ACUTE EFFECTS OF WHOLE-BODY VIBRATION ON DYNAMIC POSTURAL CONTROL IN SUBJECTS WITH FUNCTIONAL ANKLE INSTABILITY

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Abstract

DANIEL ADELMAN: Acute Effects of Whole Body Vibration on Dynamic Postural Control in Subjects with Functional Ankle Instability
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Ankle sprains are highly common in recreationally active individuals and can lead to functional ankle instability (FAI), characterized by repeated ankle sprains and functional deficits. Whole-body vibration (WBV) is a novel modality that influences neuromuscular function, and may be effective for rehabilitation of FAI. However, no study has investigated the effects of WBV on neuromuscular deficits associated with FAI. The objective of this study was to evaluate the acute effects of WBV on dynamic postural stability and muscle activity in individuals with FAI. We quantified dynamic postural stability as the time to stabilization (TTS) and measured preparatory and loading phase EMG of the gluteus medius, peroneus longus, rectus femoris, and tibialis anterior muscles of the involved leg. However, there were no significant effects of WBV on these measures. These findings suggest that acute WBV exposure may not be an effective method for rehabilitation for FAI.

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CHAPTER I

INTRODUCTION

Ankle injuries are some of the most common injuries in recreational and athletic settings with more than 25,000 ankle sprains occurring daily in the United States (Mickel et al., 2006). Ankle sprains account for up to 44% of all injuries in the physically active population, with 40-73% of these injuries being recurrent cases (Arnold, Wright, & Ross, 2011; Dizon & Reyes, 2010; Hughes & Rochester, 2008). Between 32-74% of these cases report chronic symptoms such as pain or weakness, and 32-47% report some level of functional ankle instability (Arnold et al., 2011).

Freeman and colleagues (1965) were the first to define functional ankle instability (FAI) as an ankle that displays a tendency of giving way following injury. These instabilities are caused by anatomic or mechanical instabilities, muscular weakness, deficits in joint proprioception, postural control, and neuromuscular control, making it a truly multifaceted condition resulting in decreased function (Freeman, 1965; Freeman, Dean, & Hanham, 1965; Hertel, 2002). Injury to the ankle also has implications for activities of daily living and overall health (Arnold et al., 2011). Recurrent ankle sprains are linked to an increased risk of osteoarthritis and articular degeneration (Harrington, 1979; Hertel, 2002). A previous history of at least one ankle sprain represents the greatest predisposing factor for a subsequent ankle sprain (Bahr & Bahr, 1997; Beynnon, Murphy, & Alosa, 2002; Hertel, 2002; McKay, Goldie, Payne, & Oakes, 2001; Milgrom et al., 1991). Collectively, the literature indicates that the rate of ankle injuries remains a significant problem in the athletic setting resulting in significant time lost due to injury and financial resources invested in prevention and management of the injury. (Garrick, 1977; Mickel et al., 2006; Yeung, Chan, So, & Yuan, 1994).

The neuromuscular deficits associated with FAI can be seen in numerous studies examining the effect of ankle injury on electromyography (EMG) of lower extremity musculature. Beckman and colleagues (1995) showed there were significant decreases in postural control and hip abductor muscle strength when measured following an ankle sprain. It is not clear however, if FAI caused the decreased hip musculature activation of FAI occurred due to this deficit. It was also shown that individuals with FAI displayed increased peroneal reaction time when exposed to a sudden inversion mechanism (Beckman & Buchanan, 1995; Palmieri-Smith, Hopkins, & Brown, 2009). Injury to the peroneal muscle group could cause functional compensations further up the kinetic chain, changing gluteus medius activation patterns. The neuromuscular deficits associated with both the proximal and distal muscles of the kinetic chain make FAI a truly confounding condition leading to multiple functional compensations.

Literature is inconsistent on the topic of ankle injury prevention because the forces and speed involved in acute ankle sprains are too great to be prevented from a mechanical or neural perspective (Konradsen, Voigt, & Hojsgaard, 1997). For example, the human body's reflex response is too delayed, internal static support such as ligaments and muscles are too weak, and external taping is an ineffective means of preventing initial ankle injury (Dizon & Reyes, 2010; Hughes & Rochester, 2008; Refshauge, Kilbreath, & Raymond, 2000; Wilkerson, 2002). Following initial injury, neuromuscular deficits can predispose individuals to repetitive injury (Rozzi, Lephart, Sterner, & Kuligowski, 1999). Mechanical deficits such as altered ligament laxity, synovial inflammation, articular degeneration, muscle activation impairments, or altered arthrokinematics are common after injury. Neural deficits such as decreased proprioception, arthrogenic muscle inhibition (AMI), and neuromuscular control are equally as common following injury and can manifest as decreased postural control (Hertel, 2002). AMI is characterized by activation deficits of specific muscle groups due to damaged mechanoreceptors and reflex inhibition following injury (Palmieri-Smith et al., 2009). Literature suggests that neuromuscular training that restores both the mechanical and neural deficits can reduce the rate of ankle injury after previous ankle sprains (McGuine & Keene, 2006).

Because FAI impairs neuromuscular control, research supports a multifaceted rehabilitation program that incorporates the central, neuromuscular, and mechanical deficits associated with initial ankle injury (Garn & Newton, 1988; Goldie, Evans, & Bach, 1994; Rozzi et al., 1999). Gribble and colleagues (2004) state that static postural control tasks are often not functionally applicable in assessing neuromuscular control. Postural control can be classified as static (stationary) or dynamic with dynamic postural control requiring greater muscle recruitment, proprioceptive feedback, and afferent sensory integration (Gribble, Hertel, Denegar, & Buckley, 2004).

Dynamic stabilization tasks are an adequate representation of neuromuscular control because they challenging the various neuromuscular systems and mimic the unpredictable physical demands of athletic activity (i.e. jump landing). Ross and colleagues (2003) describe the time-to-stabilization (TTS) task requiring the individual to quickly stabilize on one leg after jumping from a standardized distance as an effective measure of dynamic stability. TTS represents the time it takes for the vertical ground reaction forces (GRF) of a single-leg landing to resemble the GRF of a static single-leg stance. Single leg landing tasks are designed to challenge the postural control system and identify unstable landing patterns that could predispose an individual to recurrent ankle injury (Ross, Guskiewicz, & Yu, 2005). Literature has shown that individuals with FAI display a longer TTS than healthy subjects in the anterior/posterior (A/P) and medial/lateral (M/L) direction (Ross et al., 2005). Studies have also been conducted using an intervention period to try and improve TTS in individuals with FAI. Ross and Guskiewicz (2006) performed coordination training with stochastic resonance electrical stimulation intervention over a 6-week period in subjects with FAI, and found improved TTS after only 2 weeks. Therefore, TTS is an appropriate measure in evaluating the effectiveness of current rehabilitation programs in restoring neuromuscular control and dynamic postural stability.

Whole body vibration (WBV) is a novel exercise modality that could be used as an adjunct to dynamic stabilization training in treating FAI. WBV challenges multiple components of the nervous and musculoskeletal system simultaneously due to the enhanced discharge of type Ia afferent receptors, muscle spindles, and golgi tendon organ (GTO) activity (Rittweger, 2010). WBV has been shown to elicit improvements in muscular strength, muscular power, flexibility, and balance, which can aid in the rehabilitation of ankle injuries (Moezy, Olyaei, Hadian, Razi, & Faghihzadeh, 2008; Torvinen et al., 2002a).

In subjects with FAI who display neuromuscular deficits, WBV has potential to reduce these mechanical and neural deficits (Meinyk, Kofler, Faist, Hodapp, & Gollhofer, 2008; Moezy et al., 2008). First, increased muscular strength could improve dynamic stability of the ankle joint. Secondly, studies suggest AMI of the muscles surrounding an injured joint as the reason for lingering neuromuscular deficits (Palmieri-Smith et al., 2009). Improvements in muscle spindle activity, muscle fiber activation, and mechanoreceptor activity from WBV could reduce AMI and neuromuscular deficits from injury (Cloak, Nevill, Clarke, Day, & Wyon, 2010; Rittweger, 2010). Last, the sensory stimulation effect of WBV on muscle and cutaneous receptors improves proprioception (Bogaerts, Verschueren, Delecluse, Claessens, & Boonen, 2007). Improving joint stability via enhanced proprioception and muscular power with WBV has implications for improving neuromuscular control and dynamic postural control (Meinyk et al., 2008; Moezy et al., 2008).

Changes in neuromuscular activation as a result of WBV alters the EMG signal in the lower extremity muscles, but the results of previous studies are unclear due to the varying parameters (Abercromby et al., 2007; Erskine, Smillie, Leiper, Ball, & Cardinale, 2007; Melnyk, Schloz, Schmitt, & Gollhofer, 2009; Rittweger, Mutschelknauss, & Felsenberg, 2003; Santilli et al., 2005; Torvinen et al., 2002a). Acute WBV exposure has been shown to enhance EMG amplitude due to the increased muscle spindle response and motor unit activation similar to any muscle-loading scenario (Torvinen et al., 2002a). The exposure time to WBV could also have potential lasting neuromuscular effects. Cormie and colleagues (2006) found no significant changes in EMG activity after WBV exposure, but did find significant increase in power during a countermovement jump 30 minutes after WBV. Torvinen and colleagues (2002) also found a significant difference in stability index scores during static standing 2-minutes after a WBV intervention, and a nearly significant difference in stability index scores 60 minutes post WBV intervention.

There is paucity in the literature on WBV and its effects on dynamic postural control, more specifically, the acute WBV effects on EMG activity of ankle and hip musculature, and WBV use on an injured clinical population. It is evident that the current standard for treating

FAI could be improved (Rozzi et al., 1999). Therefore, further research is warranted in examining the use of WBV as an adjunct to traditional therapy for FAI. The purpose of this study was to determine the acute effects of WBV on dynamic stabilization and lower extremity EMG in individuals with FAI.

RESEARCH QUESTIONS AND HYPOTHESES:

RQ_1: Does whole body vibration (WBV) decrease time-to-stabilization (TTS) in individuals with functional ankle instability (FAI)?

H_1: Time-to-stabilization will decrease immediately post WBV, and remain significantly decreased 30 minutes after intervention.

RQ_2: Does WBV increase preparatory EMG of the peroneus longus, tibialis anterior, rectus femoris, and gluteus medius muscles during TTS in individuals with FAI?

H_2: Preparatory EMG relative to ground contact will be greater immediately post WBV, and remain significantly improved 30 minutes after intervention.

RQ_3: Does WBV increase mean EMG amplitude during the loading phase of the peroneus longus, tibialis anterior, rectus femoris, and gluteus medius muscles during TTS in individuals with FAI?

H_3: The mean EMG amplitude during the loading phase of all muscles will be greater immediately post WBV, and remain significantly improved 30 minutes after intervention.

INDEPENDENT VARIABLES

1. Condition

    a. Control (No WBV)

    b. WBV

2. Time

    a. Baseline

    b. Immediately Post

    c. 15 minutes Post

    d. 30 minutes Post

DEPENDENT VARIABLES

1. Time-to-Stabilization

2. Electromyographic (EMG) Onset & Mean Amplitude of:

    a. Peroneus Longus

    b. Tibialis Anterior

    c. Rectus Femoris

    d. Gluteus Medius

ASSUMPTIONS

1. All participants were honest with their level of ankle stability and previous medical and injury history.

2. All participants gave their maximal effort during participation

DELIMITATIONS

1. Subjects were a relatively homogenous sample (students at University of North Carolina Chapel Hill) of recreationally active individuals with FAI.

LIMITATIONS

1. Time-to-Stabilization measures may not have simulated functional dynamic stability requirements.

2. Only measured acute effects of coordination training with WBV up to 30 minutes, and could not make generalizations about long-term effects.

3. Time allotted for study did not allow longitudinal intervention period, only acute exposure to WBV.

4. Only measured treatment effect on individuals with FAI and cannot claim WBV would have same effects on a healthy population with goals of preventing initial ankle injury.

5. All participants were at different stages in the spectrum of FAI. Although FAI is a chronic condition, some subjects may have been coping with this syndrome for years, as opposed to an individual who only recently had been sustaining repeated ankle sprains and functional deficits.

6. Subjects performed testing barefoot without shoes and socks to ensure internal validity of the study. Athletic shoes are highly variable with differing levels of thickness and materials, which could create further variability between subjects.

7. The distance from the force plate for the TTS measure was standardized to 70cm.

OPERATIONAL DEFINITIONS

Functional Ankle Instability (FAI): A multifaceted syndrome of instability comprised of neuromuscular and mechanical instability that results in repetitive ankle sprains and prolonged symptoms of ankle injury including pain, weakness, and recurrent sensations of "giving way" (Arnold et al., 2011; Freeman, 1965; Freeman et al., 1965; Hertel, 2002; Wikstrom, Fournier, & McKeon, 2010).

Recreationally Active: Individuals who participate in 3 or more days of physical activity lasting for greater than 30 minutes a day.

Time-to-Stabilization (TTS): A dynamic stabilization task involving a jump-landing test requiring the subject to jump to 50% of their maximal vertical jump height, and then land on a single-leg on a force plate. After landing the subject must stabilize as quickly as possible in the single leg stance on the affected side (Ross et al., 2005).

CHAPTER II

REVIEW OF THE LITERATURE

INTRODUCTION

The purpose of this literature review was to provide evidence of the most current and relevant research available on the topic of FAI and WBV. This review was not meant to copy direct work from previous authors, but rather to guide the direction of this study and provide purpose based on the current gaps in research. Through an analysis of the ankle joint complex and the multifaceted FAI condition, it is clear that a more complete rehabilitation program is necessary to safely and adequately restore normal function. The goal of improving neuromuscular control by maximizing afferent input can potentially be accomplished through the adjunct of WBV to current rehabilitation protocols. This literature review illustrates the need for a more successful management strategy of treating FAI, and one that hopefully can be addressed with WBV.

EPIDEMIOLOGY

The high frequency of ankle injuries is due to a number of intrinsic and extrinsic factors. The prevalence of injury constitutes a significant social burden with a large amount of time and financial resources devoted to the treatment and management of ankle injuries. Ankle sprains are among the most common injuries in the athletic and recreational setting (Garrick, 1977). In the United States, approximately 25,000 ankle sprains occur every day (Mickel et al., 2006). In sports, ankle injuries account for 38-45% of all injuries (Fallat, Grimm, & Saracco, 1998; Garrick, 1977). Inversion ankle sprains, are the most common and are estimated at 1 per 10,000 persons per day, with 1 million people seeking medical attention each year (Fallat et al., 1998; Perlman et al., 1987).

The high prevalence of ankle injuries places a burden on time and financial resources. Complete rehabilitation has been reported to take 36-72 days with a cost of $300-$900 per patient, without considering surgical cases (Perlman et al., 1987). It has also been estimated that the evaluation and treatment of ankle injuries may amount to an annual aggregate cost of approximately 2 billion dollars (Fallat et al., 1998). From a time perspective, approximately 6% of people with repeated ankle injuries remain limited in their occupation and up to 15% report being limited for 9 months-6.5 years (Arnold et al., 2011; Schaap, Dekeizer, & Marti, 1989; Verhagen, Dekeizer, & Vandijk, 1995). Therefore, ankle injuries present a significant risk to health and quality of life. However, it is reasonable to expect that these trends will remain consistent or increase as more individuals engage in physical activity (Arnold et al., 2011).

