used was not WBV apparatus. The application site was on the skin overlying the operated site, near to the insertion of the quadriceps tendons. During application of the vibration the participants were asked to maintain isometric contraction at 50% of maximal voluntary contraction. The stimulus was placed on the skin (vibration group) or over the skin (control group) overlying the distal part of the quadriceps femoris muscle group, on the operated side and close to the tendinous insertion of rectus femoris, vastus medialis, vastus intermedius and vastus lateralis. Three applications of 10 min of vibration were administered, with 30 s of rest between each set and were administered every day over 3 consecutive days. The stimulus was administered about 4 weeks after surgery, and measurements were recorded before surgery, as well as 1, 10, 90 and 270 days after surgery. The investigators discovered that there was a significant improvement of the vibration group in peak torque. Hence, it appears that vibration may be used as part of a rehabilitation program in order to at least delay atrophy of an ACL reconstructed leg.

Whole Body Vibration

Whole body vibration is defined as a mechanical stimulus characterized by oscillatory motion delivered to the entire body, called the resonator while standing on a platform, which is called the actuator (Albasini, Krause & Rembitzki, 2010). This stimulus is also referred to as acceleration training, biomechanical stimulation or biomechanical oscillation. Platforms are of four different types: a vertical displacement platform, where the entire platform moves up and down uniformly; and alternating displacement, where the platform oscillates alternatingly on the left and right side of a fulcrum that runs along the sagittal plane of the body (Cardinale & Wakeling, 2005; Rittweger, 2010). Examples of manufacturers of vertical displacement devices include Power Plate (Rittweger, 2010), WAVE (Albasini et al., 2010), Fitvibe (Mahieu et al., 2006) Pneu-Vibe, (Ronnestad, 2009a, Ronnestad, 2009b) and Nemes Bosco (Cardinale & Lim, 2003). Examples of alternating vibration include Galileo and VibraFlex (Albasini et al., 2010). The third type of actuator, in which the platform moves through two horizontal planes has been manufactured by PowerMaxx (Pel et al., 2009). The fourth type of actuator has been manufactured by Power Plate and is designed to move in three dimensions, although the magnitude in the z-plane (vertical) is reported to be higher than the horizontal (x and y) planes (Pel, et al., 2009; Lamont et al., 2011).

Physiological Pathways

The physiological mechanisms which explain WBV's effects have yet to be fully understood. Subsequently, the two predominant hypotheses explaining the mechanism of operation of WBV will be discussed: the stretch reflex arcs and the muscle tuning hypothesis.

Reflex Arcs

The phenomenon referred to as a reflex arc is a neural pathway that has five components. There are generally two types of reflex arcs: autonomic reflex arcs, where the effector organ is smooth muscle, and somatic reflex arcs where the effector organ is skeletal muscle (Marieb & Hoehn, 2007). In this writing vibration's effects on somatic reflex arcs will be explored. The five components of a reflex arc are: a sensory receptor, it's associated sensory neuron, the integrating center located in the spinal cord, the associated motor neuron and its effector organ (i.e., skeletal muscle in this case; Marieb & Hoehn, 2007)

Stretch Reflex

The stretch reflex is a specific type of reflex arc, whereby muscles respond to sudden stretching by contracting via monosynaptic and polysynaptic reflex arc mechanisms (Marieb & Hoehn, 2007). An example of this phenomenon is the patellar knee jerk reflex.

The sensory organ of the stretch reflex arc is called a muscle spindle. It is a cluster of about 3-10 intrafusal muscle fibers enclosed in a capsule of connective tissue. An intrafusal muscle fiber is a modified muscle fiber which is mostly noncontractile in nature (Marieb & Hoehn, 2007). The muscle spindle is associated with sensory neurons called type Ia (i.e., primary endings) and type II neurons (i.e., secondary endings), which are the sensory neurons associated with muscle spindle activity. Muscle spindles are located between individual extrafusal muscle fibers, which are the effector organs of the stretch reflex arc. The motor neurons associated with skeletal muscle are α-efferent fibers which stimulate contraction and γ-efferent fibers that maintain muscle spindle sensitivity. Additionally, motor signals to antagonist muscles of the stretched muscle are inhibited in a process referred to as reciprocal inhibition (Marieb & Hoehn, 2007).

Golgi Tendon Reflexes

Golgi tendon reflexes initiate muscle lengthening and relaxation in response to contractions that may potentially tear the muscle. The golgi tendon organ is the sensory receptor of this reflex arc. Motor activity is reciprocal to that of the stretch reflex's, where the agonist fibers are inhibited and the antagonist fibers are activated in an attempt to slow or reverse contraction of the agonist. (Marieb & Hoehn, 2007).

Muscle Tuning Hypothesis

The muscle tuning hypothesis postulates that if soft tissue vibrates at its resonance frequency, muscles will change their physical quality (via contraction) in order to safeguard tissues from injury. Resonance may be defined as the frequency at which a resonator accumulates mechanical energy (Cardinale & Wakeling, 2005; Rittweger, 2010). A resonator is in danger of breaking if, at its resonance frequencies, its amplitude becomes too large, a phenomenon called resonance catastrophe (Rittweger, 2010). Thus, muscle tuning is postulated as a method to reduce traumatic injury by inducing mechanical changes via its contractile state.

In order to demonstrate this theory, Wakeling and Nigg (2001) recorded vibration qualities for the tibialis anterior as well as two groups of extensors: triceps surae (i.e., gastrocnemius lateralis/medius and soleus) and the quadriceps. The frequency and the dampening of vibrations were recorded in all of the muscle groups during isometric (0, 20, 40, 60 and 80^{o} for the quadriceps; -20, 0, 20 and 40^{o} for the ankle, doing plantar and dorsiflexion respectively). At each position subjects were told to exert 0%, 50% and 100% of maximal exertion. The 0% measurement was used to determine the force of gravity on the leg in order to negate it from the actual exerted force.

Frequency and dampening of vibration was also recorded via isotonic contractions. Zero torque values for each participant were determined using the values from the isometric portion. Isotonic contractions at a torque just below maximal (percentage max unspecified), as well as subsequent 50-100% of isotonic torque of this latter value were also performed, and vibrations of the tissue were recorded at angles of 23 and 41^{o} of both the knee and ankle. A wooden mallet hit the tissue about 4 cm away from the accelerometer during each contraction. Six vibrations were recorded for each combination of tissue region struck, joint torque and joint angle.

The general finding was that the more forceful the torque or the higher the angular velocity, the higher the resonant frequency and damping coefficients became. The authors suggested that this finding provides evidence that muscle dampens otherwise traumatic vibration stimuli by contracting, thereby decreasing the chances of soft tissue destruction by altering the mechanical properties of the muscle and its surrounding tissues. Damping of free vibration in soft tissue is dependent on mechanical qualities of muscles and connective tissue (tendons, adipose tissue, fascia), as well as the proportions of each within a particular mass of soft tissue (Wakeling & Nigg, 2001). The authors also suggest coupling of tissues may also have an influence of mechanical properties of soft tissue, for example, connections of muscle to bone and the properties of the tissue connecting them. Finally, muscle activation, length and contraction velocity can all alter the mechanical qualities of muscle, which in turn can affect damping qualities.

Studies testing the practical application of vibration as a method of training for performance and exercise are widely published. The training used in these experiments take three general types: vibration as a potentiator for other forms of activity; vibration integrated with resistance training programs; and vibration as a solo modality. Experiments using all three types have been executed with varying degrees of success, although the discrepancy of the results may be caused by factors such as research design or perhaps even discrepancies in the design of the vibration device across manufacturers (Rittweger, 2010).

Effect of Vibration upon Various Physiological Systems

Muscular System

The general trend, regardless of research design, is that vibration is able to elicit changes in parameters of performance, notably strength and power. To this writer's knowledge, studies that examine the effect of vibration on such dependent variables as changes in muscle morphology, and molecular components of muscle (i.e., example myosin heavy chain content) are scarce, with the Berlin Bed rest study (Blottner et al, 2006) being a notable exception.

Factors that influence phenotypic expression of these fibers also include genetics and exercise. Modes of training designed to increase Type II muscle fiber expression and development include sprinting (track and field) heavy powerlifting and Olympic lifting and plyometrics (Baechle & Earle, 2009).

Eccentric modalities of training (such as resistance training) use the stretch reflex arc to induce development (Aagaard, et al, 2002). This is the same mechanism that is considered to develop muscular performance parameters during vibration. Furthermore, vibration induces adaptations in the muscle similar to resistance training such as hypertrophy (Blottner et al., 2006; Cormie, Deane, Triplett & McBride, 2006; D'Antona et al., 2006). Blottner and colleagues (2006) reported both Type I and Type II fibers increased in size under a vibration stimulus. This finding could be explained by the size principle (Henneman, 1965) which states that smaller (i.e., type I) muscle fibers are recruited before larger (i.e., type II) ones.

Whole body vibration has been shown to increase either lower body strength or power in various populations. Vertical whole body vibration has been reported to increase one repetition maximum half squat in trained and untrained participants at 50 Hz (Ronnestad, 2009a) when compared to the control condition (no vibration), although no differences from the control condition were reported in either group when using the 20 and 35 Hz frequencies. Additionally, WBV at a frequency of 50 Hz increased countermovement jump (in untrained participants) and peak average power (in trained and untrained participants) whilst performing the squat jump (Ronnestad, 2009b).

Cardinale and Lim (2003) compared acute changes in performance between one group performing WBV at 20 Hz and another group performing WBV at 40 Hz. The participants were exposed to five bouts of WBV lasting 60 seconds each and an amplitude of 4 mm was kept constant for both groups. There were eight participants (21 $\pm$ 2.2 years) assigned to the 20 Hz group and seven participants (20.4 $\pm$ 0.5 years) assigned to the high frequency group. All of the participants were untrained prior to the study. Performance tests included the squat jump, the countermovement jump and the sit and reach test, and they were administered before and after the whole body vibration protocol. Using t-tests, the investigators reported significant improvements in the low frequency group following WBV. Hamstring flexibility increased by 10.1% ($p < .001$) while squat jump increased by 5% ($p < .05$). In contrast, there was a decrease in countermovement jump by 3.6% ($p < .001$) and the squat jump by 3.8% ($p < .05$) in the high frequency group.

Osawa and Oguma (2011) compared the changes in performance between one group performing an exercise regimen with WBV (RT-WBV) and another group performing the same regimen without WBV (RT). There was a total of 33 participants, with 17 participants in the RT-WBV group and 16 in the RT group. The mean age of the RT-WBV group was 37 years old, while the mean age of the RT group was 39 years old and all of the participants were previously untrained. The regimen consisted of the squat, the Bulgarian squat, the rollback with trunk twist, the trunk curl, hip walking, leg raise, back extension and stabilization exercises. All exercises were performed on the Power Plate Next generation model and the WBV-RT group performed the exercises at a frequency of 35 Hz and an amplitude of 2 mm. The exercises were performed twice weekly for 7 weeks. The performance tests included the countermovement jump, maximal isometric lumbar extension, maximum isometric knee extension, maximum isokinetic knee extension and a sit-up test. The increase in performance parameters was compared between both groups using Welch's t-tests as assumptions for use of parametric tests were violated. The RT-WBV group was reported to improve significantly compared to the RT group in maximal isometric knee extension torque by 36.8% ($p = .02$); and concentric knee extension torque by 38.4% ($p = .04$). Maximal isometric lumbar extension strength at 60^{o} of trunk flexion also improved by 26.4% ($p = .02$) and the countermovement jump improved by 3.7% in the RT-WBV group relative to the control group ($p = .02$). The use of multiple non-parametric tests without the adjustment of α may have resulted in inflation of Type I error in the reporting of these results.

However, many studies report similar findings. Untrained women improved in countermovement jump following accelerations of 2.8 g (40 Hz, 2-4 mm) and 5.83g (50 Hz, 4-6 mm) compared to controls (no WBV). No improvements were seen in men under any of the conditions (Bazett-Jones, Finch & Dugan, 2008). Similarly, countermovement jump improved in nine “moderately trained” men after 30 s of vertical WBV at 30 Hz with an amplitude of 2.5 mm (Cormie et al., 2006) and in 18 elite female field hockey players performing exercise on an alternating WBV platform at a frequency of 26 Hz (Cochrane & Stannard, 2005).

Improvements in isometric knee extensor strength, dynamic knee extensor strength were reported to increase in untrained women after 12 weeks of WBV or resistance training, when compared to control and placebo groups (Delecluse, Roelants & Verschueren, 2003), while countermovement jump improved significantly between the WBV and resistance training groups. Similar outcomes have been observed in WBV studies involving children (Mahieu et al., 2006) and in the elderly (Cochrane et al., 2008).

Endocrine System

Another way muscle mass may be increased is via the effect of the vibration stimulus on the endocrine system. Some studies have been successfully performed in order to demonstrate the effectiveness of the vibration stimulus in increasing testosterone and human growth hormone and decreasing cortisol (Bosco, et al, 2000) and vibration’s effects on insulin-like growth factor (IGF)-1 (Cardinale, Soiza, Leiper, Gibson & Primrose, 2008). Testosterone, IGF-1 and human growth hormone have been shown to have anabolic effects on skeletal muscle tissue. Therefore, it is possible, that another mechanism which vibration may improve muscle function is via endocrine response. However, not all studies agree that vibration elicits an increase in anabolic hormonal response (Alentorn-Geli et al., 2009). In the latter study, however, the participants suffered from fibromyalgia, and unmeasured inflammatory response may have interfered with IGF-1 response to vibration.

Skeletal System

One proposed mechanism via which osteoporosis occurs is through insufficient bone straining. Wolff's Law states that bone mass adapts to the demands of mechanical loads placed upon it, in addition to various metabolic factors (Marieb & Hoehn, 2007). When loading of bone is below a minimum threshold, bone metabolism adjusts the tissue's integrity so that it is within said load. Moreover, it has been suggested that the main source of mechanical loading upon bone tissue is that exerted by contracting muscles against the force of gravity. Thus atrophy and weakening of muscles (e.g., sarcopenia) would result in reduced loading of bone, and thus lower bone mass and density (Giangregorio & Blimkie, 2002; Prisby et al., 2008).

Vibration has also been explored as a method with which to induce bone development, which is also pertinent to the elderly and those exposed to conditions of microgravity. Indeed, osteoporosis is comorbid with the sarcopenic condition.

Additionally, endocrine response to vibration, as discussed previously, may also have an influence on bone development as human growth hormone has a direct effect on bone metabolism.

One study explored the effect of a relatively low magnitude vibration protocol on the bone density of the distal radius, hip and spine of 64 postmenopausal women (mean age unspecified) over a year (Rubin et al., 2004). The actuator model used was a LA18-18 and the frequency used was 30 Hz, with an acceleration of 0.2 g. The design of the model was such that the women had to be of a mass of over 45 kg and under 85 kg. The amplitude of the WBV intervention was not specified. Half of the women were placed in a control group and were given a sham vibration machine, while the treatment group was given the actual "functional" machine. In those participants who were in the highest quartile of compliance to the program, there was a 2.13% loss of femoral neck bone density as well as a 1.6% decrease in the spine of the placebo group, while there was a respective 0.04% gain and a 0.1% loss in the femoral neck and spine densities of the intervention group. Furthermore, when the investigators separated the treatment group based on body mass, they found that the lighter participants (under 65 kg) had a higher relative increase in spinal bone density than the heavier group.

Ligouri and colleagues (2012) subjected a group of 10 college age participants (19.3 + 1.3 years) to an exercise regimen performed with WBV, while an additional 14 participants remained as a control group (19.8 $\pm$ 1.1 years). The WBV group underwent a 12-week WBV program using an alternating device (Galileo 2000) and performed sessions 3 times weekly. The WBV program included a progressive resistance training program which included squats, stiff-legged dead lifts, holds in the push up position, bent over rows and jumps on to and off of the platform. Dual energy x-ray absorptiometry (DXA) was used to evaluate bone mineral density of the lateral spine and the posterior-anterior spine and data were analyzed using paired t-tests. Increases of 2.7% and 1% was observed in the lateral spine and in the posterior-anterior spine respectively, while decreases of 1.9% and 0.9% respectively were observed in the control group.

Other studies have found actual improvements in trabecular bone density upon administration of a whole body vibration program on animals (Garman, Gaudette, Donahue, Rubin & Judex, 2007; Lynch, Brodt & Silva, 2009; Rubin, Turner, Mallinckrodt et al., 2002; Rubin, Turner, Muller et al., 2002;). Another condition that is comorbid with the aging is osteoarthritis (Marieb & Hoehn, 2007). Osteoarthritis is characterized by the gradual deterioration of hyaline cartilage, which results in deformation of the joint, pain and loss of function (Marieb & Hoehn). This loss of function can therefore aggravate sarcopenia because of reduced ambulation. The deterioration of cartilage is a complex process that may involve mechanical loading and sensitivity to anabolic and inflammatory cytokines. It has been demonstrated *in vitro* that a mechanical stimulus (i.e., vibration) enhanced biochemical processes vital to chondrocyte metabolism (Liu, et al, 2001).

The Effect of Vibration on Blood Vessels

Vibration has been reported to have an effect on vascular function (Bovenzi, Welsh, Vedova & Griffin, 2006; Lohman, Petrofsky, Maloney-Hinds & Betts-Schwab, 2007). The effects may either be constructive or deleterious and are dependent upon the vibration regimen, as well as the tissue that is perfused by the vessels (Bovenzi, et al, 2006; Lohman et al., 2007; Takeuchi, Futatsaka, Imanishi & Yamada, 1983). Frequencies and durations of vibration in occupational settings (for example the use of jackhammers or heavy machinery) are usually higher in frequency and duration than those used in therapeutic settings, and injury due to this phenomenon is widely reported in scientific and occupational literature. This phenomenon is called "vibration induced white finger". Vibration induced white finger is comorbid with intense smooth muscle thickening & hypertrophy, periarterial fibrosis, arteriosclerosis, lipid deposition, demyelination of finger nerves, loss of nerve fibers, with an increase in Schwann cell number, fibroblasts and collagen (e.g., scar tissue). Some nerve regeneration is also observed although the axons are smaller and without myelin. Another study reported WBV groups and hand-arm vibration groups to present with increased white blood cell count, catecholamines, cholesterol, low density lipoprotein, and a decrease in clotting time, fibrinogen, triglycerides and high density lipoproteins relative to non-vibration controls (El-Said, El-Gazzar, Mansour & El-Gheit, 2009). Vibration protocols were not explained, however, it appears that blood flow differs in the lower extremities upon exposure to vibration. The skin blood flow of participants divided into three groups (i.e., vibration-exercise, exercise only and vibration only) was investigated by Lohman et al., (2007) without a control group. The frequency used was 30 Hz, with an amplitude of 5-6 mm on the Power Plate was employed. It was reported that mean skin blood flow increased in the vibration-only group. It was also observed that that some of the frequencies in which vascular dysfunction was observed are frequencies used to elicit an increase in hypertrophy or bone mineral density.