FUNCTIONAL ANATOMY OF THE ANKLE

Ankle injuries, especially to the stabilization ligaments, are the most frequent injuries in physical activity. This is due primarily to the interaction of the bones and ligaments that provide static anatomical support to the ankle joint.

The ankle joint (aka talocrural) is comprised of four main bones including the tibia, fibula, talus, and calcaneus. Although the other tarsal bones are essential in overall movement and function of the foot, they will not be discussed in the realm of this study. The tibia is the 2nd longest bone in the body and serves as the primary weight bearing bone of the leg. It lies on the medial side of the leg and is triangular shaped in the proximal two thirds but rounded in the distal third. The fibula is a long slender bone on the lateral aspect of the leg and has a minimal weight-bearing role (<10%). The primary purpose of the fibula is muscle attachment. Distally, the tibia and fibula form a syndesmosis joint, which is a fibrous articulation. The distal end of the tibia and fibula form the medial and lateral malleoli respectively. The fibula extends more distally than the tibia, which allows more boney stability on the lateral aspect. The malleoli serve as attachment sites for ligaments of the ankle. The talus is one of the largest tarsal bones and forms the link between the leg and foot. It has a large weight-bearing component and articulates with the calcaneus (inferiorly) and the medial and lateral malleoli. Lastly, the calcaneus forms the heel bone and is the site of many ligamentous attachments of the ankle joint, as well as the Achilles tendon (Prentice, 2009).

The ankle joint is also described as an ankle mortise, which is formed by the tibia (superior and medial), fibula (lateral), and the talus (inferior) called the talocrural joint. There are several degrees of freedom allowed at the ankle complex because of the mortise shape. The rearfoot, composed of the subtalar joint, consists of the articulation of the talus and calcaneus and allows for inversion, eversion, pronation, and supination to occur. The square shape of the talus also contributes to ankle stability because it is wider anteriorly than posteriorly. Therefore, in the dorsiflexed position, the ankle is in a close-packed position because the wider anterior aspect grips the narrow anterior portion of the malleoli. Conversely, the wider portion of the tibia receives the narrower portion of the talus when the ankle is moved into plantarflexion. This motion makes the plantarflexed position much less stable and compromises stability. Normal function of the ankle and foot depends largely on the subtalar joint and motion occurring in the rearfoot (Prentice, 2009). The coordination of the plantarflexion/dorsiflexion, inversion/eversion, and adduction/abduction movements allow for smooth congruent movement simultaneously in all three planes of motion.

The stabilizing ligaments of the ankle provide additional static support to the articulations of the bones. Connecting the tibia and fibula are the tibiofibular ligaments, which create a strong interosseus membrane in the syndesmosis joint. The oblique arrangements of these fibers allows for diffusing of forces placed on the leg. The primary static restraint on the medial side is the triangular shaped deltoid ligament. The deltoid ligament is comprised of four parts including the anterior tibiotalar, tibionavicular, tibiocalcaneal, and tibial talar part. The deltoid ligament attaches superiorly on the medial malleolus and inferiorly on the medial surface of the talus, the sustentaculum tali of the calcaneus, and the posterior margin of the navicular bone. The deltoid ligament resists eversion of the ankle and also helps support the longitudinal arch along with the calcaneonavicular (aka spring) ligament. On the lateral aspect there are three main static supports including the anterior talofibular (ATF), posterior talofibular (PTF), and calcaneofibular (CF) ligaments. The ATF and PTF limit anterior and posterior translation of the talus respectively and the CF limits calcaneal inversion. Due to the orientation of these ligaments, there is more range of motion (ROM) allowed in inversion compared to eversion. The arrangement of the medial and lateral ligament structures allows for dorsiflexion and plantarflexion of the talocrural joint and limits eversion and inversion at the subtalar joint. (Prentice, 2009).

The ankle musculature is innervated anteriorly by the superficial and deep peroneal nerves and posteriorly by the tibial nerve. Although motion rarely occurs in a single, isolated plane, the muscles of the ankle do have individual actions (Hertel, 2002). The tibialis anterior, extensor digitorum longus, and extensor hallicus longus all act to dorsiflex the ankle. The peroneus longus and brevis act to evert the ankle with the longus inserting on the 1st ray of the metatarsals and the peroneus brevis inserting on the base of the 5th metatarsal. The gastrocnemius and soleus muscles combine to form the triceps surae, which inserts on the calcaneus via the achilles tendon and acts to plantarflex the ankle. The tibialis posterior, flexor digitorum longus, and flexor hallicus longus pass along the medial aspect of the ankle and act to invert the ankle (Prentice, 2009). When contracted, the musculotendinous units generate tension, which leads to dynamic protection of joints. When considering dynamic stability, it is more important to consider the muscles eccentric action. The peroneus longus and brevis muscles concentrically create eversion, but eccentrically they control supination and inversion of the rearfoot and protect against lateral ankle sprains (Hertel, 2002). Although static and dynamic structures act to control movement, only dynamic structures can initiate movement (Hertel, 2002).

Isolated motion rarely occurs within the individual joints of due to the complex approximation of joints and joint angles. The isolated motions include: plantarflexion and dorsiflexion in the sagittal plane, inversion and eversion in the frontal plane, and internal and external rotation in the transverse plane. Functional movement occurs around an oblique axis due to the orientation of the subtalar and talocrural joint. Pronation and supination are the culminating motions that occur as a result of the movement allowed at all three joints. Restricted motion in any of the three joints can lead to obligatory compensatoin other joints. Pronation in the open chain condition consists of dorsiflexion, eversion, and external rotation, while supination in the open chain is comprised of plantarflexion, inversion, and internal rotation. In the closed chain (i.e. during weight bearing), pronation consists of plantarflexion, eversion, and external rotation, while supination consists of dorsiflexion, inversion, and internal rotation. Together, these joints also contribute to static stability due to the bony congruency of the articulating surfaces, the static ligamentous support, and the musculotendinous structures that supply dynamic stability (Hertel, 2002).

ETIOLOGY

The unpredictable nature of physical activity leads to an inherent risk for injury. Ankle injuries in particular are increasingly common due to the complex movement that occurs at the joints during dynamic activities. Individuals who participate in a wide variety of tasks that require jumping and landing, cutting, decelerating, and changing directions are particularly vulnerable to these injuries. Basketball, volleyball, and soccer, are examples of sports that require aforementioned movements that can stress the ankle to its structural limitations, and can result in injury.

The mechanism of injury for most lateral ankle sprains may seem simple in nature but the exact causes are often more complex. Injury occurs, when the straining force on the ligaments exceeds the tensile stress of the tissues (Hertel, 2002). Hertel and colleagues (2002) suggests that lateral ankle sprains occur when the rearfoot undergoes excessive supination on an externally rotated tibia. Excessive inversion and internal rotation at the subtalar joint, coupled with external rotation of the tibia results in strain to the lateral ankle ligaments. Excessive plantarflexion can also increase the likelihood of injury creating an open-packed position of the talocrural joint (Hertel, 2002). In a study by McKay and colleagues (2001) of over 10,000 basketball players, the varying mechanisms of injury were ranked from most common to least common. The most common mechanism of ankle injury during basketball occurred during landing (45%) either on another players' foot or on the court surface. Other mechanisms included sharp twist/turn (30%), collision (10%), and fall (5%) (McKay et al., 2001).

Wilkerson and colleagues discuss how the talus is the key structure when examining ankle pathomechanics (Wilkerson, 2002). The talus is the key linking structure between the leg and the foot, making the subtalar joint the point of integration for the proximal talocrural joint and the distal transverse tarsal and lateral tarsometatarsal joints. In weight bearing, these joints act as a torque converter, distributing ground reaction forces to the proximal structures. Rotation at one segment must be coupled by rotation at another. When the lateral border of the foot inverts, the transverse tarsal and subtalar joint lock in full inversion while the tibia externally rotates (Wilkerson, 2002). The combination of these motions, and the force by which they are produced, puts significant stress on the ATF and CF ligaments in particular, often pushing them to their anatomical limit, resulting in injury.

FUNCTIONAL ANKLE INSTABILITY

Although the acute lateral ankle sprain is considered primarily a local event, the associated dysfunction is often overlooked. The noticeable anatomical changes such as hemorrhage and edema are present but the neuromuscular changes are typically less evident in appearance (Beckman & Buchanan, 1995). As with any other musculoskeletal injury, it is important to consider the implications of even a minor injury altering the kinetic chain.

DEFINITION

The first definition of FAI was proposed by Freeman and colleagues (1965) and was described as an ankle that displays repeated sensations of “giving way” following initial injury (Freeman et al., 1965). Specific definitions of FAI have changed since 1965 but the basic principle still applies. Konradsen and colleagues (1990) added to Freeman’s definition by including recurrent ankle sprains and a sensation of joint weakness as contributing to the definition. (Konradsen & Ravn, 1990). The common trend throughout the classifications of FAI is some culmination of mechanical instability and articular deafferentation after injury to the lateral structures (Gutierrez et al., 2012). Distinguishing whether the injurious episode is acute or chronic also can lead to varying terminology and definitions. Chronic ankle instability denotes the occurrence of repeated bouts of lateral ankle instability, resulting in numerous ankle sprains (Hertel, 2002).

For the purposes of this study, the definition of FAI were broader than Freeman’s definition in 1965 to include to occurrence of recurrent joint instability and the sensation of joint instability due to the neuromuscular deficits associated with injury. The neuromuscular deficits are likely due to the injury to the musculotendinous and neural receptors. These deficits can be manifested as impaired balance, reduced joint position sense (JPS), decreased motor unit activation, decreased nerve conduction velocity, impaired cutaneous sensation, impaired strength, and decreased ROM (Hertel, 2000).

PREDISPOSING FACTORS

Previous History of Injury

Literature is in consensus that the greatest predisposing factor to ankle sprain is having a previous history of at least one ankle sprain (Bahr & Bahr, 1997; Beynnon et al., 2002; Hertel, 2002; McKay et al., 2001; Milgrom et al., 1991). After injury there are associated mechanical deficiencies, such as ligament laxity, and neural deficiencies such as deafferentation and proprioceptive deficits (Hertel, 2000). Proprioceptive deficits include damage to the mechanoreceptors, which are abundant in ligaments and tendons at the ankle (Michelson & Hutchins, 1995; Takebayashi, Yamashita, Minaki, & Ishii, 1997). Decreased sensitivity of these receptors leads to altered joint position sense (JPS) and decreased control. Mechanoreceptors are most active at end range of motion and respond to changes in tension. They are essential in preventing injury to limit excessive stress and deformation of the tissue surrounding the joint (Hertel, 2000). However, the tensile strength of these receptors is less than that of connective tissue, and when mechanoreceptors are damaged, the decreased afferent message compromises the joint receptor sensitivity and postural reflex responses, which predisposes the joint to further injury (Freeman et al., 1965). Increased risk of recurrent injury involves the close interactions between the mechanical (both static and dynamic stabilizers), and neural systems (mechanoreceptors) that maintain ankle stability following injury. High injury recurrence rate illustrates how ineffective these systems are at regaining ankle stability following initial injury. Certainly the cause is not due to mechanical or neural deficits alone, but a combination of the systems (Fallat et al., 1998; Hertel, 2002).

Fatigue

There are several other risk factors involved in ankle sprains. Gribble and colleagues (2004) discuss how fatigue can disrupt the afferent feedback of the muscle spindle discharge, which alters joint awareness (Gribble et al., 2004). In a group of 30 subjects (16 healthy, 14 chronically instable) Goldie and colleagues (2004) measured the effects of fatigue on a dynamic stabilization task known as the Star Excursion Balance Test (SEBT). Through a series of 5 fatiguing tasks including isokinetic ankle fatigue, isokinetic knee fatigue, isokinetic hip fatigue, lunging tasks, and a control group, subjects performed the star excursion task in the anterior, medial, and posterior direction. Results found a significant difference in maximum reaching distance between the group and side interaction (anterior $p=.026$, medial $p=.022$, posterior $p=.013$) indicating the detrimental effect of muscle fatigue contributing to joint stability (Gribble et al., 2004). Altering joint awareness changes the joint proprioception and kinesthetic properties, which may predispose it to injury.

Extrinsic Factors

In a prospective study of 10,000 basketball players, McKay and colleagues (2001) found shoe type and a lack of stretching during warm up to be other significant predisposing factors to ankle injury in basketball players. Goldie found that shoes with air cells located in the heel of the shoe made athletes 4.3 times ($p=.01$) more likely to suffer and ankle injury. He proposed that this was due to the heel counter decreasing rearfoot stability (McKay et al., 2001).

Intrinsic Factors

McKay and colleagues (2001) noted that not stretching the posterior muscles of the gastrocnemius and achilles increased injury risk by 2.3 times ($p=.03$). Tight gastrocnemius muscle causes increased plantarflexion and supination at heel strike, making the joint unstable in the open-packed position (McKay et al., 2001). Other intrinsic factors such as foot type, muscle strength, and muscle reaction time could also be predisposing factors for initial ankle injury. However, research on these topics is controversial due to the different classifications of foot types and parameters to measure strength and reaction time (Beynnon et al., 2002).

Landing Mechanics

Freeman and colleagues (1965) discussed how FAI could result from delayed reflex responses to stress on the ankle as a result of damage to the joint receptors during initial injury (Freeman et al., 1965). Konradsen and colleagues (1997) however suggested that dynamic control of the ankle is achieved by feed-forward mechanisms of the CNS rather than by feedback mechanisms from the peripheral reflexes (Konradsen et al., 1997). Subjects with FAI show altered movement patterns during landing tasks, prior to initial ground contact, such as increased hip flexion and hip external rotation (Cathleen N. Brown, Padua, Marshall, & Guskiewicz, 2011). These differences may arise out of compensations over time that alter normal mechanics and make the joint less efficient at dispersing forces. Caulfield and colleagues (2004) found changes in timing and magnitude of peak forces exhibited in subjects with FAI during jump landings (Caulfield & Garrett, 2004). These changes are due to faulty pre-programming of the ankle joint motion immediately pre- and immediately post-impact. The alterations are likely a result of increased stress placed on the static ankle structures and could result in repeated injury. Within the first 0-50ms post-impact, peak lateral force occurred approximately 13ms earlier in subjects with FAI. This caused subjects with FAI to bear 5-15% of their body mass with increased laterally directed forces, while control subjects bore the same forces medially. Garrett and colleagues (1999) discussed how reflex response would not be possible at this stage because the monosynaptic reflex latency of the ankle is 35-40ms, meaning the injurious force would occur before the protective reflex activation (Garrett, Kerr, & Caulfield, 1999). Caulfield and colleagues (2004) also discussed how subjects with FAI displayed a greater vertical component of ground reaction force (GRF). The rapid increase in vertical GRF reflects an inability to control the rate of weight distribution and force absorption capacity of the ankle and knee (Caulfield & Garrett, 2004). The tasks described above are directly related to the demands of sport and the importance of dynamic stability in preventing recurrent ankle injury.