Training Parameters of Whole Body Vibration

It is well-documented in the literature that various types of resistance exercise can affect qualities such as size and contraction velocity of muscles (Aagaard et al., 2002; Holm et al., 2008), properties which may affect the qualities of damping (Wakeling, Nigg and Rozitis, 2002). Intensity of vibration is usually quantified by duration of WBV (i.e., amount of time spent on the platform), amplitude (peak to peak displacement), frequency (i.e., oscillations per second), and acceleration measured in "g's" (9.81 ms^{-2}; Lorenzen, Maschette, Koh & Wilson, 2008). The acceleration itself may be defined in terms of the amplitude and frequency using the formula $a = A(2\pi f)^2$, where A is half of the peak-to-peak amplitude and f is the frequency of the vibration stimulus. Thus number of g's would be expressed as $g = A(2\pi f)^2/9.81$ (Lorenzen et al., 2008).

However, this formula assumes that there is constant stimulus to the body during the treatment, which some investigators seem to disbelieve. One study (Osawa & Oguma, 2011) demonstrated that an object's mass on a Power Plate vibration platform had a direct relationship upon its acceleration at the same amplitude and frequency. Using an accelerometer, they measured the accelerations of various masses (i.e., barbell plates) using a frequency of 35 Hz and 2 mm, against control trials using 0 Hz and 0 mm. They reported that with no mass on the platform, its acceleration was 2.10 m/s^2. The accelerations increased to 2.75, 2.80, 2.91 and 2.95 m/s^2 when respective masses of 40, 50, 60 and 70 kg (achieved using barbell plates) were placed on the platform. One theory provides a possible explanation for this phenomenon. Rittweger (2010) states that a mass that is rigidly attached to an actuator follows the sinusoidal trajectory of the actuator. If a mass is not rigidly attached to the actuator, then it may be argued that it has a higher chance of being airborne during the time which the platform transitions from its maximum positive amplitude toward decreasing values (in other words, the body no longer maintains contact with the platform as it descends). Therefore, the maximum training stimulus is not transferred to the body in question. During that transient period of being airborne, the acceleration of said body would decrease, approaching 1 g from whatever higher acceleration it had previously attained. Rittweger (2010) then elaborates that vibration plate users should hold firmly to the machine in such a way that downward force is exerted in order to reap the full training effect of the stimulus.

As the idea of resonance was previously discussed, a critical factor influencing intensity seems to be frequency. Some writings suggest optimum parameters seem to range between about 25-50 Hz to induce a training effect (Albasini et al., 2010; Cochrane et al., 20008; Hopkins et al., 2009; Mahieu et al., 2006). Some authors suggest that about 20 Hz seems to elicit a relaxation effect (Albasini et al., 2010), while one study reported using a frequency of 35 Hz to reduce delayed onset muscle soreness (DOMS; Aminian-Far et al., 2011). Albasini, et al (2010) also suggests that 50 Hz is alleged to result in muscle damage, but this information is inconsistent across studies as frequencies of 50 Hz have been used as a warm-up intervention for golfers. Another study reported that a 45 s bout of WBV at a frequency of 40 Hz and an amplitude of 4-6 mm resulted in an improvement in countermovement jump in women, but no changes were seen in men (Bazett-Jones, Finch and Dugan, 2008). Alternatively Cardinale and Lim, (2003), another study found that a frequency of 20 Hz increased squat jump by 4%, and a frequency of 40 Hz decreased countermovement and squat jumps by 3.8 and 3.6% respectively. The latter protocol consisted of 5 bouts of 60 s of vibration alternating with 60 s of rest. There seems to be no protocol that has been consistently measured across various experiments; therefore no recommended exercise protocols using whole body vibration based on scientific investigations have been established (Cochrane, 2011).

Damping properties are shown to be influenced by the contractile properties of the sarcomere in mammals (Rack & Westbury, 1974). According to this experiment, the contractile proteins of the sarcomere influence a muscle's damping properties. In other words, actin and myosin interaction is directly related to the amount of stiffness, and thus damping ability of a muscle. If this idea extrapolates to humans, then a reasonable hypothesis may be that hypertrophy which is the increase in the thickness and number of myofibrils, would then increase damping ability.

In summary, evidence suggests that WBV's effects on skeletal muscle are similar to the effects of resistance training on skeletal muscle, and may elicit an increase in strength and power. As a result, it is hypothesized that a progressive WBV lower body exercise program will delay lower resistance exercise detraining.

CHAPTER III

METHODS

Calculation of Sample Size

This study explored the effect of a 3-dimensional actuator on parameters of isokinetic strength and countermovement jump force in 20 women ages 18-39 years old. Sample size was determined based on sample size analysis performed on G-Power (Erdfelder, Faul & Buchner, 1996) and an effect size of 0.99. The effect size was chosen based upon a meta-analysis (Marin and Rhea, 2010), which stated that vertical platforms elicited a treatment effect size of 0.99 and the actuator to be used in this experiment vibrates mostly in the vertical plane (Lamont et al., 2011; Pel et al., 2009). With β set at 0.80 and α at 0.05, 14 participants were needed. The participants were nonresistance trained at the commencement of the study, and were resistance trained for 6 weeks and then randomly placed into a detraining (control) group or a WBV training group for 6 more weeks.

Data Collection

The resistance training program was designed to increase strength of the extensors and flexors of the knee and ankle. Isokinetic concentric knee flexion and extension (60 deg/s) and isokinetic concentric dorsiflexion and plantar flexion (30 deg/s) were measured using the Biodex System 3 Pro dynamometer. Mahieu and colleagues (2006) measured isokinetic data at various speeds. For this study the slower speeds were chosen because the training protocol was designed for strength and the exercises were performed at slower speeds. In addition, the five repetition maximum (RM) squat was evaluated by a certified strength and conditioning coach.

Isokinetic data and five (RM) squat were collected immediately before and after the 6-week resistance training program, and again at Weeks 2, 4 and 6 of the detraining period, for a total of five times. All of the participants were resistance trained and then randomized into two groups: one half of the participants were placed in a detraining (control) group and the other half in a WBV (experimental) group. Microsoft Excel was used to place the participants in random order, and the first 10 were placed in the control group while the second 10 participants were placed in the WBV group.

Participants in the WBV group were instructed to sit in the dynamometer where they were secured using the dynamometer's straps. This was done in order to more accurately measure strength of the pertinent muscle groups (flexors and extensors of the knee and ankle) while minimizing contribution from other muscle groups. The lateral epicondyle of the femur of the participant's dominant leg was found by palpation and aligned with the pivot of the dynamometer. The range of motion for extension of the knee was acquired by the following process: the participants were asked to extend the knee as much as possible (without hyperextension) and this information was uploaded into the dynamometer's computer. The participants were then asked to flex the knee as much as possible and this information was also uploaded into the computer. The range of motion of the ankle was found by a similar procedure; participants were asked to plantar flex and dorsiflex the ankle maximally and the respective data were uploaded into the dynamometer's computer. Upon beginning the data collection, the participants were asked to contract maximally during flexion and extension throughout the entire range of motion for the complete number of repetitions, and were told when to stop contracting. After data collection was complete, the participants were released from the dynamometer.

Resistance Training Protocol

In order to assign loads, the ten repetition maximum of each participant was obtained by increasing the loads by 10 pounds until the participants were no longer able to perform 10 repetitions of the assigned load. During the first week, the participants then performed a pyramid routine for the squat exercise, using 10 repetitions (the previous 10 repetition maximum) and three sets of 8 repetitions for the first week. In the following week the sets were modified to one set of 10 repetitions, one set of 8 repetitions and three sets of 5 repetitions. Participants also performed three sets of 5 repetitions of hang cleans and 3 sets of 10 repetitions of knee extensions, hamstring curls, toe presses and dorsiflexion exercises. Loads were adjusted based on verbal feedback, performance of previous sets during the same training session and/or ease of performance of analogous sets during the previous training session. All participants were trained twice per week for 6 weeks.

Whole Body Vibration Protocol

The WBV group was subjected to a protocol where amplitude (mm) and frequency (Hz) and total time exposure to the stimulus (s) were progressively increased, and rest time (30 s) remained constant. The actuator used was the Power Plate Next Generation model. The WBV program lasted for 6 weeks and the progression of training was as follows: Week 1: 6 sets, 30 s of vibration at low amplitude with frequencies of 30 Hz (2.56g-5.11g); Week 2: 7 sets, 45 s of vibration at low amplitude with frequencies of 30 Hz (2.56g-5.11g); Week 3: 5 sets, 60 s of vibration at low amplitude with frequencies of 30 Hz (2.56g-5.11g); Week 4: 6 sets 45 s of vibration at high amplitude with frequencies of 30 Hz (5.11g-7.68g); Week 5: 6 sets 60 s of vibration at high amplitude with frequencies of 30 Hz (5.11g-7.68g); and Week 6: 7 sets of 60 s of vibration at high amplitude with frequencies of 30 Hz (5.11g-7.68g). Participants were trained 3 times per week. The control group underwent no further training.

Statistical Analysis

Independent t-tests were used to explore any differences in mass or age between the control and intervention groups. The independent variables used were the treatment (WBV and detrained/controls), and time, as the dependent variables were measured at 5 time points. The dependent variables for ankle strength measured by the dynamometer included peak torque measured in foot pounds (ft. lbs) for dorsiflexion and plantar flexion at an angular velocity of 30 deg/s The dependent variables for knee strength included peak torque for knee flexion and knee extension at angular velocities of 60 deg/s. Five-repetition maximum (5RM) for the squat was also measured. The assumptions for use of MANOVA were violated as the squat had no correlation with the other variables. Additionally, the assumption of multi-collinearity was violated as the knee extension variable exceeded a variance inflation factor of 10. Hence the statistical analyses used were a two-way (condition vs. time) factorial analysis of variance (ANOVA) for the squat, and a two way (condition vs. time) factorial MANOVA for the plantar flexion, dorsiflexion and knee flexion variables. In order to control for inflation of Type I error, a Sidak adjustment was used to modify α from .05 to .0253. Sidak post-hoc adjustments were also used to explore the differences between means. There was no further evaluation of the torque of knee extension.

CHAPTER IV

RESULTS

The purpose of this study was to explore the effect of whole body vibration on detraining extensors and flexors of the knee and the flexors and extensors of the ankle. Participants were randomized into two detraining groups, a control group which performed no further exercise and a WBV group which performed a progressive static WBV regimen. Data was collected at five time points: 0 weeks, which was the start of the power lifting program; 6 weeks, which marked the end of the power lifting program and the beginning of the detraining period; 8 weeks, 10 weeks and 12 weeks, the latter marking the end of the detraining period.

To examine the relationship between the detraining of the knee flexors and treatment used, a 2-way (2-treatments x 5 time points) repeated measures MANOVA was used for torque of the knee flexors, ankle flexors and ankle extensors. A 2-way (2-treatments x 5 time points) repeated measures ANOVA was used for number of pounds lifted in the squat.

The mean and standard deviation values for both torque and pounds lifted were determined for each treatment (control vs. WBV) for 5 levels of time (Week 0, Week 6, Week 8, Week 10 and Week 12). Recall that both groups performed the same conditioning program between the first and second levels of time.

For the torque variables, the null hypothesis for the interaction effect for time vs. condition was rejected. The main effect null hypothesis for differences between conditions was retained, while the null hypothesis for the main effect of time was rejected. For the number of pounds lifted in the squat, the interaction effect for time vs. condition was rejected.

The results of this study will be presented in the following order:

1. Descriptive statistics of the participants.
2. Summary tables of group data.
3. MANOVA summary tables.
4. ANOVA summary table.
5. Graphs representing significant data trends.
6. Hypothesis testing for main and interaction effects.

Age and Mass

There were no significant differences in either the mean weights or the mean ages of the control and WBV groups. The means and standard deviations for weight and age for both groups are presented in Table 1.

Table 1
Descriptive Statistics

Variable	Control (n=10)	WBV (n=10)
Age		
Mean	22.8	25.3
S.D.	3.46	5.46
Weight (pounds)		
Mean	176.26	151.92
S.D.	59.14	29.21

The summary data for plantar flexion, dorsiflexion, knee flexion and the 5-repetition maximum squat are presented below in Tables 2, 3, 4 and 5 respectively.

Table 2

Summary Table: Group Data for Plantar Flexion Torque (Newton Meter)

	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control Group					
Mean	57.3	71.2	69	65.1	63.98
S.D.	25.7	25.8	19.1	21.4	25
WBV Group	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Mean	46.2	66.3	66.4	68.8	62
S.D.	16.8	21.8	20.6	18	16

Table 3

Summary Table: Group Data for Dorsiflexion Torque (Newton Meter)

	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control Group					
Mean	21.69	29.56	31.82	31.09	26.59
S.D.	7.72	8.64	8.26	7.1	6.96
WBV Group	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Mean	18.67	22.06	23.88	27.01	24.55
S.D.	4.38	5.86	5.76	6.86	6.24

Table 4

Summary Table: Group Data for Knee Flexion Torque (Newton Meter)

	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control Group					
Mean	77.98	83.62	93.34	85.5	79.96
S.D.	19.18	15.5	28.17	14	18.99
WBV Group	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Mean	62.01	88.83	84.55	77.2	80.3
S.D.	16.7	25.15	12.81	11.41	16.82

Table 5

Summary Table: Group Data for 5 Repetition Maximum Squat (Pounds)

	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control Group					
Mean	89.5	148	143	135.5	132
S.D.	59.7	46.9	47.3	47.34	47.7
WBV Group	0 weeks	6 weeks	8 weeks	10 weeks	12 weeks
Mean	62.5	155	152.5	144	137
S.D.	43.9	22.48	28.6	23.8	28.7

The summary tables for the univariate analyses of variance are presented in Tables 6, 7, 8 and 9. The summary table for plantar flexion torque is presented in Table 6. Plantar flexion torque at Week 6 was significantly higher than plantar flexion at Week 0. However, plantar flexion torque at Week 8, Week 10 and Week 12 were not different from one another, nor did they significantly differ from either Week 0 or Week 6.

Table 6
ANOVA Summary Table: Plantar Flexion Torque

Source	df	SS	MS	F	p	Partial Eta^2 (Greenhouse-Geiser)
Condition	1	280.898	280.898	.177	.679	.01
Time	2.598	3920.063	1509.127	5.771	.003	.243
Condition by Time	2.598	577.087	1509.127	5.771	.46	.045

The summary table for dorsiflexion torque is presented in Table 7. Dorsiflexion torque at Week 6 was significantly higher than plantar flexion at Week 0. Dorsiflexion torque did not significantly decrease after 6 weeks in either the WBV or control groups.

Table 7
ANOVA Summary Table: Dorsiflexion Torque

Source	df	SS	MS	F	p	Partial Eta^2 (Sphericity assumed)
Condition	1	604.176	604.176	3.33	.085	.156
Time	4	926.882	231.72	16.623	<.001	.48
Condition by Time	4	141.934	231.72	16.623	.068	.124

The summary table for knee flexion torque is presented in Table 8. Knee flexion torque at Week 6 was significantly higher than knee flexion torque at Week 0. Knee flexion torque did not significantly decrease from Week 6 to Week 12.

Table 8

ANOVA Summary Table: Knee Flexion Torque

Source	df	SS	MS	F	p	Partial Eta^2 (Sphericity assumed)
Condition	1	756.8	756.8	.752	.397	.04
Time	4	4237.437	1059.359	5.905	<.001	.247
Condition by Time	4	1385.473	1059.359	5.903	.115	.097

The summary table for 5-repetition maximum squat is presented in Table 9. Interaction differences were observed among time points for each group observed. For the control group, the squat at week 0 was significantly less that all other time points. The time points for Weeks 10 and 12 were also significantly less than Week 6. For the WBV group, the squat at Week 0 was also significantly less than all other time points. Week 12 was significantly less than Week 6.

Table 9

ANOVA Summary Table: Five Repetition Maximum Squat

Source	df	SS	MS	F	p	Partial Eta^2 (Greenhouse-Geiser)
Condition	1	1687401	1687401	.001	<.973	0
Time	1.727	76171.5	44096.112	72.506	<.001	.801
Condition by Time	1.727	4818.5	2789.457	4.587	.022	.203

A graph showing significant differences among analysis of variance interaction means for condition vs. time using Sidak comparisons is presented in Figure 1. There were no significant differences between conditions at any time point.

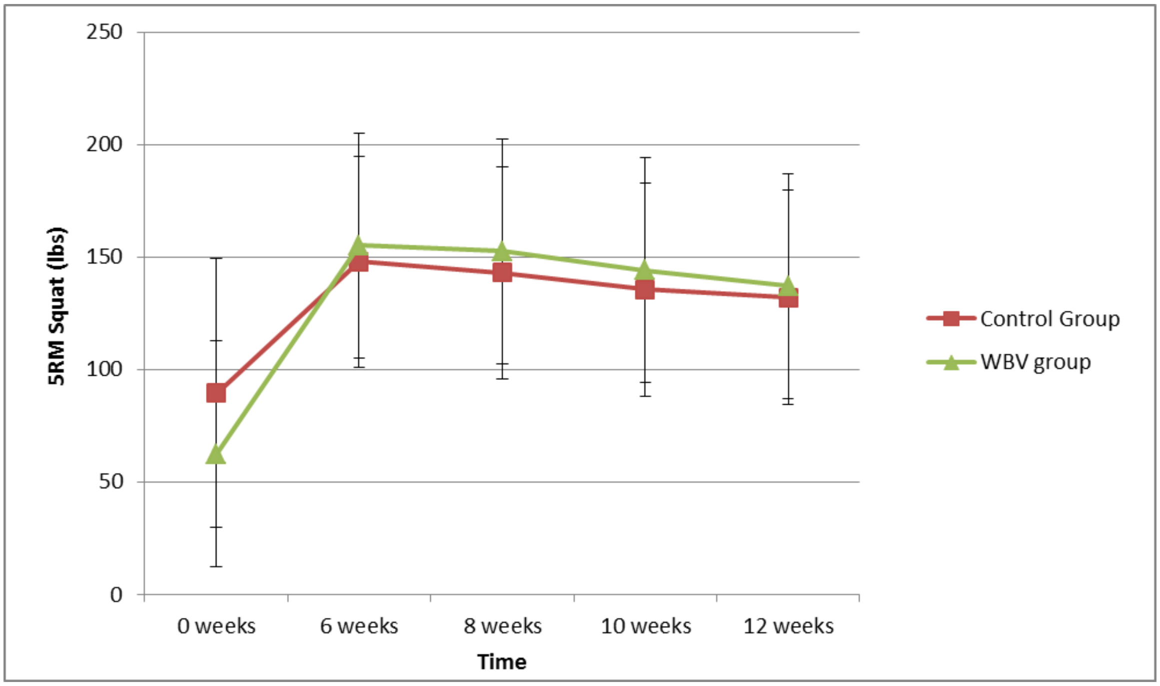

Figure 1. Interaction means for condition vs. time using Sidak comparisons

Null Hypothesis Testing for Torque Variables

Main Effects

The null hypothesis for univariate main effect of condition was retained as no significant difference in any of the torque variables was determined between the control group and the WBV group. The null hypothesis for univariate main effect of time was rejected as a significant difference was observed between the first time point (Week 0) and all of the other time points (Weeks 6, 8, 10 or 12) for dorsiflexion, plantar flexion and knee flexion. There were no differences between the time points for any of the variables.