RESIDUAL SYMPTOMS AND DEFICITS

Residual symptoms following a lateral ankle sprain affect 55-72% of patients after 6 weeks to 18 months (Hertel, 2002). Because of the prolonged symptoms and functional deficits following injury, the term *"sprained ankle syndrome"* has been developed to emphasize the point that there is no such thing as a simple ankle sprain (Fallat et al., 1998; Hertel, 2002; McKay et al., 2001). There are different ways an ankle injury can manifest as a long-term, chronic condition. Mechanical ankle instability is caused by factors that affect the structural stability of the joint including ligament laxity, synovial inflammation, articular degeneration, or altered arthrokinematics. Chronic ankle instability (CAI) refers to the occurrence of repetitive bouts of lateral ankle instability, resulting in numerous ankle sprains (Hertel, 2002). FAI is a culmination of these factors that manifests as specific deficiencies in proprioception, neuromuscular control, postural control, and neuromuscular strength.

Balance

It is well documented that there are significant deficits in balance following lateral ankle sprains (Garrick, 1977; Goldie et al., 1994; Lentell et al., 1995; Tropp, Ekstrand, & Gillquist, 1984). These balance deficits are typically measured with a single leg stance on the injured limb while examining postural sway. In a landmark study by Freeman and colleagues (1965), 85 subjects with recent ankle sprains underwent testing to detect proprioceptive deficits following ankle sprains and the effects of coordination training on ankle instability. In order to detect proprioceptive deficits, they used the Rhomberg test, which required single-leg standing on the involved and uninvolved side with eyes open and eyes closed. Although several subjects were excluded from the proprioceptive testing due to pain or stiffness following injury, they found that 34% of subjects displayed proprioceptive deficits while performing the single-leg balance task (Freeman et al., 1965). The limitation of this study, however, is the Rhomberg test is a subjective assessment of balance and lacks sensitivity and objectivity (Guskiewicz & Perrin, 1996). More recently, technological advancements have allowed for more objective measures of balance and isolation particular deficits in sensory organization. The use of force plates, multiaxial tilting platforms, and the sensory organization tests are examples of more advanced and objective measurements of balance.

Postural sway is defined as the deviation from the mean center of pressure (COP) of the foot (Tropp, Eckstrand, & Gillquist, 1984). Postural sway is objectively measured using a piezoelectric force plate measuring the magnitude and direction of the sway in GRF. Symmetry is the ability to distribute forces evenly between two feet in an upright stance. Dynamic stability is the ability to transfer center of gravity (COG) around a supporting base (Goldie, Bach, & Evans, 1989; Guskiewicz & Perrin, 1996). Brown and Mynark (2007) examined the effects of ankle instability on dynamic stability measured with TTS. The study found that anterior/posterior TTS values were significantly different between the non-injured (0.71s ± 0.09) and injured groups (0.78s ± 0.12) (p=.04) (C. N. Brown & Mynark, 2007).

Joint Position Sense (JPS)

Following initial ankle injury, there are reductions in JPS and the ability to detect passive ankle motion (Garn & Newton, 1988; Lentell et al., 1995). JPS is defined as the ability to replicate joint movement or position in space (Garn & Newton, 1988; Gross, 1987). Garn and colleagues (1988) found evidence of diminished awareness of passive plantarflexion following repeated ankle sprains (Garn & Newton, 1988). Even without a previous history of ankle injury, diminished JPS is seen as a predictor of ankle injury due to the inability to comprehend the joint position appropriately in space (Hertel, 2000). Lentell and colleagues (1995) found that subjects with unstable ankles had demonstrated significant deficits in passive inversion. Forty-two subjects with chronic ankle instability were tested for passive movement sense with a moveable-platform box. The study found that passive movement sensation was significantly different between the involved and uninvolved ankle (mean 4.3^{o} involved ankle, mean 3.2^{o} uninvolved ankle, p=.01), meaning the injured ankle could not detect changes in movement compared to the uninjured. A diminished awareness of passive movement may be responsible for the documented delays in muscle reflex activity (Lentell et al., 1995). Conversely, Gross (1987), in a study of 21 subjects, found that there was no significant difference in an individual's ability to judge ankle position regardless of unilateral ankle injury. However, he did find that passive motion was significantly better at detecting position than active motion among subjects who never complained of ankle pain (Gross, 1987).

Delayed Peroneal Activation

Along with the altered JPS, FAI can cause delayed reaction time of the peroneal muscle group compared to an uninjured subject. The peroneal muscle groups play a crucial role in dynamic stability of the ankle because they are the first to contract in response to a sudden ankle inversion mechanism (Konradsen & Ravn, 1990; Konradsen et al., 1997; Palmieri-Smith et al., 2009). Konradsen and colleagues (1997) examined the peroneal muscles reaction time to a sudden inversion mechanism and found that the involuntary reflex response was too slow to prevent injury to the static ligamentous structures (Konradsen et al., 1997). Ten volunteer subjects with mechanical ankle instability were tested in different standing and walking situations using an inversion trap-door model. The trap door was set to 30^o degrees in the frontal plane to control the magnitude and onset of the inversion mechanism. Kondradsen and colleagues (1997) found that peroneal EMG activity was detected at 54ms following inversion (Konradsen et al., 1997). Subjects with previous history of ankle injury have shown significantly slower reaction times in the peroneus longus, peroneus brevis, and tibialis anterior. Konradsen and Raven (1990) found decreased peroneal activation in a group of 15 unstable subjects compared to 15 stable subjects in a similar trapdoor study (Konradsen & Ravn, 1990; Konradsen et al., 1997). The increased delay of the peroneal reaction time with FAI, contributes to the continuing neural deficits associated with FAI.

Altered Hip Musculature

Numerous studies have examined how ankle injury has implications for altering hip strength and movement patterns up the kinetic chain (Beckman & Buchanan, 1995; Cathleen N. Brown et al., 2011; Bullocksaxton, 1994; Friel, McLean, Myers, & Caceres, 2006). Brown and colleagues (2011) examined changes in hip kinematics during a stop-jump landing task in 63 subjects with chronic ankle instability. They divided subjects into 3 groups: mechanical instability, FAI, and "copers", defined as having repeated history of ankle sprains without instability, and found that subjects with distinct instability displayed significantly greater hip flexion at initial contact, maximum hip flexion, hip external rotation, and hip flexion displacement during the landing task. They cited laxity of the lateral ankle as explanation for altered hip kinematics and altered sagittal plane motion causing increased compensation in the hip (Cathleen N. Brown et al., 2011).

Bullock-Saxton (1994) stated that the altered sensory deficits associated with injury may initiate a chain adaptation of reactions, resulting in altered movement patterns. In a study of 31 subjects (20 previous history ankle sprain), she used vibration stimulus of the ankle to detect EMG changes in the muscle recruitment patterns for hip extension (biceps femoris, gluteus maximus, and lumbar erector spinae). Results found significant delays in gluteus maximus onset of the injured group compared to the control group. The author stated that even though this study could not determine a cause and effect relationship, its findings supported the idea of the reflex chain of events that occur following injury (Bullocksaxton, 1994).

Hertel (2000) states that individuals with a previous ankle sprain will use a hip strategy for balance rather than an ankle strategy. The ankle strategy occurs when muscle contractions first fire at the ankle joint and cause a torque moving the body towards the stable surface. Conversely, the hip strategy occurs when hip flexion or extension is used to move towards the stable surface (Hertel, 2000). Brown and colleagues (2011) discuss how healthy adults can use an ankle strategy of stabilization where the center of gravity can be supported within the ankle joint. After injury however, individuals must utilize a more central hip strategy of stabilization, which explains the increased hip flexion and external rotation motion during the stop jump-landing task. Altering hip mechanics during a landing task has implication for injury else where along the kinetic chain including the knee, hip, and back (Cathleen N. Brown et al., 2011).

Muscular Strength

Research on strength deficits associated with lateral ankle sprains is inconclusive due to the varying parameters used to assess muscular strength at the ankle. Studies often use different isokinetic dynamometers at inconsistent speeds, which are typically measured at slower speeds than functional activities (Hertel, 2000). Also, these tests are often performed in an open kinetic chain position and measure concentric muscle strength, making them less applicable to their role in dynamic stability. Kondradsen and colleagues (1998) found that there were significant deficits in evertor strength in subjects with FAI. This study used isometric, open chain force plate testing to measure the evertor strength and found that eversion strength was 88% of the normal side at 3 weeks post injury, and 96% of the uninjured side 12 weeks post injury (p=.04) (Konradsen, Olesen, & Hansen, 1998). However, Ryan and colleagues (1994) reported significant weakness in inversion (22.7N) of the injured ankle but no significant strength deficits in eversion (26.6N) when measured via Cybex II dynamometer (Ryan, 1994).

The eccentric strength of the peroneals also plays an important role in dynamic stability. Palmieri-Smith and colleagues (2009) discuss how arthrogenic muscle inhibition (AMI) can inhibit muscle strength and function following ankle injury (Palmieri-Smith et al., 2009). The study involved testing 42 subjects (21 unstable, 21 stable) as they walked down a pathway with bilateral trapdoor capabilities to 30^o inversion. The unstable group demonstrated decreased reflex response of the injured limb, suggesting inhibition of the peroneal alpha-motorneurons, meaning decreased motorneurons available for recruitment. The healthy, uninjured population did not display side-to-side differences in reflex response, which strengthens the argument that peroneal AMI is present following injury (Palmieri-Smith et al., 2009). Ryan (1994), in a group of 45 subjects, also reported diminished strength in both the invertor and evertor muscles following injury (Ryan, 1994). Subjects performed muscle strength tests with the dynamomter, instability tests, and balancing tests assessing the extent of neuromuscular deficits. He found a significant difference in strength of the invertor muscles between the affected and unaffected ankle using a Cybex II dynamometer. Results however, found no significant difference in the strength of the evertor muscles in the affected and unaffected side. Ryan (1994) cited that order effect and learning effect was a limitation of his study that could have contributed to the closeness of the values. (Ryan, 1994).

Although strength deficits in the evertors are under debate, the overall presentation of FAI as a syndrome can manifest as ankle "weakness" (Konradsen & Ravn, 1990).

The contributing factors of FAI create a cycling effect that has led to further use of the term *syndrome* to describe ankle sprains. These compounding factors make FAI a truly debilitating condition that is difficult to address and manage in the effort to return an individual to normal function.

WHOLE BODY VIBRATION

HISTORY

A recent exercise modality that has increased in popularity is whole body vibration (WBV) units. Sanders (1936) and Whedon and colleagues (1949) studied vibration training using an oscillating bed as means to counteract cardiovascular and musculoskeletal deconditioning. Nazarov and Spirak (1985) were the first to apply vibration training to the athletic setting as an exercise modality in 1985 (Nazarov & Spivak, 1985). Since then, vibration training has emerged as a common rehabilitative and performance enhancement device among many clinicians in the health and exercise setting (Cloak et al., 2010).

PHYSIOLOGICAL EFFECTS

The definition of vibration is a mechanical oscillation with periodic alterations of force, acceleration, and displacement over time. Vibration training is when the force is transferred from an actuator (i.e. the vibration device) to a resonator (i.e. the human body) and the perception for the patient is similar to that of downhill skiing due to ranging and banging of the feet on the device (Rittweger, 2010). The exact physiological effects of vibration training are still controversial and to the authors' knowledge, there are only two comprehensive reviews on the topic of vibration training as an exercise modality (Rittweger, 2010; Sitja Rabert et al., 2012). The proposed benefits of whole body vibration training (WBVT) include: enhanced muscle spindle activation due to the alternating changes in muscle length and tension, joint-receptor activity due to the repetitive loading of the joints mimicking rapid landings, central nervous system (CNS) stimulation due to the enhanced mechanoreceptor activity, improved strength and power due to repeated muscle contractions, and improved balance and postural control due to a combination of all other factors (Abercromby et al., 2007; Cloak et al., 2010; Pollock, Provan, Martin, & Newham, 2011; Rittweger, 2010; Torvinen et al., 2002b). Other physiologic changes include increases in: stimulation of skin receptors, skin and muscle profusion, neurotransmitter and hormone concentration, energy metabolism, intramuscular temperature, and improved bone health (Moezy et al., 2008; Rittweger, 2010; Schuhfried, Mittermaier, Jovanovic, Pieber, & Paternostro-Sluga, 2005). Bogaerts and colleagues (2007) discussed how the strong mechanical stimuli are transmitted to the body and stimulate the primary endings of the muscle spindles, which cause further sensory stimulation of other proprioceptors (Bogaerts et al., 2007). The exact physiologic mechanisms by which these other biologic responses such as changes in cell metabolism and intramuscular temperature will not be covered in this thesis, as it is not the primary goal.

WBV IN ELDERLY POPULATION

Currently, there are a number of studies investigating at the use of WBV units with the elderly population. Benefits of exercise in the elderly population are well documented, and WBV has been demonstrated as an effective adjunct to exercise programs aimed at reducing the predisposing factors associated with falls, improving osteoporosis through increased bone mineral density, and improving walking ability (Bogaerts et al., 2007; Kawanabe et al., 2007; Moezy et al., 2008). It is suggested that WBV applies a stimulus to the body, which is similar to those produced by traditional exercise, but without the associated risk of falls. The alternating lengthening and shortening of muscles and tendons is thought to mimic the stresses of exercise training (Rittweger, 2010). Cheung and colleagues (2007) found that 75 elderly subjects improved balance after 3 months of WBV treatment. Subjects stood on the WBV platform operating at a frequency of 20Hz 3 minutes a day, 3 days a week. The whole body vibration groups significantly improved movement velocity (deg/s), maximum point excursion, and direction control measured via postural sway on a force plate. Cheung and colleagues (2007) attributed the balance improvements to increased recruitment of muscle fibers, muscular adaptation, and neuromuscular coordination with WBV (Cheung et al., 2007).

Bruyere and colleagues (2005) also used WBV and physical therapy to improve muscle function and potentially reduce the risk of falling. This study had a control and WBV group perform therapy including gait and balance training, weight transfer skills, and strengthening exercises 3-times per week, only to find that the group with the adjunct of WBV significantly improved their muscular strength and balance (Bruyere et al., 2005).

WBV EFFECTS ON MUSCULAR STRENGTH

In the athletic setting, WBVT is thought to improve muscular strength, muscular power, and flexibility. The increases in muscular strength are suggested to be a result of the tonic vibration reflex (TVR), which is provoked by length changes in the muscles that stimulate the muscle spindles primarily through type Ia afferents (Cormie, Deane, Triplett, & McBride, 2006; Mahieu et al., 2006). TVR is composed of motor unit activity that is synchronized and unsynchronized within the vibration cycle (Martin & Park, 1997). It has also been proposed that the strength improvements are due to a lowering of the motor recruitment threshold during WBV, resulting in a more rapid activation of high-threshold motor units (e.g. fast twitch fibers), resulting in a greater summation of motor units (Delecluse, Roelants, & Verschueren, 2003; Mahieu et al., 2006; Rittweger, Beller, & Felsenberg, 2000).

Torvinen and colleagues (2002) found that there was a significant increase in vertical jump height after two months of WBV, and an increase in isometric lower extremity strength in a group of 23 young, nonathletic subjects (Torvinen et al., 2002b). Although scarce, the literature on WBV in sports medicine supports the use of WBV as a means of improving muscular strength and power and tissue extensibility (Issurin, Liebermann, & Tenenbaum, 1994; Mahieu et al., 2006; Rittweger, 2010). Mahieu and colleagues (2006) examined the improvements in muscular strength in a group of 33 competitive skiers. They found increases in high box jump test with the adjunct of WBV over a 6-week training period ($p<.001$, effect size 0.72). Because both groups displayed increased repetitions on the high box test, a comparison between groups revealed the WBV group increased scores by 13.53 ± 9.79cm, while the resistance training group increased high box test scores by 5.44 ± 7.66cm ($p=.013$, effect size .92) (Mahieu et al., 2006).

The acute benefits of WBV on muscular strength are conflicting in research primarily due to the differing parameters used in the studies. In an acute setting, WBV has been found to increase norepinephrine levels and increase power output in the arm flexion movement (Bosco et al., 2000; Cormie et al., 2006). In a study of 9 men, Cormie and colleagues (2006) found acute increases in vertical jump height of the WBV group versus and sham treatment group immediately performing a non-fatiguing intervention. Jump height increased from 49.02 ± 7.58cm at baseline to 49.34 ± 7.17cm immediately post WBV intervention, whereas the sham group decreased jump height scores from 50.67 ± 7.13cm to 49.34 ± 6.9cm immediately post ($p<.05$ between groups). They concluded that WBV would be a valuable adjunct to a warm-up because of the enhanced jump height associated with treatment (Cormie et al., 2006). Rittweger and colleagues (2000) conversely found that vertical jump height was lessened after acute exposure to WBV in a group of 37 subjects. However, the intervention that was used in this study consisted of a fatiguing task before measuring vertical jump, which would account for the diminished jump height (Rittweger et al., 2000).

WBV EFFECTS ON BALANCE

The effects of WBV on balance and dynamic postural control are not well supported in younger populations. Improvements in balance after WBV are supported in the elderly population, partially due to balance deficits associated with aging. In a more athletic population, the need for dynamic stability is essential due to the unpredictable nature of sport, particularly those that require jumping, reacting, and cutting maneuvers. Moezy and colleagues (2010) determined that WBV training elicited greater improvements in joint stability and balance in individuals with anterior cruciate ligament repairs, when compared to conventional training groups (Moezy et al., 2008). The WBV group performed exercises alternating between static and dynamic squats, lunges, and balancing tasks. They claimed the repetitive nature of the stimulus might cause change in the balance control strategies, causing overall improvements in postural stability. The study found significant differences between WBV and control groups overall stability indices, anterior/posterior stability indices, and medial/lateral stability indices. These changes may be due to the beneficial effects of WBV on muscle strength, improved synchronization of motor unit firing (indicating more efficient signal activation), and improved co-contraction of synergist muscles, which would improve postural control (Moezy et al., 2008). Cloake and colleagues (2010) also reported balance improvements in the anterior, medial, and anteromedial direction after a 6-week training intervention in a group of professional dancers with FAI during a SL stance. They implemented a training protocol, which consisted of single leg (SL) balance task and the star excursion balance test (SEBT) twice a week, over a 6-week period. This study was in contrast with other current research that measured balance for periods greater than 8-weeks with more than three training sessions per week. However, the author notes that the study sample had outstanding balancing ability prior to injury, which could also contribute to higher scores (Cloak et al., 2010).

There is tremendous variability in the literature in quantifying and measuring balance as well as improvements in balance. It is also difficult to make clinical applications of balance measures because they are often done in a static position that rarely utilized in everyday life. The studies investigating improvements in fall prevention in the elderly were careful to say that the improvements were in muscular strength and balance, which are only predictive factors for falls. Rees and colleagues (2009) stated that their vibration-training program with WBV reflecting that practicing and learning a motor skill could be responsible for the measured improvements (Rees, Murphy, & Watsford, 2009). Likewise Pollock and colleagues (2011) in a study of 18 subjects, stated the lack of change in balance could be due to the relatively simple tasks performed with the adjunct of WBV, and that the effects of more challenging tasks is unknown (Pollock et al., 2011). Their subjects performed 5x1 minute bouts of WBV prior to measuring JPS, cutaneous sensation, and balance. Clinically, balance has a multifaceted meaning that should be considered when interpreting results.

WBV EFFECTS ON EMG

The most likely mechanism by which WBV elicits motor output changes is through the tonic-vibration reflex (TVR). TVR is provoked by the stimulation of type Ia afferent fibers and is composed of both synchronized and unsynchronized motor unit activity with the vibration cycle (Martin & Park, 1997). It has also been suggested that WBV elicits a type Ia-afferent-mediated myotatic (stretch) reflex, eliciting muscle contraction (Delecluse et al., 2003; Rittweger et al., 2000). These changes in motor output are detected through EMG recordings of specific muscles involved in the specific task. WBV causes increased stimulation of the muscle spindles and subsequent increased EMG activity.

Abercromby and colleages (2007) proposed that changing muscle length through varying position and fiber tension would increase type Ia afferent sensitivity. Therefore, the responses of WBV would be greater in magnitude during eccentric contractions than during isometric and concentric contractions. The proposed effects of postural variation would change EMG readings at the vastus lateralis, biceps femoris, gastrocnemius, and tibialis anterior. Abercromby and colleagues (2007) found a significant effect of muscle length on neuromuscular response to WBV, and that WBV-increased muscle activation may minimize the potentially damaging effects of vibration via muscle tuning (Abercromby et al., 2007).

Muscle tuning is defined as dampening that occurs in soft tissue as a response to direct mechanical stimulation (Wakeling, Nigg, & Rozitis, 2002). Similar to shock distribution during heel strike in walking and running, muscle tuning increases dampening coefficient so that surrounding soft tissue can reduce tissue resonance (Wakeling et al., 2002).

Prolonged exposure to WBV can elicit EMG measurements that would appear as though the muscle is fatigued (Rittweger et al., 2000). Rittweger and colleagues (2000), in a study of 37 subjects, found significant rapid and slow-onset fatigue with the exhaustive WBV exercises. Subjects underwent initial fatiguing test on the bicycle ergometer, followed by two subsequent fatiguing tests with WBV including squatting and vertical jumping. After the first WBV fatiguing tasks, researchers found a significant difference in the following variables compared the bicycle ergometer (BE): increased perceived exertion, decreased heart rate (171±16 BE, 122±28 WBV), specific oxygen uptake (44.8±7.9 BE, 21.3±4.0 WBV), lactate production (7.7±2.7 BE, 3.5±1.6 WBV), respiratory quotient (0.98±.05 BE, .90±.08 WBV), systolic blood pressure (148±18 BE, 132±16 WBV), and diastolic blood pressure (65±15 BE, 52±14 WBV). They stated that the WBV fatigue was not associated with cardiac insufficiency but rather the neuromuscular system (Rittweger et al., 2000). Fatiguing of the TVR decreases voluntary force until 10-20 seconds after the end of vibration, affecting the ability to fire high threshold motor units. There is also a proposed fatiguing of the Ia afferent fibers themselves (Rittweger et al., 2000).

EMG recordings with WBV studies are taken with surface electrodes placed over the muscle belly of the desired muscle, with the ground electrode on a bony landmark. Intramuscular EMG is difficult to obtain due to the inherent electromagnetic noise associated with WBV.

GAPS IN WHOLE BODY VIBRATION LITERATURE

Because WBV is a relatively new modality that is not well supported by evidence in the sports medicine community, clinicians are hesitant to use these devices as adjuncts to their rehabilitation practices. However, emerging popularity of these devices cannot be ignored, and there are several gaps in the literature that should be investigated as the prevalence of these machines increases in the realm of exercise and sport science.

Perhaps the most apparent gap in WBV research is the population used in randomized-controlled trials. There is a large amount of research conducted with an elderly population looking at the benefits of WBV on fall prevention and walking ability. More current research has moved to looking at the benefits of WBV on a healthy, younger population, and even moving into an athletic population (Cormie et al., 2006; Mahieu et al., 2006; Torvinen et al., 2002b; Torvinen et al., 2003). The proposed improvements in muscular strength are useful for the athletic community, but research is lacking and inconclusive on precise benefits.

There is minimal research on the use of WBV in an injured athletic population. In a study of professional dancers with FAI, Cloake and colleagues (2010) stated the greatest difficulty was developing a training protocol for subjects due to the lack of objective evidence in support of the use of WBV in FAI patients (Cloak et al., 2010). Therefore, there is a gap in the literature in applying these benefits to the injured athletic population. Currently there are no studies that measured the effects of WBV on functional, and dynamic tasks required in sport.

Another gap in WBV research involves the parameters of treatment. In particular, most studies investigated the effects of WBV after a long-term intervention period (Cloak et al., 2010; Mahieu et al., 2006; Melnyk et al., 2009; Torvinen et al., 2002b; Torvinen et al., 2003). Few studies investigated the acute effects of WBV on muscle strength, muscle power, and postural stability. Rittweger and colleagues (2003) examined the acute neuromuscular effects of WBV after a period of exhaustive exercise (Rittweger et al., 2003). The associated fatigue effects of exhaustive exercise make it difficult to make claims about WBV as adjunct to therapy. Cormie and colleagues (2006) found acute increases in vertical jump height but could not make any correlation between changes in jump height and neuromuscular activity. While this study made claims about the acute effects of WBV, the intervention only consisted of 30-second exposure to WBV (Cormie et al., 2006). To my knowledge, there is currently no study that has investigated the acute changes in neuromuscular control following a bout of rehabilitation exercise with WBV, particularly in regards to changes in EMG activity.

CURRENT REHABILITATION & PREVENTION TECHNIQUES

Rehabilitation of FAI must target all aspects of the injury due to the syndrome-like complexity associated with ankle injury. Muscle strengthening alone is not sufficient enough to challenge the neural system and overcome the neuromuscular deficits. Therefore, current rehabilitation and exercise training modalities are becoming more advanced in an effort to target the neuromuscular system and improve central deficits associated with injury.

SHIFT IN REHABILITATION PARADIGM

A rehabilitation program that focuses on the central and neuromuscular systems by emphasizing balance, coordination, and strength training has been recommended for improving ankle stability and postural stability in stable and unstable ankles (Bernier & Perrin, 1998; Eils & Rosenbaum, 2001; Freeman et al., 1965; Goldie et al., 1994; Michell, Ross, Blackburn, Hirth, & Guskiewicz, 2006; Ross & Guskiewicz, 2004; Rozzi et al., 1999; Tropp & Odenrick, 1988). The goal of rehabilitation is to include functional exercises that are directly transferable to the demands of activity and have the potential to reduce injury rate. Introducing a new adjunct to traditional shows how rehabilitation paradigms have shifted to introduce new movements and muscle activation patterns with the goal of improving postural stability.

REESTABLISHING NEUROMUSCULAR CONTROL

FAI causes deficits in neuromuscular control. These can manifest as deficits in proprioception, JPS, balance, postural control, muscular strength, and muscular power. Improving neuromuscular control has been reported to decrease ankle sprain incidence in individuals with and without FAI (Eils & Rosenbaum, 2001; McGuine & Keene, 2006). McGuine and Keene (2006) performed a study of 765 high school soccer and basketball players divided into an intervention group (373 subjects) who performed balance training, and a control group (392 subjects). Of the intervention group, 23.8% reported previous history of ankle injury. The tasks of the intervention group included single leg balance, single leg balance and dribbling, double leg balance on wobble board, single leg balance on wobble board, and single leg balance on wobble board while dribbling. Sixty-two (8.1%) subjects sustained an acute ankle sprain during their season. Researchers then compared the effect of each variable on the rate of ankle sprain and found that previous history of an ankle sprain was the leading risk factor, participation in the balance training program significantly reduced injury rate, indicating balance intervention programs are effective at reducing ankle sprains (McGuine & Keene, 2006).

Evaluating balance or postural stability is one method of assessing sensory deficits following injury (Mattacola & Dwyer, 2002). Balance is comprised of sensory stimulus from the visual, vestibular, and somatosensory systems. Rehabilitation exercises can be modified to challenge or isolate these specific systems. Balance is also a crucial component of all closed-kinetic chain activities because it incorporates sensory stimulus from the peripheries as well as visually and spatially (Hertel & Denegar, 1998). Decreased stability in the single leg standing task suggests altered proprioceptive response with a decreased efficacy of producing protective reactive mechanisms. Because balance uses the same peripheral afferent mechanisms as joint proprioception, it is a good indicator of lower extremity dysfunction.

In a 4-week balance training program with 26 subjects (13 with FAI), Rozzi and colleagues (1999) implemented a series of balance training tasks to treat proprioceptive deficits and restore joint stability. Subjects underwent single leg standing and single leg standing on a Biodex Stability Surface and the results showed there was a significant difference in pre-training (stability index score of 5.93 ± 3.65) versus post-training (Stability index score of 2.63 ± 1.92) in stability measures ($p<.05$), with lower scores representing greater stability (Rozzi et al., 1999).

Restoring neuromuscular control is an important goal of rehabilitation because unlike other treatment goals, such as restoring normal ROM, neuromuscular control is complex and multifaceted (Hertel & Denegar, 1998). Pain, swelling, and damage to joint mechanoreceptors can impede reflex control as well as volitional muscle contractions. Therefore, the rehabilitation should address restoring volitional control, normal reflex patterns, and pattern-generated movements to improve neuromuscular control and restore complex pattern-generated movements that will mimic those required in sport (Hertel & Denegar, 1998).

Another method of assessing neuromuscular control is by measuring EMG for muscle receptor activity and reaction time (Hertel & Denegar, 1998). EMG can be used in the rehabilitation setting as biofeedback, but it is also valuable in measuring latencies and neural deficits associated with injury. EMG measures allow the clinician to track whether the appropriate exercises are being used to optimize motor unit stimulation. By recording EMG activity of the hip musculature as well, the clinician can evaluate whether there are faulty movement patterns associated with proximal control as a contributing factor to injury (Beckman & Buchanan, 1995). While EMG does not directly represent neuromuscular control, it is a valuable measurement tool during rehabilitation to ensure that all exercises are having a meaningful effect on motor unit activation and amplitude.

CURRENT STRATEGIES

Mattacola and colleagues (2002) discussed current rehabilitation strategies for ankle injuries ranging from gentle ROM exercises to challenging balance tasks with provoked perturbations (Mattacola & Dwyer, 2002). Many of the exercises described can fit into multiple goals of rehabilitation, further emphasizing the multifaceted nature of neuromuscular control.

Restoration of full muscle strength is essential if normal function is to be regained. Strength training can be achieved with a wide variety of equipment including sport cord, theraband, free weights, weight machines, and isokinetic devices. In general non-weight bearing should progress to full weight bearing and then additional resistance should be followed. Double leg exercises are progressed to single leg exercises. Isometric contractions are progressed to concentric and eventually eccentric contractions. Hudson (2009) states that the local muscle groups for improvement following ankle injury are the gastrocnemius/soleus complex and the evertors (Hudson, 2009). Docherty and colleagues (1998) implemented a 6-week strength-training program with elastic tubing. The results showed that the 20 subjects with FAI improved the mean strength (N) of dorsiflexors from 33.3 ± 4.8 pretest to 50.6 ± 6.3 posttest ($p<.0005$), and evertors from 30.9 ± 6.5 pretest to 45.0 ± 4.9 posttest ($p=.005$). They also found improvements in JPS (degrees of error) in inversion from 6.8 ± 5.0 pretest to 2.8 ± 2.8 posttest ($p=.009$), and plantarflexion from 7.9 ± 6.0 to 1.4 ± 0.9 posttest ($p=.027$). Researchers stated the improvements in JPS were due to stimulation of afferent muscle spindles and reestablishing the neural connections from the static and dynamic gamma-efferent nerves (Docherty, Moore, & Arnold, 1998).