Interaction Effects

The null hypothesis for the interaction of condition and time was retained as no significant differences were observed between the groups at any time point. The multivariate interaction null hypothesis was retained, as were the univariate interactions.

Null Hypothesis Testing for 5 Repetition Maximum Squat

Main Effects

The null hypothesis for the condition was retained as no significant difference in the 5-repetition maximum squat was determined between the control group and the WBV group.

The null hypothesis for time was rejected as significant differences in the 5-repetition maximum squat were observed between the first time point (Week 0) and all of the other time points (Weeks 6, 8, 10 and 12). The squat at Week 6 was also significantly different from the squat at Week 10 and Week 12 but was not significantly different from Week 8, while the squat at Week 8 was not significantly different from the squat at Week 10 but was significantly different from the squat at Week 12. The squat at Week 10 and Week 12 were not significantly different.

Interaction Effects

The null hypothesis for the interaction of condition and time was rejected for the squat variable. The control group and WBV group were not significantly different at any time point. However, in the control group a significant difference was observed between

Week 6 and Week 10, whereas no significant difference was observed between Week 6 and Week 10 in the WBV group. The squat at Week 6 was significantly different from Week 12 in the WBV group.

CHAPTER V

SUMMARY OF FINDINGS, DISCUSSION, CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

This study explored the effect of whole body vibration on detraining of the extensors and flexors of the knee and the flexors and extensors of the ankle. All participants were trained using a lower body power lifting program. At the end of the program (Week 6), they were randomized into either a control group which performed no further training or a WBV group which performed a progressive static WBV program. Data was collected at Week 0 at the commencement of the resistance training program; Week 6; Week 8; Week 10; and Week 12 at the end of the detraining period. The Summary of Findings will be discussed first, followed by the Discussion, Conclusion and Recommendations for Further Study.

Summary of Findings

Age and Mass

There were no significant differences in the mean weight of the control and WBV groups (176.26 $\pm$ 59.14 and 151.92 $\pm$ 29. 21 lbs. respectively). There were also no significant differences in the mean age of both groups (22.8 $\pm$ 3.46 and 25.3 $\pm$ 5.44 years for the control and WBV groups respectively).

Torque

The null hypothesis for the main effect of time was rejected for torque of dorsiflexion, plantar flexion and knee flexion. Torque was higher for all three variables at the end of the powerlifting program (Week 6), and did not significantly decrease until Week 12 in either the WBV or control groups for the dorsiflexion torque. Knee flexion torque was maintained from Week 6 until Week 10 and did not significantly decrease until Week 12. Plantar flexion torque at Week 8, Week 10 and Week 12 did not significantly differ from either Week 0 or Week 6. This was likely because of the large amount of variation in the data for this sample, which will be discussed later. There were no differences in torque between either group at any of the time points.

Squat

The null hypothesis for the interaction between intervention and time was rejected for the 5 repetition maximum squat variable. The control group differed in 5 repetition squat maximum between 0 and 6 weeks ($p < .001$). No loss of strength was observed until four weeks after cessation of training ($p = .022$). The WBV group also differed in 5 repetition maximum between 0 and 6 weeks ($p < .001$). However, no loss of strength was observed until week 12 ($p = .008$). Despite the seemingly attenuated loss of strength for the vibration group, there was still no significant difference at Week 10 or Week 12 between the control or intervention groups.

Discussion

The results of this study would suggest that doing no training or performing a progressive whole body vibration program using accelerations between 2.56 and 7.68 g show no difference in loss of unilateral torque in the flexors and extensors of the ankle six weeks after the cessation of a lower body power lifting program. Doing no training or performing a progressive whole body vibration program using accelerations between 2.56 and 7.68 g also show no difference in the loss of unilateral torque in the flexors of knee, or 5-repetition maximum for the squat exercise after six weeks of detraining.

Comparison to Other Detraining Studies in Healthy Participants

Osawa and Oguma (2013) investigated the training effect of an exercise program with WBV compared to an exercise program without WBV, as well as the subsequent detraining of both groups. Thirty-two untrained participants completed the study, which consisted of a 13-week training period and a 5-week detraining period. The mean age of the exercise/WBV group was 36.8 $\pm$ 8.4 years old, while the exercise group was 37.7 $\pm$ 9.5 years old. There were 14 females and 2 males in the exercise/WBV group and 13 females and 3 males in the exercise group.

After performing warm-up exercises, the participants performed a regimen that included squat exercises for the lower body while wearing socks, but no shoes. From Week 1 to Week 4, participants performed all of the exercises using body weight only. From Week 5 to Week 7, women performed the exercises with 10% of bodyweight, while men used 15% of body weight. The training intensity was progressed via the use of dumbbells or a weight vest. Weight loading was increased every 2 weeks afterward to a maximum of 30% for women and 45% for men until Week 13. Both groups performed the exercises on the WBV platform. The exercise/WBV group performed the exercises concurrently with a WBV stimulus defined by an acceleration of 4.92 g (frequency of 35 Hz with an amplitude setting of 2 mm).

Dependent variables included concentric and eccentric (isokinetic) knee extension torque, countermovement jump, and isometric knee extension. These variables were measured 4 times; at the beginning, middle and end of the 13-week training period and at the end of the 5-week detraining period. At 13 weeks both the exercise/WBV and the exercise only groups improved significantly in countermovement jump ($p < .001$) and isometric knee extension force ($p = .001$). The exercise/WBV group significantly increased concentric (isokinetic) knee extension force ($p = .004$), but the exercise only group did not. Significant interactions between group and time were observed for all three variables.

From Week 1 to Week 13, countermovement jump increased from 24.5 $\pm$ 8.6 to 27.9 $\pm$ 8.6 cm in the exercise/WBV group, and from 23.4 $\pm$ 7.0 to 25.8 $\pm$ 6.9 cm in the exercise only group. Isometric knee extension force increased from 5.7 + 1.4 to 8.8 $\pm$ 1.1 N.m.kg^{-1} in the exercise/WBV group, and from 5.5 $\pm$ 0.8 N.m.kg^{-1} to 6.8 $\pm$ 1.2 N.m.kg^{-1} in the exercise only group. Concentric knee extension force increased from 1.1 $\pm$ 0.2 to 1.9 $\pm$ 0.5 N.m.kg^{-1} in the exercise/WBV group, and from 1.3 $\pm$ 0.2 to 1.5 $\pm$ 0.4 N.m.kg^{-1}

in the exercise only group. The authors reported that all three dependent variables were significantly higher in the exercise/WBV group compared to the exercise group.

Detraining resulted in a significant decrease in these variables in the exercise/WBV group, resulting in no significant differences between the exercise/WBV group and the exercise group at the end of the 5-week detraining period (i.e., Week 18). Countermovement jump decreased to 26.6 + 8.4 cm in the exercise/WBV group and decreased to 25.4 $\pm$ 6.8 cm in the exercise group; isometric knee extension force decreased to 7.9 $\pm$ 1.3 $N \cdot m \cdot kg^{-1}$ in the exercise/WBV group and was reported to be 7.0 $\pm$ 1.4 $N \cdot m \cdot kg^{-1}$ in the exercise group; and concentric knee extension force decreased to 1.6 $\pm$ 0.5 $N \cdot m \cdot kg^{-1}$ in the exercise/WBV and 1.5 $\pm$ 0.6 $N \cdot m \cdot kg^{-1}$ in the exercise group, which indicated no change.

The authors concluded that performance of regular exercise is important to maximize the effects of WBV in previously untrained individuals. There are clear differences in the methods associated with the study conducted by Osawa and Oguma (2013) and the present study. However, the results of the present study were similar in that participants in the WBV and control groups experienced decrements in strength during the detraining period, although the measures of strength at the end of both studies were significantly higher than their respective pretraining measures.

This trend is observed in other detraining studies conducted on previously sedentary populations such as older men after 16 weeks of training and 4 weeks of detraining (Lovell, Cuneo & Gass, 2010). In this study, 12 participants were assigned to a control group (C) that did no training and 12 participants were assigned to a strength training (ST) group. After training all dependent variables were significantly higher in the strength training group than in the control group. All dependent variables were also significantly increased in the strength training group after 16 weeks of training as compared to baseline. Rate of force development increased by 14%; maximum bilateral isometric force increased by 25%; force produced in 500 ms increased by 22%; upper leg muscles mass increased by 7%; and strength increased by 90% in the strength training group. After 4 weeks of detraining, measures for all dependent variables decreased significantly compared to the post training period. However, after detraining these measures were all significantly higher than pretraining values with the exception of rate of force development. Other studies that report similar findings include one using older adults subjected to 12 weeks of high or moderate intensity and 12 weeks of detraining (Tokmakidis, Vasilios, Kalapotharakos, Smilios & Parlavantzas, 2009); and younger sedentary males doing 12 weeks of training and 12 weeks of detraining (Andersen, Andersen, Magnusson & Aagard, 2005). In summary, there are several studies using previously untrained participants that report a trend of incomplete detraining when the training period is at least as long as the detraining period.