Proprioception improvements through afferent sensory organization have also been shown to rapidly improve dynamic stability, reduce the incidence of ankle sprain, and reduce injury recurrence (Hudson, 2009; Rasool & George, 2007; Rozzi et al., 1999). Eils and Rosenbaum (2001) studied 30 subjects with CAI and put them through a series of 12 consecutive proprioceptive exercises over a 6-week period and measured postural sway, joint position sense, and reflex activity. The 12 exercises included: single leg standing on different surfaces, single leg stance on mobile platform, single leg stand on ankle disk, movement in different directions, single leg stance with resisted hip abduction of contralateral leg, double leg and single leg stance on inversion/eversion board, single leg stance on mini trampoline, single leg forefoot balance, uneven walking, balance on horizontal and vertically mobile platform, and maintain balance on computer controlled platform. Subjects held the balance positions for 45 seconds and had 30 seconds rest between exercises. The study found a significant difference in pretest and posttest groups in total sway, although individually, maximum sway in the medial-lateral was significant, and anterior-posterior sway was non-significant. Eils and Rosenbaum stated this was because medial-lateral sway occurs at the subtalar joint while anterior-posterior sway occurs at the tibiotalar joint (Eils & Rosenbaum, 2001).

Rehabilitation protocols that restore postural stability have also been effective at reducing ankle sprain incidence (McGuine & Keene, 2006). In a study of 30 healthy athletes, Rasool and George (2007) tested the effects of a 4-week intervention of the Star Excursion Balance Test (SEBT) on improving dynamic stability. The SEBT is a functional test that incorporates single leg standing on one leg and maximal reach with the other in the anterior, lateral, and posterior directions. They found overall improvements in reach distance by 11-36% after a 4-week intervention. The posterior reach direction improved from 97 ± 6cm at baseline to 112 ± 9cm and 121 ± 7cm at 2 and 4-weeks respectively ($p<.001$) (Rasool & George, 2007). Not only did this study show improvements in dynamic postural stability, these improvements were seen after only 4 weeks of intervention. Neuromuscular training and its effects on dynamic postural stability in an injured population have not been researched thoroughly, but individuals who return to play without adequate dynamic postural stability might account for the high recurrence rate of injury (Ross & Guskiewicz, 2006).

GAPS IN REHABILITATION LITERATURE

Every rehabilitation program must be individualized to the patient. This concept in itself leads to difficulty making universal accusations about specific rehabilitation techniques (Mattacola & Dwyer, 2002). While current rehabilitation paradigms and protocols may progressively involve more complex tasks, the general principle is to maximize neuromuscular improvements. The results of individual programs are so varied leading to uncertainty in the best treatment guidelines. Every perturbation, jump landing, or unstable surface is meant to challenge the neuromuscular system and strengthen the proprioceptive deficits that occurred as a result of injury. Depending on the resources available to them, a clinician may have a multitude of tools and instruments that could challenge the neural system. Therefore, the rehabilitation parameters of current studies vary significantly and rarely measure acute effects of treatment. Although restoring functional ability and return to play should be the ultimate goal of all rehabilitation, understanding the acute effects of treatment may be valuable to guide further appropriate treatments. There are currently no studies investigating the outcome of dynamic stability in an acute response to enhanced neuromuscular training. The purpose of this study is to further investigate specific protocols for restoring neuromuscular control and integrate current exercise modalities in the process.

TIME TO STABILIZATION

DEFINITION

Time to stabilization (TTS) is a measure of dynamic postural control following a landing task. Ross and colleagues (2005) describe TTS as signifying when the GRF range of variation at the beginning of a SL jump landing resembles the GRF range of variation of a standardized SL stance (Ross et al., 2005). Anterior-posterior (A/P) and medial-lateral (M/L) TTS have been used to evaluate the dynamic stability of subjects with FAI after a SL jump landing (Ross & Guskiewicz, 2003, 2004; Ross et al., 2005). In calculating TTS the first step is to define the range of variation of a given GRF component. These values are defined as the smallest absolute range value of GRF component during the last 10 seconds of the single leg stance portion of a jump landing task (Ross & Guskiewicz, 2003).

The jump-landing task provides means to control for jump height and distance of each individual. Individuals are measured for maximum vertical-jump height at a distance of 70cm away from the device. Then the individual performs a double leg jump at 50% of the maximum jump height on to the center of a force plate. A measuring device is placed at 50% jump height. The individual is instructed to stick the landing on one leg and stabilize as quickly as possible and remain as motionless as possible for the duration of the test. Data collection begins at initial ground contact and lasts for 20seconds post. The jump landing data are collected on a force plate (Ross & Guskiewicz, 2003).

DYNAMIC STABILITY VERSUS STATIC POSTURAL SWAY

Unlike static measures of postural sway and balance where the subject is standing still, TTS requires the subject to actively stabilize. TTS therefore has a stronger clinical significance in the athletic setting because it incorporates numerous aspects of neuromuscular control including balance, proprioception, strength, and reflex system. Ross and colleagues (2003) state that athletes are very capable at stabilizing normally on a SL, which leads many clinicians to question the functionality of such tests. TTS is a way to quantify postural stability during a dynamic task. By definition, dynamic stabilization is an attempt to maintain a stable base of support while completing a prescribed movement (Gribble et al., 2004; Winter, Patla, & Frank, 1990). Essentially maintaining the center of gravity within the stable base of support during prescribed movement. The difficulty arises when the individual must stabilize responding an unanticipated movement such as reacting to a defender or object.

Compared to SL postural sway measures, TTS measures challenges the postural control system and allow clinicians to identify unstable landing patterns that could contribute to injury and be addressed through therapy (Ross et al., 2005). While landing strategies may be different for subjects with FAI, it is difficult to compare these strategies in laboratory and clinical setting. Correcting faulty landing strategies, that are identified with TTS, could have implications for improving ankle stabilization and preventing excessive stress at the ankle (Ross et al., 2005).

AREAS OF FURTHER INVESTIGATION

The literature on FAI and WBV is abundant but to date, only one study has investigated the effects of WBV on subjects with FAI. There limited research on FAI and advanced rehabilitation techniques although evidence suggests that challenging neuromuscular control-oriented exercises are effective at minimizing the deficits of FAI. WBV is touted as an excellent adjunct to therapy in increasing muscle spindle activity and balance, but has not yet been applied to an injured population. The potential for reducing the deficits of FAI through WBV has lead to the development of this thesis.

CHAPTER III

METHODOLOGY

EXPERIMENTAL DESIGN

This study utilized a randomized crossover design to evaluate the acute effects of WBV on dynamic postural control and EMG of the lower extremity musculature in subjects with FAI. Subjects completed two counterbalanced testing sessions separated by one week during which TTS and EMG of the gluteus medius (GM), rectus femoris (RF), peroneus longus (PL), and tibialis anterior (TA) were assessed prior to and immediately, 15 minutes, and 30 minutes following an intervention (Control of WBV). All testing procedures were conducted barefoot, and the order of testing sessions (Control of WBV) was counterbalanced.

SUBJECTS

A priori power analysis was performed based on an unpublished study by Ross et al. using the TTS procedure after an intervention (stochastic resonance electrical stimulation) in individuals with FAI. Ross's study utilized stochastic resonance and coordination training over a 6-week period and measured dynamic postural stability via TTS. Thirteen subjects would be necessary for a power = 0.80 for $\alpha \leq 0.05$. Tihanyi and colleagues (2007) found increases in quadriceps strength and EMG activity following an acute WBV intervention in 16 stroke patients. These power analyses together helped determine the number of subjects needed to examine our dependent variables sufficiently. Because the effects of WBV in individuals are unknown, we recruited 26 individuals with confirmed FAI to ensure adequate statistical power.

Twenty-six individuals with confirmed FAI (12 females, 14 males; age = 20.4 ± 1.33, height = 172.48 ± 8.94cm, mass = 72.75 ± 11.37kg) were recruited to participate in the study. Two subjects failed to report for the 2nd (control) testing session making our total sample size for the control condition n = 24. Subjects ranged from 18 to 30 years of age and were recreationally active as defined by participation in physical activity for at least 30 minutes, three times per week. Subjects included their primary mode of physical activity in the prescreening questionnaire to identify any individuals who participate in current balance oriented activity (i.e. yoga, ballet,). This was not a primary variable in the inclusion/exclusion criteria but acted as a supplemental variable. Subjects were required to sign an informed consent form approved by the University of North Carolina Institutional Review Board.

All subjects displayed unilateral or bilateral FAI, defined as meeting each of the following self-reported criteria:

- Suffered at least two ankle sprains in the last 12 months that resulted in one or more of the following symptoms: swelling, ecchymosis, and decreased range of motion (Arnold et al., 2011; Freeman et al., 1965; Hertel, 2000, 2002).
- Experienced at least two sensations of "giving way" or feelings of instability in the last 12 months in their involved ankle.

In the case bilateral FAI, the side that displayed a greater CAIT score was used for the study. Subjects were excluded if they participated in ankle rehabilitation within the last 3 months: displayed acute signs of ankle sprain at time of testing (i.e. swelling, ecchymosis); self-reported a history of lower extremity fracture, significant knee or hip injury requiring surgery; visual or vestibular impairments that would affect balance; or neurologic dysfunction. Subjects were also excluded if they have contraindications for WBV including, cardiovascular, metabolic, or neuromuscular diseases, epilepsy, osteoporosis, osteoarthritis, menstrual irregularities, or pregnancy (Mahieu et al., 2006; Pollock et al., 2011; Torvinen et al., 2002b).

Subjects were required to answer the Cumberland Ankle Instability Tool (CAIT) as part of the online prescreening. The CAIT is a 9-item, 30-point tool for measuring the severity of ankle instability. Hiller and colleagues (2006) found the CAIT to be both a reliable and valid tool for assessing ankle instability (ICC=0.96). A score of 28 or higher indicates the individual is unlikely to have ankle instability while a score of 27 or lower indicates they likely have FAI. The CAIT not only quantifies the level of ankle instability but has also been cited as having the potential to predict future sprains in those with FAI (Hiller, Refshauge, Bundy, Herbert, & Kilbreath, 2006). Appendix 1 provides an example of the CAIT questionnaire.

All subjects also completed the Functional Ankle Disability Index (FADI) and FADI Sport questionnaire to further quantify their level of instability. The FADI consists of 26 items and total point value of 104 points, whereas the FADI Sport consists of 8 items for a total of 32 points. Each item is scored from 0 (unable to do) to 4 (no difficulty at all) and items related to pain are scored as 0 (unbearable) to 4 (none). The FADI Sport includes additional items related to higher baseline level of function observed in athletes. These additional items prevent a ceiling effect that has been evident in some cases with the FADI. The FADI Sport is, therefore, more appropriate for the athletic population and additional questions also make the FADI Sport sensitive to tracking changes or deficits in stability

(Hale & Hertel, 2005). Appendix 2 & 3 provide a representation of the FADI and FADI Sport questionnaire respectively.

EMG

A surface electromyography (EMG) system (Delsys Inc., Boston, MA; amplification factor=1000 (20-450Hz); CMRR at 60Hz > 80dB; input impedance > 10^{15}//.02 Ω//pF) was used to capture activity of the peroneus longus, tibialis anterior, rectus femoris, and gluteus medius muscles during the TTS and MVIC measures with surface EMG electrodes (Delsys Inc., Boston, MA). Sampling frequency was 1000Hz.

The tibialis anterior and peroneus longus muscles were included in EMG analysis because previous literature has cited deficits in the lower extremity motor unit activity in subjects with FAI. Konradson and Ravn (1990) found significant EMG activity deficits and increased peroneus longus activation time following ankle injury. The peroneus longus and tibialis anterior are also the primary dynamic restraints to a lateral ankle sprain with the primary mechanism of plantarflexion and inversion (Melnyk et al., 2009). The rectus femoris and gluteus medius were included in this study because numerous studies have examined the effects of delayed muscular activation as either a cause or effect of ankle injury and decreased neuromuscular control (Beckman & Buchanan, 1995; Cathleen N. Brown et al., 2011; Bullocksaxton, 1994). Beckman and colleagues (1995) found that individuals who sustained ankle injury displayed poor hip musculature neural recruitment patterns during stabilization, and decreased gluteus medius activation and strength, due to either anatomical changes, compensations, or central processing impairments.

All subjects were fitted with surface EMG electrodes for the peroneus longus, tibialis anterior, rectus femoris, and gluteus medius of the affected side. Prior to electrode placement, the area of the electrodes were marked with a felt tip marker, shaved with an electric razor, lightly abraded, and cleaned with isopropyl alcohol. A reference electrode was positioned on the tibial tuberosity.

Electrode placement for the peroneus longus muscle belly was determined with the subject seated in 30 degrees knee flexion and the lower extremity externally rotated. First, the distance between the fibular head and lateral malleolus was recorded with a tape measure. The peroneus longus muscle belly was palpated during resisted isometric ankle eversion with resistance applied to the lateral side of the foot. The electrode was placed distal to the fibular head, 25% of the distance between the fibular head and the lateral malleolus over the greatest muscle bulk (Hermens HJ et al., 2000).

Electrode placement for the tibialis anterior muscle was determined with the subject seated in 30 degrees knee flexion and placed in dorsiflexion and inversion. First, the distance between the head of the fibula and the medial malleolus was recorded. The tibialis anterior muscle was palpated during resisted isometric ankle dorsiflexion and inversion with resistance applied to the medial/dorsal foot. The electrode was placed at the proximal 1/3 of the line between the tip of the fibular head and the tip of the medial malleolus over the greatest muscle bulk (Hermens HJ et al., 2000).

Electrode placement for the rectus femoris muscle was determined with the subject in the supine position and the knee slightly flexed. First, the distance from the anterior superior iliac spine (ASIS) to the superior pole of the patella was recorded by tape measure. The rectus femoris was palpated during isometric knee extension with resistance applied to the ankle in the direction of knee flexion. The electrode was placed 50% from the ASIS to the superior pole of the patella over the area of greatest muscle bulk (Hermens HJ et al., 2000).

Electrode placement for the gluteus medius was determined with the subject in the side lying position on the unaffected side. First, the distance between the midpoint of the iliac crest and superior point of the greater trochanter was recorded with a tape measure. The gluteus medius was palpated during resisted hip abduction. The electrode was placed 50% from the iliac crest to the greater trochanter over the area of greatest muscle bulk (Hermens HJ et al., 2000).

Electrode placement was confirmed by observing muscle activity during isometric contraction of each muscle. All electrodes were secured with adhesive tape prior to testing to limit motion artifact.

TIME TO STABILIZATION (TTS) ASSESSMENT

Dynamic postural stability was assessed via time to stabilization (TTS). Ross and Guskiewicz (2003) described this procedure as an effective measure of dynamic postural stability. The jump-landing TTS task controls for jump height and distance of each individual. Individuals were measured for maximal vertical-jump height at a distance of 70cm away from a Vertec vertical jump device. The distance away from the force plate was standardized to 70cm for every subject. The subject performed a double leg jump reaching up to 50% of the maximal jump height, and then landed single-leg on the center of a force plate. The individual was instructed to land on the affected leg and stabilize as quickly as possible for 20 seconds while positioning their hands on their hips. The jump landing data were collected on a Bertec piezoelectric nonconductive force plate (Model #NC4060 Bertec

Corporation, Columbus OH) and integrated with Motion Monitor Software system (Innovative Sports Training, Chicago, IL). Vertical ground reaction force (GRF) was sampled at a frequency of 1000Hz.