Comparison to Other Studies using Whole Body Vibration as a Rehabilitation Tool

Although the design of the present study differs from other studies that use WBV as a rehabilitation tool, it is useful to compare it with such studies based upon the justification of performing this experiment. Studies described below differ from this one primarily in that the former use already injured participants, use different training protocols and measure different dependent variables.

Johnson and colleagues (2010) compared eight elderly male and female patients of total knee arthroplasty who underwent a traditional rehabilitation regimen with eight similar patients who underwent a training program while exposed to concurrent WBV stimulus. The measured dependent variables included knee extensor strength, mobility, pain, quadriceps activation, and range of motion. Although both groups improved significantly from baseline, there were no significant differences between the groups for any of the dependent variables measured. Knee extensor strength increased by 77.3% in the traditional regimen, while knee extensor strength improved by 84.3% in the WBV group. Timed up and go scores improved by 32% in the traditional group and by 31% in the WBV group. It should be noted though, that in this study participants in the WBV group were allowed to wear footwear during WBV training, and it is possible that the footwear may have dampened the stimulus.

Brunetti and colleagues (2006) evaluated parameters of muscle function of participants (n = 15) undergoing a rehabilitation program with hand –held vibration compared with participants (n = 15) undergoing a similar program without vibration. Measured parameters of muscle function included balance, EMG activity, knee extension torque, knee range of motion and ligament laxity.

The rehabilitation program was reported to be a standard one for ACL rehabilitation. During the first week, the participants wore an articulation brace on the locked knee, performed straight leg raises, dorsiflexion, plantar flexion and were subjected to cryotherapy. After eight days the brace was removed and they performed active and passive flexion exercises for the knee, straight leg raises and cryotherapy. After 21 days the progression included independent ambulation, gait recovery and loading on the straight leg raises. After 40 days the program was progressed to proprioceptive exercises, with a progression to linear running after 60 days. Light sporting activity began after 90 days.

The vibration group was also treated with a hand-held vibration device using a frequency of 100 Hz and amplitudes of 5-15 μm. Treatment was administered three times a day for three consecutive days. Each application was 10 min long (for a total of 30 min a day), and a rest period of 30 s was allowed between consecutive sessions. The stimulus was applied on the skin overlying the distal part of the quadriceps group near to the tendon insertion of rectus femoris, vastus intermedialis, vastus lateralis and vastus medialis. Treatment began 30 days after surgery. The non-vibration group was treated with a placebo condition.

Single limb balance was evaluated at five time points: before vibration treatment began, 24 h, 10, 90 and 270 days after treatment. Center of pressure signal (COP) and average velocity of COP were used to measure balance. Both groups were initially equal. At 270 days there was a significant improvement in closed eye balance (of the operated leg) in the vibration group, with a reduction of elliptic area amplitude by 40% and a reduction in velocity by 27%. Compared to the non-operated sides of the vibration and non-vibration groups, the operated side of the vibration group showed a drastic increase in COP and velocity. The investigators reported that one day after surgery COP (198 mm^2) and velocity (60.9 $mm \cdot s^{-1}$) were equal to the non-operated sides of the vibration group (196 mm^2, 58.3 $mm \cdot s^{-1}$) and the non-vibration group (199 mm^2, 58 $mm \cdot s^{-1}$).

Extensor muscle torque was measured before surgery and also 90 and 270 days after commencement of the vibration treatment. No torque tests were performed within three months of surgery, in order to prevent a relapse of injury on the operated leg. There was a 14 % decrease in torque in the operated leg of the non-vibration leg, while the participants in the vibration group recovered their torque to pre-surgical levels.

The final torque measurement was 6 $\pm$ 7.8 % less than that of the non-operated side, which suggested almost complete recovery of strength in the vibration group. Conversely the operated leg of the non-vibration group the torque was 28 $\pm$ 16 % of the non-operated side.

Intersubject Variability

It is important to discuss the high amount of inter-subject variability of the data used in this study. Several WBV studies explore the variability of biodynamic outcome variables between people (Desta, Saran & Harsha, 2011; Toward & Griffin, 2011), but the reason for this variability is not understood (Toward & Griffin, 2011). In this study anecdotal observation of variability was observed even before WBV training, during the powerlifting programs. For example, some participants were unable to perform the squat lift with a 45-pound bar, whereas others were able to perform the squat lift with up to 155 pounds. While all participants were nonresistance trained for at least 6 months at the commencement of the study, some participants expressed previous powerlifting experience. The extensive inter-subject variability may be explained by an interaction of several factors. Studies that explore the reason for the high amounts of variability between participants have focused on biochemical factors (Murton et.al, 2013; Timmons 2011), structural variations of skeletal muscle (Erskine, Jones, Williams, Stewart & Degens, 2010; Hubal et. Al, 2005) and individual synergist employment strategies of experienced lifters (Kristiansen, Madeleine, Hansen & Samani, 2013). Erskine and colleagues (2010) reported large variability in one repetition maximum of unilateral leg extension after nine weeks of training (68 ± 30%) with individual changes ranging from 18% to 113%. Similarly, Hubal and colleagues (2005) reported an increase in cross sectional area of the unilateral bicep curl between 15 and 25%, with 36 participants gaining below 5% and 10 participants gaining more than 40%

The mention of such variation is pertinent, because the use of conventional statistical analysis in studies using WBV and weight training could potentially mask important findings. For example, future studies could examine trends in participants with a similar training history in order to determine if a range of WBV accelerations has a similar effect on training or detraining. In summary, inter-subject variability may be explained by an interaction of several genetically determined factors such as biochemical response and individual physical qualities, in addition to previous lifting experience.

Frequency of Training

In this study, the WBV participants were originally scheduled to perform the intervention three days a week for 6 weeks. However due to other commitments, some participants sometimes had to be scheduled for once or twice per week. This could have been a limitation as frequency of exercise is able to affect progress in parameters of physical fitness. When participants missed a WBV session, their WBV protocols were adjusted so that they spent the same total amount of time doing the intervention. In other words if a participant was scheduled to come in three times, doing 6 repetitions each time, and they only came in twice, then they completed 9 repetitions; or all 18 repetitions if they were only able to come once per week. Hence duration was modified in the case of decreased frequency of training. Moreover, there is evidence to support that if a resistance training program's intensity and duration is maintained, participants are able to maintain strength for up to 12 weeks even if frequency is reduced. Lower body strength was maintained in professional soccer players for 12 weeks after reducing frequency from twice weekly to once weekly (Ronnestad, Nymark & Raastad, 2011), while isometric lumbar extension strength was maintained for participants who reduced training from 1-3 times weekly to once every 2 weeks or once every 4 weeks (Tucci, Carpenter, Pollock, Graves & Leggett, 1992). Based upon this information, it is reasonable to assume that if the WBV program used in this study were an equivalent stimulus to the powerlifting program, then the outcome variables for the WBV group would have showed no difference between the end of the powerlifting program (Week 6) and the end of the study which was 6 weeks later. Recall that the WBV group decreased in strength at Week 12 in the squat, dorsiflexion torque and knee flexion torque.

Acceleration and Safety

This study also used a relatively small range of accelerations for the intervention. Accelerations used were between 2.56 g and 7.68 g, where g is equivalent to acceleration due to the earth's gravity or 9.81 $m \cdot s^{-2}$. The Power Plate WBV platform is capable of theoretically reaching accelerations of at least 15 g (Muir, Kiel & Rubin, 2013). Accelerations above 7.68 g were not used because of considerations of comfort and safety of participants. Accelerations above 2 g are considered unsafe for exposure for any time period more than 1 min according to the International Standards Organization's ISO-2631 guidelines (Muir, Kiel & Rubin, 2013). However these guidelines were created in 1997, based off of criteria established in order to curtail WBV's effects as an occupational hazard. Indeed, much of the research work cited in this writing, which uses WBV as a therapeutic intervention or as a mode of exercise was completed after the creation of the ISO-2631 guidelines. Conditions associated with chronic WBV exposure include musculoskeletal disorders such as chronic lower back pain in the occupational setting, and also disorders of the gastrointestinal and urogenital systems, especially in the female gender (Kittusamy & Bucchholz, 2004). Others have reported that occupational exposure to WBV has a negative influence on performance parameters such as perceptual tasks, cognitive tasks, continuous and discrete fine motor tasks (Conway, Szalma & Hancock, 2007); sensory effects such as vision in the seated posture (Ishitake, Ando, Miyazaki & Matoba, 1998); or motion sickness in military personnel (Chan, Moochhala, Zhao, Wl & Wong, 2006). This is pertinent to those performing WBV as a method of exercise or therapy, because the potential exists for discomfort or injury upon exposure to the stimulus. Non-dampened WBV also can result in acceleration of the head, which may result in severe discomfort (Muir, Kiel & Rubin, 2013).

Whole body vibration is cited as an occupational hazard amongst operators of heavy equipment, such as hoisting and portable engineers who operate backhoes, bulldozers, cranes, front end loaders and graders (Kittusamy & Bucchholz, 2004), operators of large vehicles such as trains (Birlik, 2008) and hand-held pneumatic drills (Majd & Nassiri, 2009). Those in the aviation and maritime industries are also cited to be at risk (Chan, et al., 2006; Conway, Szalma & Hancock, 2007). Kittusamy & Buccholz (2001) reported compromised seated neck, shoulder and trunk posture to be a deciding factor in musculoskeletal injury on backhoe and excavator operators in preliminary findings. The conditions of WBV as an occupational hazard are in contrast to those found in WBV used as a lower body exercise intervention, in that WBV meant for exercise is performed in a modified squatting position or while performing lower body exercises upon the platform. The large muscles of the lower body extremities are more likely to damp accelerations in the standing position via tuning (Kiiski, et al., 2008; Wakeling & Nigg, 2001), whereas most workers exposed to WBV are in the static seated position (Kittusamy & Buccholz, 2004) where there is less damping of WBV; there is more direct WBV stimulus transmitted to the axial skeleton and adjacent organs. In the case of pneumatic drill operators, WBV is transferred via the upper body extremities, which usually have smaller skeletal muscle content than the lower body extremities.

Those exposed to WBV while in some sort of standing or squatting position are likely at a decreased risk for exposure injury than those in a static seated position because of the tuning ability of the large skeletal muscle groups in the lower body. Moreover, these muscles are more able to tune in deeper squatted positions (Muir, Kiel & Rubin, 2013). In summary, based upon the results of this study, the range of accelerations used do not appear to be an equivalent stimulus to the powerlifting program as the range was chosen based upon concerns of safety and comfort. The time and conditions whereby the ISO guidelines were established do not appear to take the tuning ability of skeletal muscle groups of the lower appendicular skeleton into consideration, and thus may need to be amended in order to consider WBV in exercise conditions, which differ from those in occupational settings.

Length of Detraining Time

Another limiting factor was the time of detraining. As aforementioned, there were no differences between either group for the squat, knee flexion torque or dorsiflexion torque. Rehabilitation protocols typically last several months, and based upon the results of the torque variables, time for detraining should have been longer in order to observe a more significant loss of torque. It is also possible that there may also be a threshold of time where torque in the WBV group could have shown a plateau response as detraining continued in the control group. Several studies using WBV as a training method have seen improvements in performance variables using programs as long as 6 weeks (Mahieu, et. al, 2006), 12 weeks (Delecluse, Roelants & Verschueren, 2003) and 13 weeks (Osawa & Oguma, 2013). In contrast, de Ruiter and colleagues (2003) found no differences in knee extensor strength after 11 weeks of WBV training. Those studies that reported a difference employed protocols that combined WBV with exercise, whereas the study by de Ruiter and colleagues used a protocol that employed WBV only.

There was also no difference between either of the groups in the 5 repetition maximum squat. In order to truly determine that WBV accelerations used had no effect upon strength it would theoretically be best to modify the design used in this study to use a detraining protocol that lasted at least until the participant or patient was cleared to do dynamic exercise; at least 10 weeks (Shelbourne & Nitz, 1992). However, experimental attrition could become a problem. From this perspective, it would be feasible to use injured participants, but this could also be problematic. Studies using these participants would have to be based on the rehabilitative protocol such as those described in the following section, as it would be impossible to predict which participants would become injured, as well as when the event would happen. In other words, it would be difficult to obtain an accurate preinjury strength assessment immediately before injury, as predicting the event would not be possible. It would also be impractical from the point of view that newly injured participants would not be able to maximally perform the tests used in this study with the injured leg.

Conclusion

Static whole body vibration using accelerations between 2.56 g and 7.68 g does not appear to attenuate detraining of the flexors and extensors of the knee and ankle after 6 weeks. Future study designs requiring the use of higher accelerations, longer detraining periods, and the measurement of other dependent variables of skeletal muscle function should be employed.

Recommendations for Future Study

(1) The first category of studies that should be established may compare accelerations and effects of WBV in the seated position (found in occupational settings) and the squatting position (used in exercise). The purpose of these studies would be to ascertain if the guidelines found in ISO-2631 apply equally to WBV in the exercise setting as they do in the occupational setting. To extrapolate upon this idea it would also be appropriate to explore the effect of WBV with higher intensities than 7.68 g in similar detraining protocols.

(2) The second category of study that should be explored may entail using different outcome variables of muscular function. This study also did not explore the use of WBV on other parameters commonly measured in vibration studies or rehabilitation. As WBV is thought to affect function of the stretch reflex, it would be useful to observe the effects of WBV on detraining of electromyography (EMG), balance, power and voluntary muscle activation. As the outcome variables of torque were no different

between either group after 6 weeks of detraining, study designs with longer detraining periods may be considered.

(3) The third category of study addresses the problem stated previously concerning the length of time of detraining. A control group receiving a traditional rehabilitation method would be compared to a WBV experimental group; each participant's uninjured leg would be used as a control in order to compare with the injured knee. Dependent variables as described previously (EMG, biodex, maximum voluntary contraction, etc.) would be measured on the uninjured leg at the onset of injury before the beginning of the rehabilitation program, and again when the injured knee is able to perform the associated tests, at which time both knees will be measured. Subsequent tests would then be performed on both knees as scheduled by the managing therapists. Comparisons could then be made between the injured and uninjured knees throughout the length of the rehabilitation program.

(4) The fourth category of study that should be explored entails a more profound exploration of WBV as a mode of resistance training when compared to more established and conventional modes of resistance training. Recall the inconsistency in results between the studies conducted by de Ruiter and colleagues (2003) and others (Delecluse, Roelants & Verschueren, 2003; Mahieu, et. al, 2006; Osawa & Oguma, 2013). Much of the discrepancy in results within the WBV literature would appear to stem from inconsistent use of concurrent exercise protocols with WBV. Hence, it would be useful to compare balance, EMG, power, torque and voluntary muscle activation of a group

performing static stance and dynamic exercise with WBV before and after such a program, and comparing these dependent variables to those of groups performing traditional resistance training without WBV. This would also serve to explore the interaction of exercise and WBV more closely. Empirical findings of skeletal muscle adaptation to WBV exercise would also help to justify the revision of the ISO-2631 guidelines to accommodate the positive applications of WBV as a training tool.

(5) The fifth category of future study describes the use of WBV on the upper body. Although several studies exist (Boland, Boland, Carroll & Barfield, 2009; Hand, Verschuere & Osternig, 2009), to this writer's knowledge there is less WBV literature exploring use of WBV for the upper appendicular skeleton than there is for the lower appendicular skeleton. Furthermore, many of the concerns described above for safety and parameters of use for WBV should be investigated. The muscles of the upper appendicular skeleton are generally smaller than those of the lower appendicular skeleton, and the bones are shorter. In theory there may be less of a damping ability for the upper appendicular skeleton, as there may be a smaller capacity for those muscles to tune in order to prevent resonance catastrophe. Conversely, the potential benefits of WBV to increase strength, induce bone anabolism and enhance rehabilitation programs in the upper extremities should not be ignored. Thus it is important to ascertain proper parameters of WBV use in order to effectively design parameters of WBV use for such applicable populations as the elderly and injured. Optimally all proposed studies for the

use of lower body WBV as described previously should be implemented for use in the upper body.

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APPENDIX A

Institutional Review Board 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 940-898-4416
e-mail: IRB@twu.edu

May 16, 2013

Mr. Keston Lindsay
1201 North Austin Street, #4
Denton, TX 76201

Dear Mr. Lindsay:

Re: The Effect of Whole Body Vibration on Lower Body Resistance Detraining (Protocol #: 17330)

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 is enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. A copy of the signed consent forms must be submitted with the request to close the study file at the completion of the study.

This approval is valid one year from May 3, 2013. Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any unanticipated incidents. If you have any questions, please contact the TWU IRB.

Sincerely,

Rhonda R Buckley

Dr. Rhonda Buckley, Chair
Institutional Review Board - Denton

cc. Dr. Charlotte Sanborn, Department of Kinesiology
Dr. David Nichols, Department of Kinesiology
Graduate School

APPENDIX B

Informed Consent

INFORMED CONSENT

Title: The effects of whole-body vibration on lower body resistance detraining

Principal Investigator: Keston Lindsay 940-465-5974 klindsay@twu.edu

Faculty Advisor David Nichols, Ph.D. 940-898-2522 dnichols@twu.edu

Explanation and Purpose of the Research

You are being asked to partake in a research study for Keston Lindsay's dissertation at Texas Woman's University. The purpose of this study is to examine the effects of a 6-week whole body vibration intervention on lower body resistance detraining (i.e., loss of training adaptations after cessation of a resistance training program). There will be 2 phases to the study, a training phase and a detraining phase. The training phase will consist of 6 weeks of lower body resistance training (weight training). The detraining phase will consist of 1 of 2 interventions: either a control group in which no further training will be applied, or a whole body vibration training group in which participants will be exposed to a vibration protocol.

Description of Procedures

Participants will be assessed for a total of 5 times: Before the resistance training protocol (week 0), immediately after the resistance training protocol (week 6), 2 weeks after (week 8), 4 weeks after, (week 10) and 6 weeks after resistance training. Strength testing will consist of 3 strength assessments; 1 for the knee and 1 for the ankle on the Biodex machine in the biomechanics laboratory in Pioneer Hall. The 3rd assessment will be performed at the Fitness and Recreation Center. The time taken for each test session will be about 30 minutes.

After the first assessment you will be asked to perform resistance training exercises. The exercises will include the squat, the leg press, knee extensions, hamstring curls, toe presses, ankle flexion and ankle extension. Loads will be increased based on verbal feedback and performance of various sets during the previous or same exercise session. You will be asked to train for an hour, twice weekly for 6 weeks.

After the 2nd assessment you will be randomized into one of two groups: a control group or a whole body vibration group. The control group will be asked to cease training for the next 6 weeks. The whole body vibration group will be asked to stand in a squatted position on the vibration platform 6 times during each session for a time period between 30 and 60 seconds at a time. Break periods will be equal to that of exposure periods. The amplitude of the intervention will vary between 2 and 6 mm and the frequency of the intervention will be 30 Hz. Data will be assessed for all participants 2 weeks, 4 weeks and 6 weeks after cessation of resistance training. Total time commitment will be 20.5 hours, or 1,230 minutes divided into 35 sessions.