WHOLE BODY VIBRATION

A PowerPlate pro5 AIRdaptive WBV unit (PowerPlate® Pro 5, Power Plate International B.V., Badhoevendorp, The Netherlands) was used for the WBV intervention. All subjects performed 6 1-minute intervals of WBV. These parameters were based on the study by Tihanyi and colleagues (2007), who measured the effects of acute WBV exposure on muscular strength, and EMG activity post WBV treatment in recovering stroke patients. Tihanyi utilized an acute intervention of 6 1-minute intervals of WBV with 30Hz frequency and high amplitude, followed by a 2-minute rest period.

TESTING PROCEDURES

Subjects reported to the Neuromuscular Research Laboratory at the University of North Carolina Chapel Hill for a total of two sessions separated by 7 days throughout the study. The pretest screening was administered online to all interested subjects with FAI. Subjects answered the IRB approved questionnaire and determined if they meet the inclusion/exclusion criteria for the study.

Height, weight, and age were collected during the first testing session for anthropometric measures. Subjects started by riding a stationary cycle ergometer at moderate intensity for 5 minutes. Upon completion of the warm-up, subjects were fitted with EMG electrodes over the GM, RF, TA, PL. Electrodes were secured with tape to the skin, and cables were securely fixated on hip to minimize slack that could inhibit normal movement patterns. Once fitted with electrodes, subjects performed three trials of the maximal voluntary isometric contraction (MVIC) for each muscle. Each MVIC was recorded via manual muscle test for 5 seconds in the position and direction based on SENIAM guidelines (Hermens HJ et al., 2000).

After MVIC measures, the subject performed three trials of the maximal vertical jump test, with the best score being used to establish the necessary 50% maximal vertical height for the TTS procedure.

Subjects were then allowed to practice the TTS procedure between 3-5 times to familiarize themselves. When the subject was comfortable with procedure, they performed three baseline trials. Trials were excluded and noted separately if the subject touched down with the contralateral leg or bounced on the affected leg while trying to stabilize. If an error occurred, the trial was discarded and repeated, however, the error was recorded separately as a supplemental measure of stability. Subjects were allowed a maximum of 7 errors per testing period.

After completion of baseline measurements, subjects began their respective testing procedures on the WBV device. For both the control and WBV session, subjects were positioned in an isometric squat (40^{o} knee flexion), and instructed to hold the isometric contraction for 60 seconds, followed by a 2-minute rest. The control session subjects stood on the WBV device following the same instructions in the mini-squat position, but with the device inactive.

After completion of the WBV intervention, subjects immediately performed three TTS trials. After completion of the three trials, subjects waited until 15 minutes post completion of the WBV before completing the next TTS measure. During the waiting time, subjects completed the FADI and FADI Sport questionnaire as a supplemental variable in quantifying their level of instability. This was followed by 15 more minutes of rest. At 30 minutes post intervention, subjects completed three more TTS trials to complete the first testing session.

Subjects reported for their second testing session 7 days later. Due to the counterbalanced testing procedure, subjects were placed into the opposite testing procedure as the first testing session.

DATA REDUCTION

Ground reaction forces (GRF) were filtered using a second-order, recursive low-pass Butterworth digital filter with an estimated optimum cutoff frequency of 12.53Hz, based off previous research (Ross et al., 2005). During the final 10s of each trial, the minimum range of the anterior/posterior (A/P) and medial/lateral (M/L) ground reaction forces were calculated (range-variation) and averaged across trials to provide the mean ± standard deviation (SD) variation for each ground reaction force component. GRF components were rectified and an unbounded third polynomial was then fit to each rectified ground reaction force time series. TTS was defined as the point at which the polynomial fell below the mean + 3SD of the range-variation (Ross et al., 2005).

EMG data were bandpass (20-350Hz) and notch filtered (59.5-60.5Hz) using a 4^{th} order Butterworth filter, and smoothed using a 25ms root mean square sliding window function. Mean EMG amplitudes were calculated prior to (preparatory) and following (loading) initial ground contact (IGC) via custom LabVIEW Software (11.0.1-32bit, National

Instruments, Austin, TX). Initial ground contact was defined as the instant the vertical ground reaction force exceeded 10N. The preparatory phase was defined as 150ms prior to IGC, and the loading phase was defined as 150ms following IGC. EMG data were normalized as percentage of MVIC recorded during manual muscle tests. MVIC was determined with a 100ms moving average to calculate the largest 100ms interval.

STATISTICAL ANALYSIS

Repeated measure 2x3 ANOVAs were used to analyze change scores as a percentage between the WBV and control conditions at the individual time points. Change scores for each measurement $\left(e.g. \%\Delta = \left(\frac{(15\min post - Baseline)}{Baseline}\right) \times 100\right)$ were compared between conditions (Control vs. WBV) via 2 (Condition) x 3 (Time) repeated measure ANOVA. Change scores were calculated by comparing the TTS and EMG results at each time point (immediate, 15min, 30min), and each condition (WBV, control) to the respective values at baseline. The scores were calculated as a percentage of change from baseline following the WBV or control intervention. EMG data was evaluated separately for the preparatory and loading phases of the landing. Significant findings were evaluated *post hoc* via Bonferroni's testing. Statistical significance was established *a priori* as a $\alpha \leq 0.05$.

CHAPTER IV

RESULTS

There was no significant main effect of Condition ($F_0 = 0.042$, $p = 0.839$), Time ($F_2 = 0.524$, $p = 0.596$), or Time x Condition interaction effect ($F_2 = 0.009$, $p = 0.991$; Figure 1) for TTS in the A/P direction. Similarly, the main effect for Condition ($F_0 = 0.192$, $p = 0.665$) and the Time x Condition interaction effect ($F_2 = 0.386$, $p = 0.682$) for TTS in the M/L direction were non-significant. However, there was a significant main effect of Time for TTS in the M/L direction ($F_2 = 3.665$, $p = 0.033$). *Post hoc* analysis identified a significant difference between M/L TTS Immediately and 15 minutes post WBV ($t_{49} = 2.281$, $p = 0.027$).

No significant Time or Condition main effects or Time x Condition interaction effects were identified for the preparatory or loading phase EMG amplitudes for any muscle. Table 3 illustrates the statistical results for these analyses.