Approved by the Texas Woman's University Institutional Review Board Date: 5-3-13

_______ Initials

Potential Risks

You will be exposed to the following potential risks:

Loss of time

All training and testing procedures will be performed as quickly and efficiently as possible and the principal investigator will be present at all sessions to assist participants.

Injury/physical discomfort/muscle soreness

Physical discomfort or injury can occur during resistance training and testing. Discomfort can be minimized by adequate warm up before training or testing. In order to minimize discomfort or injury during whole body vibration training, participants will be asked to stand in a squat position, as standing in an upright position may cause discomfort due to resonance. Muscle soreness is usually alleviated 2-3 days after the initial training session.

Erythema

Whole body vibration has been associated with itching and redness of the skin. The application of ice packs may alleviate this.

Loss of confidentiality

Collected data will be coded and names will not be used to identify data. Hard copies will be left in a secure filing cabinet in an office. Strength data will be compiled using a password-secured computer using a secure network. All training and testing information will be treated as confidential. There is a potential rick of confidentiality loss in all email, downloading and internet transactions. Confidentiality will be maintained to the extent allowed by law.

Falling

Risk of falling from the vibration platform will be minimized by asking you to hold on to the platform's guard rail. All resistance training and vibration sessions will be supervised by the primary investigator. Risk of falling will be minimized in resistance training by teaching you proper technique.

Loss of anonymity

Resistance training will take place at the fitness center and in the exercise physiology laboratory, which are public sites. The primary investigator will avoid stating names during training.

The primary investigator will try to prevent any problem that could happen because of this research. You should let the primary investigator know at once if there is a problem and he 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.

Approved by the
Texas Woman's University
Institutional Review Board
Date: 5-3-13

_______ Initials

APPENDIX C

Physical Activity Readiness Questionnaire (PAR-Q)

All information received on this form will be treated as strictly confidential. Please fill out the forms ***completely and accurately***.

PAR-Q FORM Please mark YES or No to the following:	YES	NO
Has your doctor ever said that you have a heart condition and recommended only medically supervised physical activity?	____	____
Do you frequently have pains in your chest when you perform physical activity?	____	____
Have you had chest pain when you were not doing physical activity?	____	____
Do you lose your balance due to dizziness or do you ever lose consciousness?	____	____
Do you have a bone, joint or any other health problem that causes you pain or limitations that must be addressed when developing an exercise program (i.e. diabetes, osteoporosis, high blood pressure, high cholesterol, arthritis, anorexia, bulimia, anemia, epilepsy, respiratory ailments, back problems, etc.)?	____	____
Are you pregnant now or have given birth within the last 6 months?	____	____
Have you had a recent surgery?	____	____
Do you suffer from epilepsy?		
Have you had any surgery or medical procedure in the past year that may affect your physical activity?	____	____
Are you aware of any condition that may prohibit you from exercise?	____	____
For women: Are you pregnant?	____	____

If you have marked YES to any of the above, please elaborate below:

____

____

____

Please provide additional details if necessary:

____

____

____

Do you take any medications, either prescription or non-prescription, on a regular basis? Yes/No

What is the medication for?____

How does this medication affect your ability to exercise?

____

____

If you answered YES to one or more questions, talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness assessment or program. Tell your doctor about the PAR-Q and which questions you answered YES.

I certify that the answers to the questions outlined on the PAR-Q form are true and complete to the best of my knowledge. I acknowledge that medical clearance has been attained if I have answered "Yes" to any of the questions on the PAR-Q form. I understand and agree that it is my responsibility to inform the primary investigator of any conditions or changes in my health, now and ongoing, which might affect my ability to exercise safely and with minimal risk of injury.

Signed by Participant…………………………………….. Date: ……………………..

Signed by Investigator………………………………… Date: ……………………...

APPENDIX D
Participant Raw Data

Participant	Mass_lbs	Height_inches	Age_yrs	Condition	exercise_status	FiveRMSquatTP1	TorquePlantarTP1_30deg
1	224.4	67	22	0	0	85	71.7
2	263.2	73.5	29	0	0	0	63.8
3	130	64	29	0	0	45	32.2
4	273	66	22	0	0	0	43.5
5	152.4	68	22	0	1	100	74.8
6	128.6	65	19	0	1	85	52.8
7	117	66	20	0	1	155	58.5
8	130.8	64	21	0	1	115	23
9	200.2	65	21	0	1	170	112.7
10	143	64	23	0	1	140	40
11	196.8	63.5	31	1	0	0	54.3
12	144	63	33	1	0	0	31.2
13	180.8	68	19	1	0	145	45.7
14	138	66	31	1	1	65	79.3
15	143.8	65	22	1	1	65	54.6
16	107.6	61.5	19	1	1	75	39.8
17	130	66	30	1	1	45	34.5
18	130.2	64.5	21	1	1	85	50.9
19	191.6	62.5	25	1	1	45	17.4
20	156.4	71	22	1	1	100	54.3

FiveRMSquatTP3	TorquePlantarTP3_30deg	TorqueDorsiTP3_30deg	TorqueKneeExTP3_60	TorqueKneeFlexTP3_60	FiveRMSquatTP4	TorquePlantarTP4_30
145	94.9	31.4	226.1	95.5	145	86.3
85	41.1	29.6	150.3	90.1	65	56.1
150	55.2	21.6	164.3	80.6	145	34.3
55	61.5	26.1	140.7	84.1	60	55.5
135	55.2	20	182.8	84.8	120	51.1
115	78.6	35.8	131	73.6	120	67.5
185	67.4	46.2	129.7	67.8	175	51.8
185	57.6	29.8	192.8	102.2	145	64.4
205	102.3	40.6	223.8	168.4	215	111.2
170	76.3	37.1	145	86.3	165	72.8
145	63.1	29.4	143.2	101.1	135	72.3
125	63.1	22.7	166	74.3	125	59.6
215	110.2	36.1	186.5	87.8	195	93.1
145	77.1	23	159.6	84.2	155	88.1
150	44.6	16.7	126	104	155	52.3
145	37.5	24.3	120.5	62.9	135	35.4
185	63.6	16.1	168.7	81.6	145	68.5
115	54.2	22	170.5	76.7	105	56.5
155	67.4	24.8	182.9	77.4	155	81.3
145	83.6	23.7	196.8	95.5	135	81.3

FiveRMSquatTP3	TorquePlantarTP3_30deg	TorqueDorsiTP3_30deg	TorqueKneeExTP3_60	TorqueKneeFlexTP3_60	FiveRMSquatTP4	TorquePlantarTP4_30
145	94.9	31.4	226.1	95.5	145	86.3
85	41.1	29.6	150.3	90.1	65	56.1
150	55.2	21.6	164.3	80.6	145	34.3
55	61.5	26.1	140.7	84.1	60	55.5
135	55.2	20	182.8	84.8	120	51.1
115	78.6	35.8	131	73.6	120	67.5
185	67.4	46.2	129.7	67.8	175	51.8
185	57.6	29.8	192.8	102.2	145	64.4
205	102.3	40.6	223.8	168.4	215	111.2
170	76.3	37.1	145	86.3	165	72.8
145	63.1	29.4	143.2	101.1	135	72.3
125	63.1	22.7	166	74.3	125	59.6
215	110.2	36.1	186.5	87.8	195	93.1
145	77.1	23	159.6	84.2	155	88.1
150	44.6	16.7	126	104	155	52.3
145	37.5	24.3	120.5	62.9	135	35.4
185	63.6	16.1	168.7	81.6	145	68.5
115	54.2	22	170.5	76.7	105	56.5
155	67.4	24.8	182.9	77.4	155	81.3
145	83.6	23.7	196.8	95.5	135	81.3

APPENDIX E

Resistance Training Protocol

Resistance Training Protocol									
Name:									
Hang cleans (3 sets)									
8-10x									
Start Date									
Squats									
10x									
8x									
5x									
5x									
5x									
Alternating Hamstring curls (3 sets)									
Each leg									
10x									
Alternating Leg extensions (3 sets)									
Each leg									
10x									
Single leg Calf Raises (3 sets)									
10x									
Heel Walk (dorsiflexion; 3 sets)									
10x									

APPENDIX F
Whole Body Vibration Protocol

Name:										
Month	Week	Day	Series	Frequency (Hz)	Amplitude (mm)	Duration (s)	Rest	Total Vibration Time (s)	RPE (Borg)	# of Trials
1	1	1	6	30	2-4	30	30	180		
		2	6	30	2-4	30	30	180		
		3	6	30	2-4	30	30	180		
	2	1	7	30	2-4	30	30	210		
		2	7	30	2-4	30	30	210		
		3	7	30	2-4	30	30	210		
	3	1	5	30	2-4	60	30	225		
		2	5	30	2-4	60	30	225		
		3	5	30	2-4	60	30	225		
	4	1	6	30	4-6	45	30	270		
		2	6	30	4-6	45	30	270		
		3	6	30	4-6	45	30	270		
2	1	1	5	30	4-6	60	30	300		
		2	5	30	4-6	60	30	300		
		3	5	30	4-6	60	30	300		
	2	1	6	30	4-6	60	30	360		
		2	6	30	4-6	60	30	360		
		3	6	30	4-6	60	30	360		
	3	1	7	30	4-6	60	30	420		
		2	7	30	4-6	60	30	420		
		3	7	30	4-6	60	30	420		