FIGURES

Figure 1: Mean TTS A/P by Condition and Time

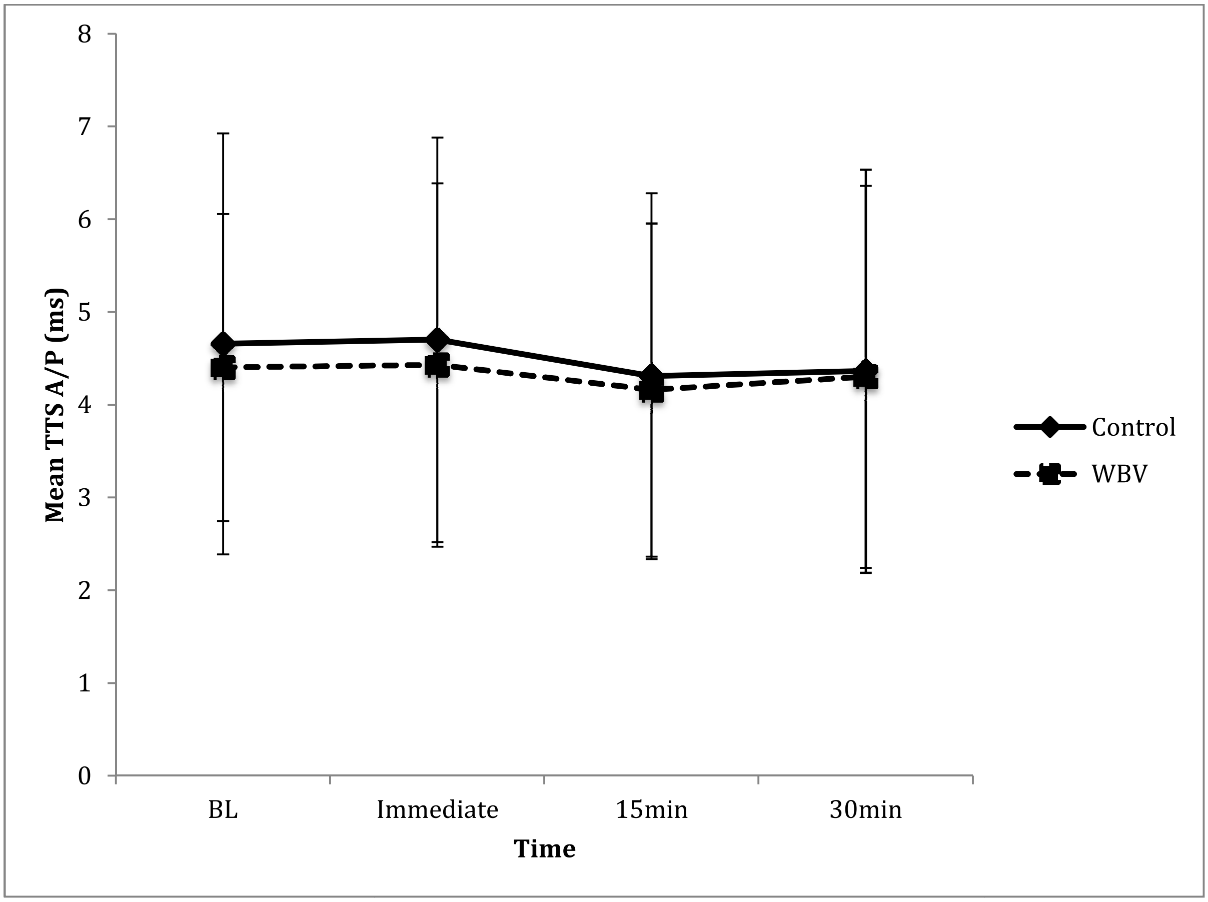


Figure 2: Mean TTS M/L by Condition and Time

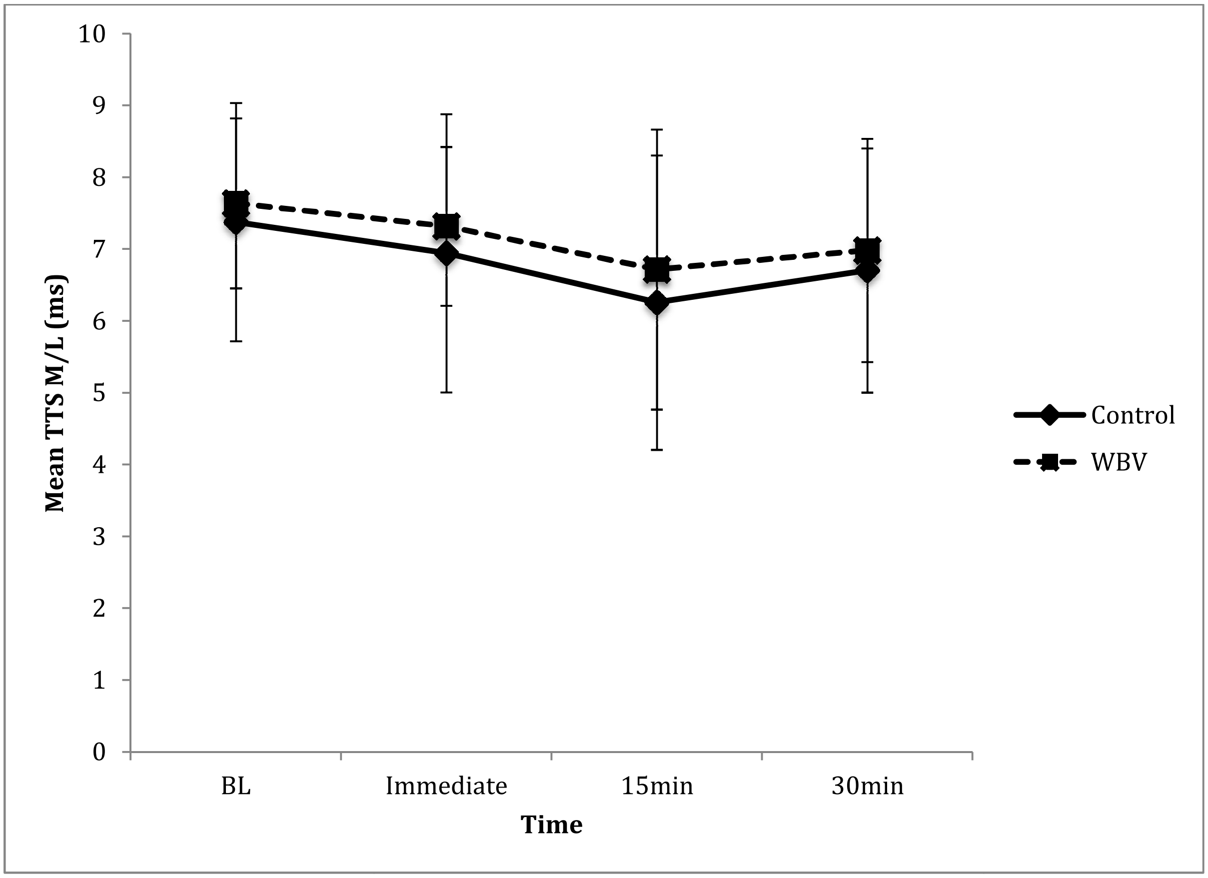


Figure 3: Gluteus Medius Preparatory EMG

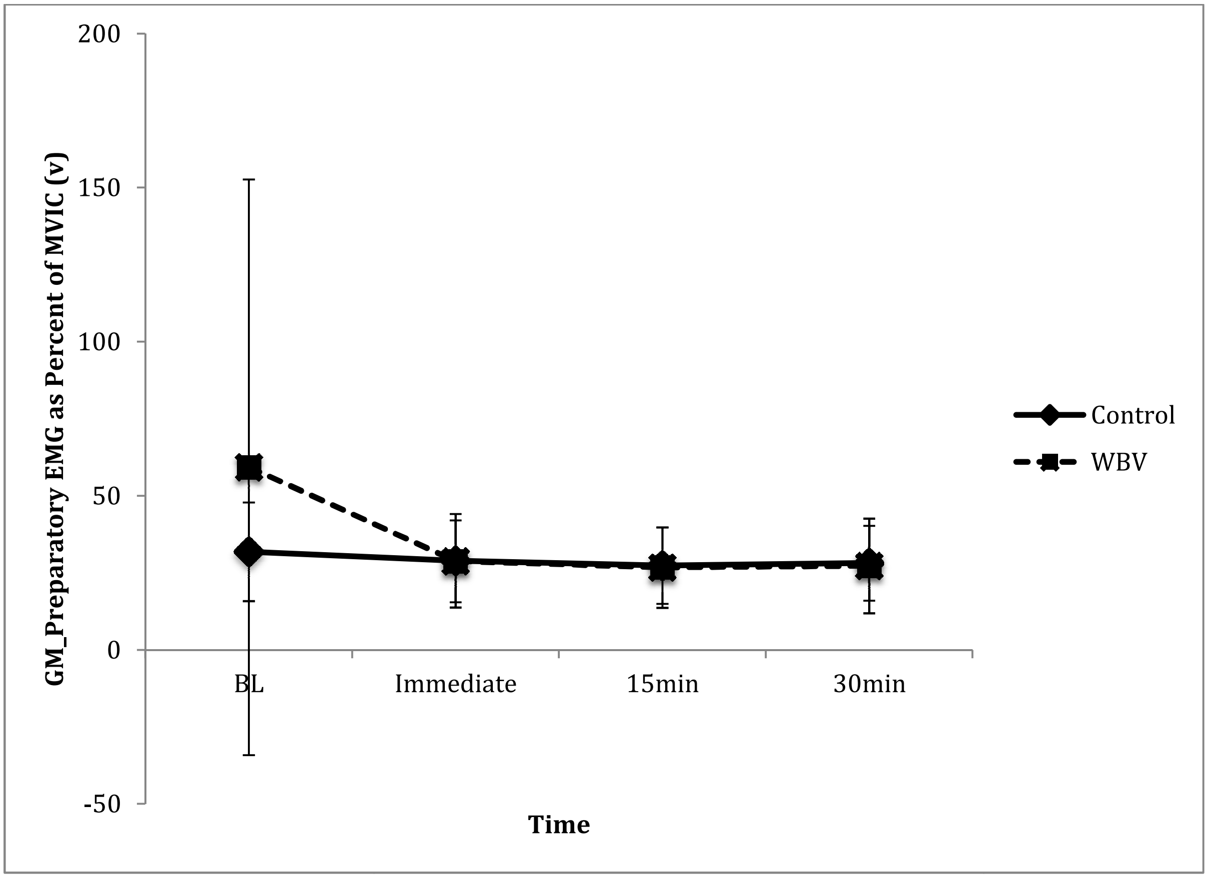


Figure 4: Gluteus Medius Loading Phase EMG

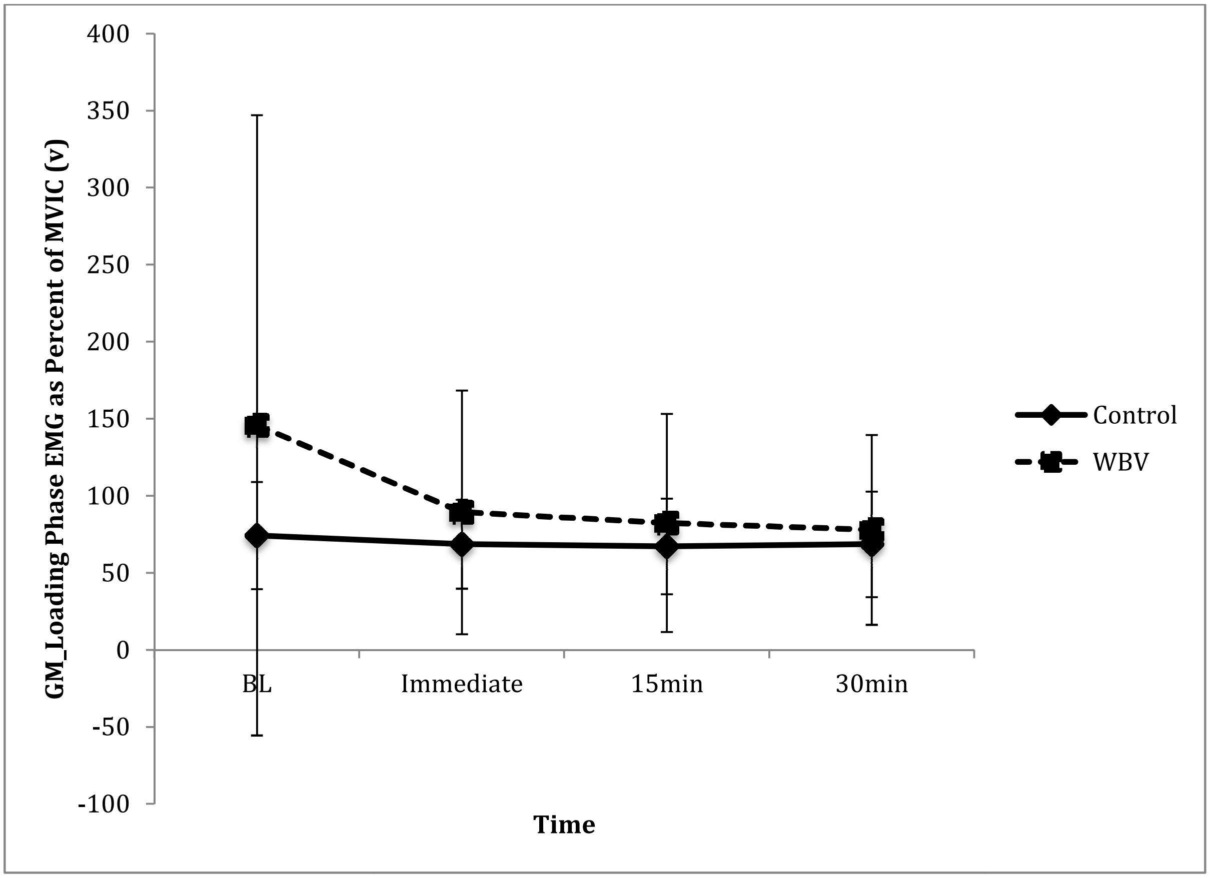


Figure 5: Peroneus Longus Preparatory EMG

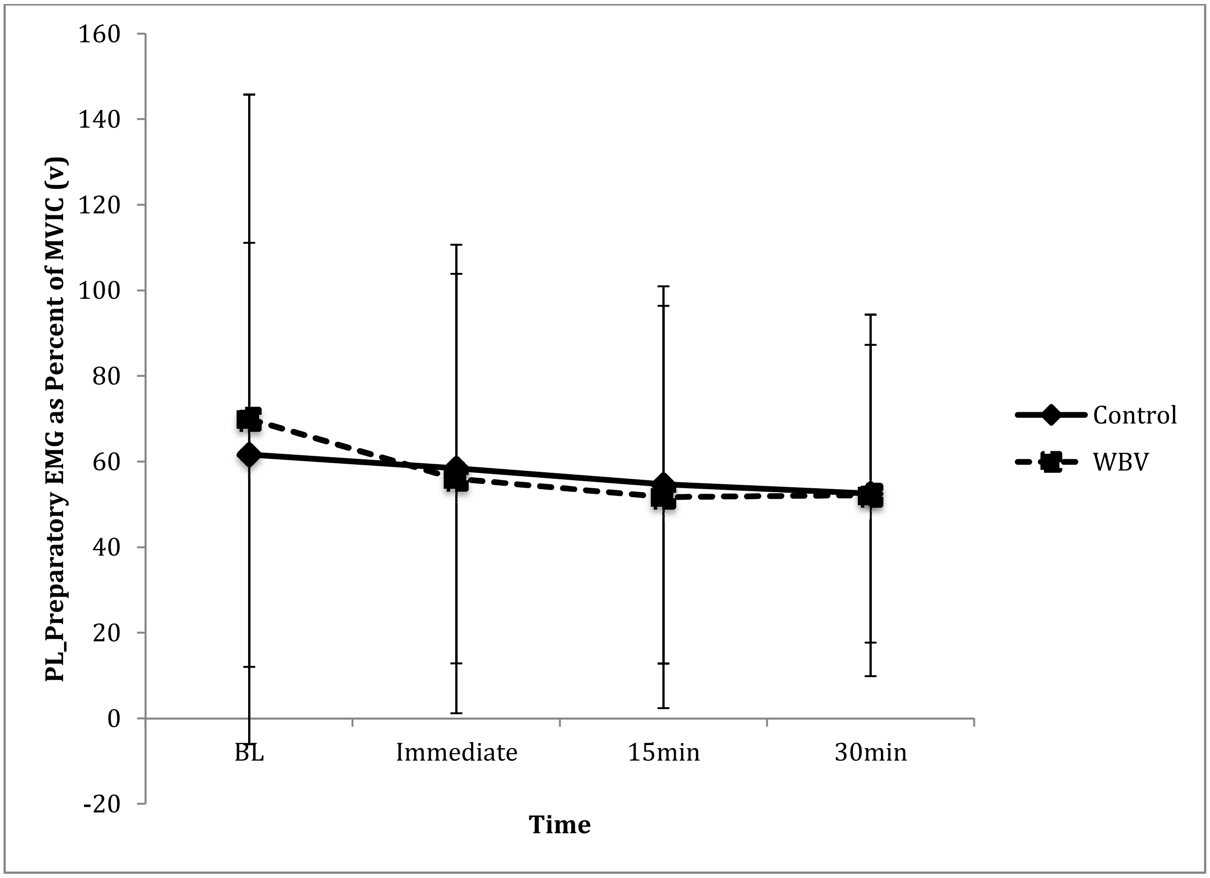


Figure 6: Peroneus Longus Loading Phase EMG

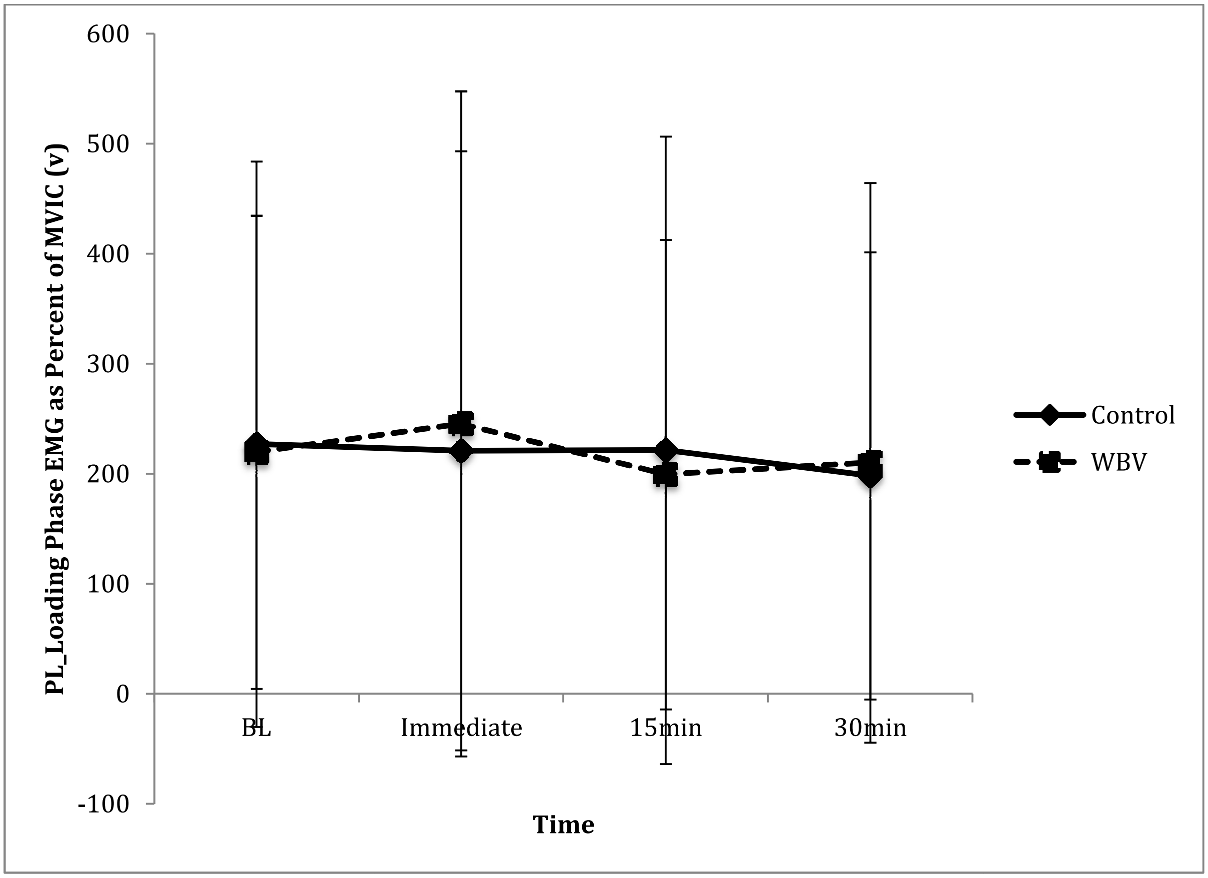


Figure 7: Rectus Femoris Preparatory EMG

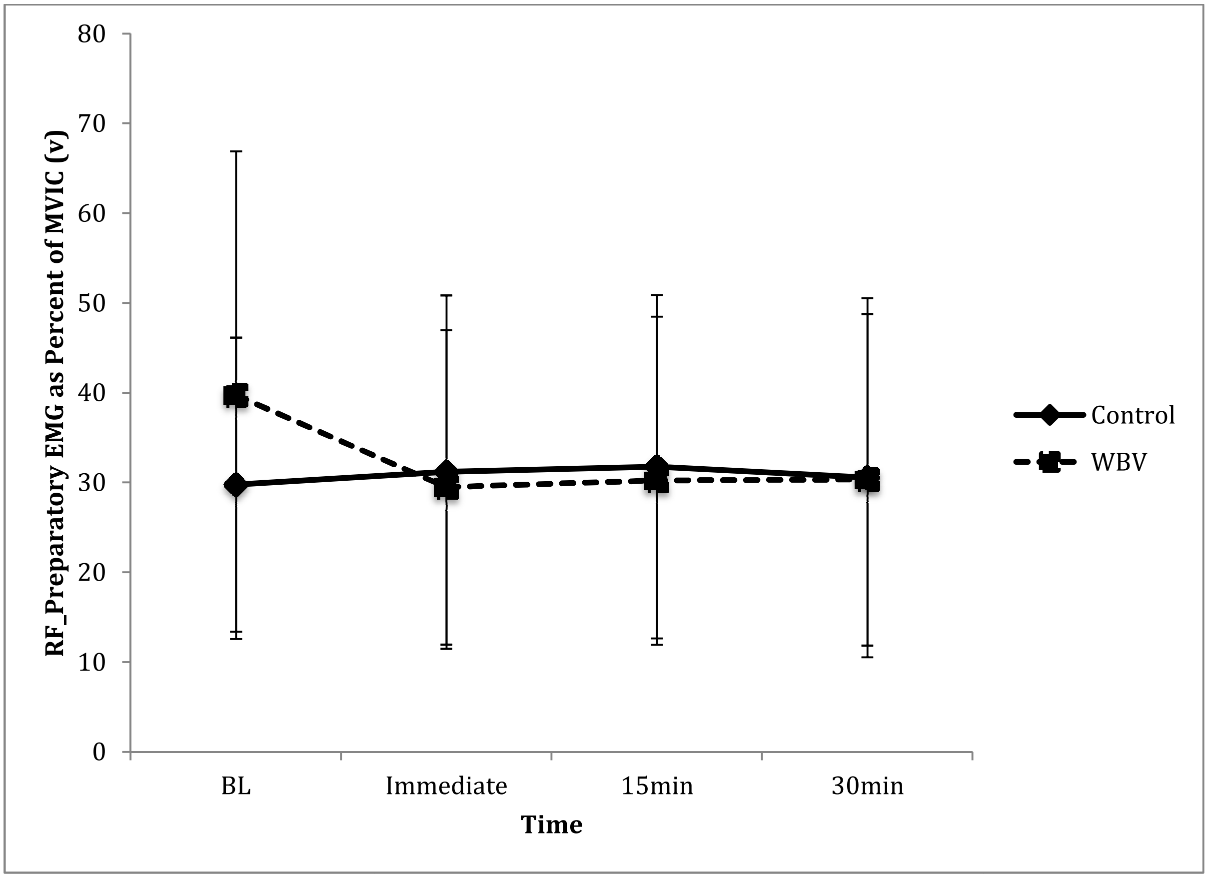


Figure 8: Rectus Femoris Loading Phase EMG

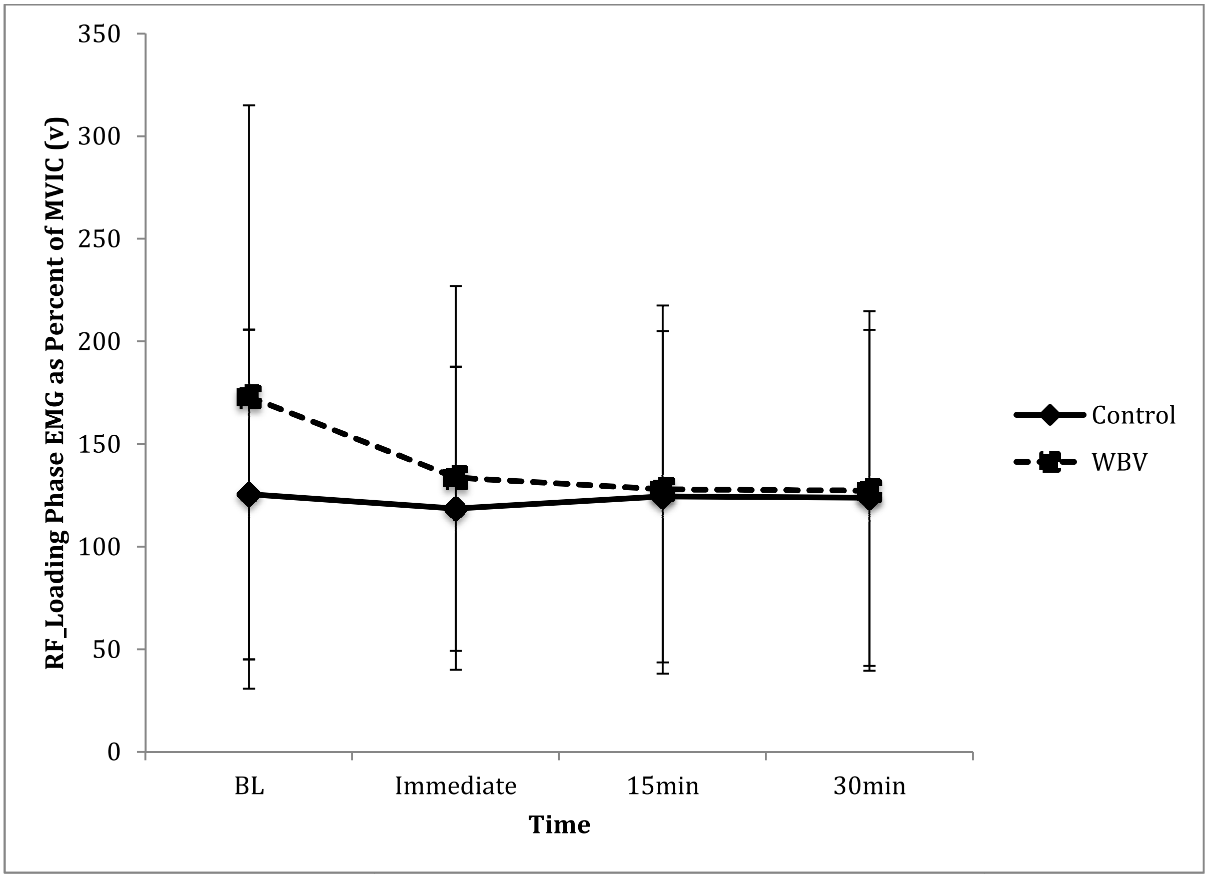


Figure 9: Tibialis Anterior Preparatory EMG

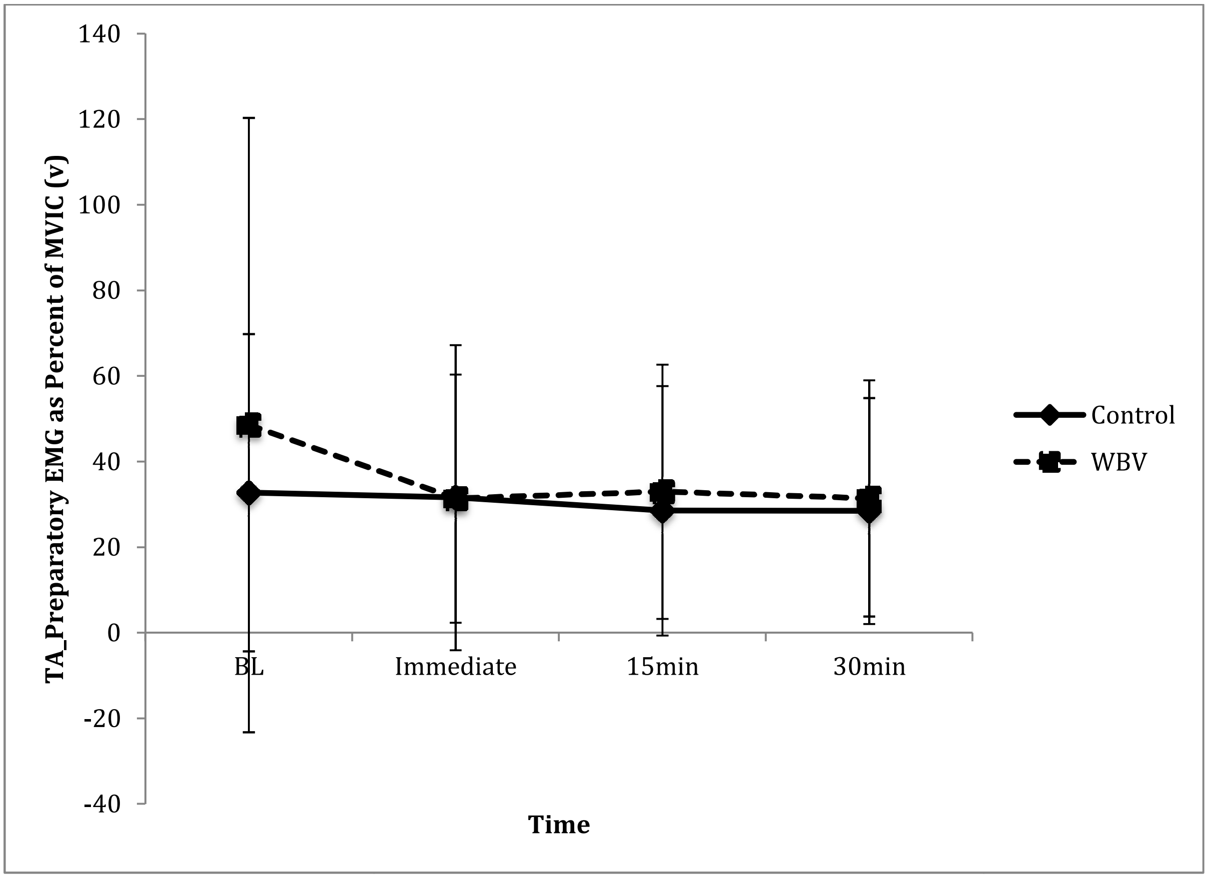
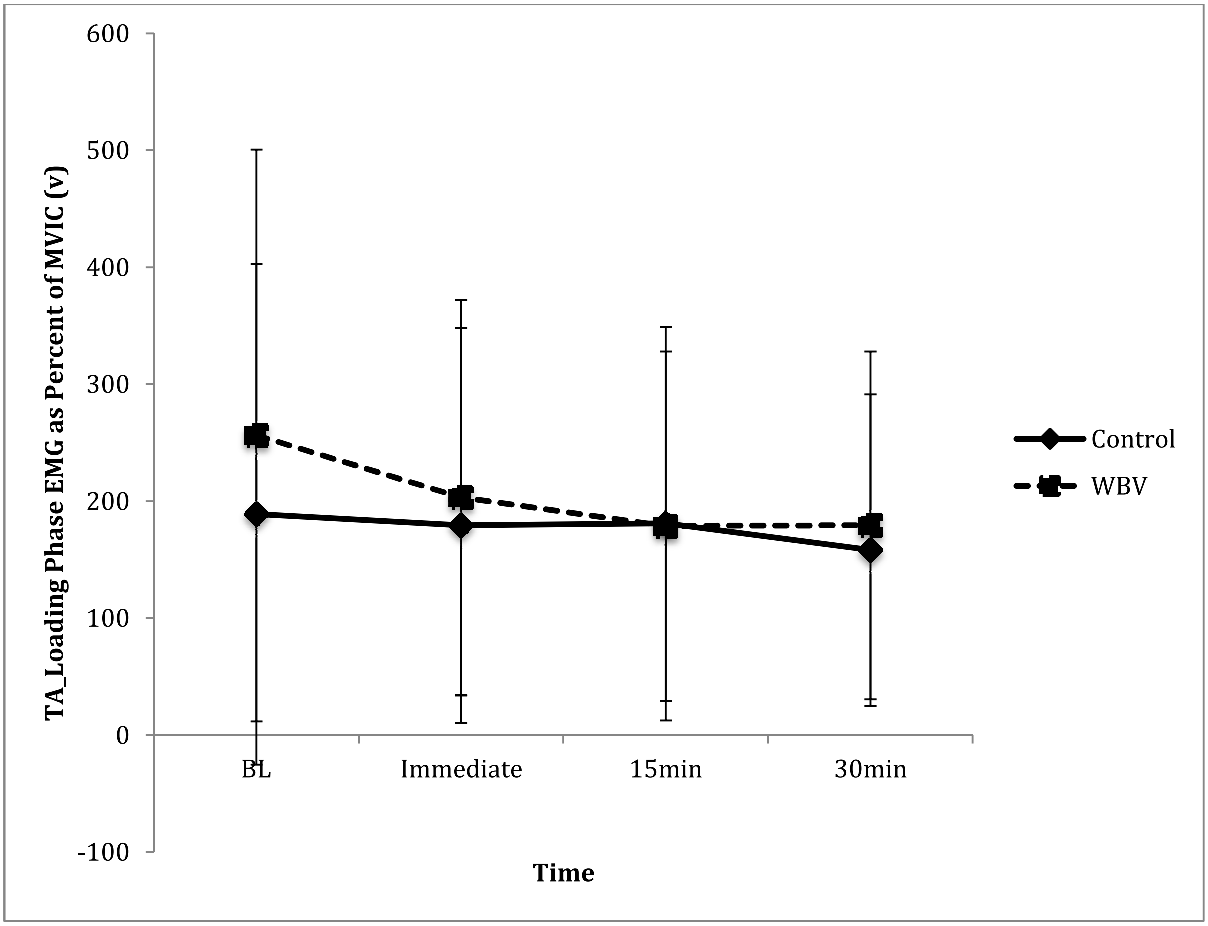


Figure 10: Tibialis Anterior Loading Phase EMG



TABLES

Table 1: Statistical Analyses

Question	Description	Data Source	Comparison	Method
1	Does whole body vibration (WBV) decrease time-to-stabilization (TTS) values in individuals with FAI?	TTS performance at baseline, Immediately post, 15 minutes post, and 30 minutes post intervention in both WBV and non-WBV groups	TTS scores compared to baseline scores among both conditions	2x3 Repeated Measures ANOVA
2	Does WBV increase preparatory EMG of the peroneus longus, tibialis anterior, rectus femoris, and gluteus medius muscles in individuals with FAI?	Examining EMG data during TTS task performed at baseline, Immediately post, 15 minutes post, and 30 minutes post intervention in both WBV and non-WBV groups	Mean EMG amplitude of TA, PL, RF, and GM during the WBV and control sessions	2x3 Repeated Measures ANOVA
3	Does WBV increase EMG during the loading phase of the peroneus longus, tibialis anterior, rectus femoris, and gluteus medius muscles in individuals with FAI?	Examining mean EMG amplitude during TTS task performed at baseline, Immediately post, 15 minutes post, and 30 minutes post intervention in both WBV and non-WBV groups	Mean EMG amplitude of TA, PL, RF, and GM during the WBV and control sessions	2x3 Repeated Measures ANOVA

Table 2: Condition x Time Interaction

Time	Baseline		Imm. Post		15min Post		30min Post	
Condition	WBV	Control	WBV	Control	WBV	Control	WBV	Control

Table 3: Statistical Results for Analyses of EMG Amplitudes

Variable	Condition Main Effect		Time Main Effect		Interaction Effect	
	F_0	p	F_2	p	F_2	p
GM_Prep	1.993	0.171	1.713	0.202	1.247	0.284
GM_Load	2.460	0.130	2.622	0.166	1.899	0.180
PL_Prep	3.635	0.069	2.735	0.075	0.806	0.419
PL_Load	1.514	0.231	2.859	0.087	1.889	0.179
RF_Prep	0.566	0.460	0.207	0.745	0.935	0.400
RF_Load	0.471	0.499	1.189	0.314	0.540	0.586
TA_Prep	1.903	0.181	0.961	0.348	1.609	0.218
TA_Load	1.125	0.300	1.377	0.256	0.941	0.365

Prep = preparatory phase
Load = Loading phase

CHAPTER V

MANUSCRIPT

Introduction

Ankle injuries are highly common in physically active individuals with more than 25,000 ankle sprains occurring daily in the United States (Mickel et al., 2006). Furthermore, as many as 73% of these injuries are recurrent cases (Arnold et al., 2011; Dizon & Reyes, 2010; Hughes & Rochester, 2008) which result in chronic symptoms such as pain, weakness, and functional ankle instability (FAI) (Arnold et al., 2011). Freeman et al. (1965) defined FAI as a tendency of giving way following injury. FAI results from anatomic or mechanical instabilities, muscular weakness, and deficits in proprioception, postural control, and neuromuscular control (Freeman, 1965; Freeman et al., 1965; Hertel, 2002). Neuromuscular deficits associated with FAI also include reduced hip abductor streng[1]th (Beckman & Buchanan, 1995; Cathleen N. Brown et al., 2011), increased peroneal reaction time when exposed to sudden inversion (Palmieri-Smith et al., 2009), and reduced activity of the tibialis anterior and peroneus longus (Konradson and Ravn 1990), which act as the primary dynamic restraints to sudden inversion/plantarflexion (Melnyk et al., 2009). These neuromuscular deficits resulting from FAI may manifest as decreased postural control due to damaged mechanoreceptors and reflex inhibition (Hertel, 2002; Palmieri-Smith et al., 2009).

Whole body vibration (WBV) is a novel rehabilitation modality that challenges multiple components of the nervous and musculoskeletal systems simultaneously due to stimulation of type Ia afferent receptors (muscle spindles), and Golgi tendon organs

[1] **(*Formatted for submission to Journal of Athletic Training*)**

(Rittweger, 2010). WBV has been shown to elicit improvements in muscular strength, muscular power, flexibility, and balance, which can aid in the prevention and rehabilitation of ankle injuries (Moezy et al., 2008; Torvinen et al., 2002a). Several studies have demonstrated significant improvements in balance, strength, and proprioception with WBV exposure following ACL reconstruction (Brunetti et al., 2006a; Fu et al., 2013; Moezy et al., 2008). These findings suggest that WBV has the potential to reduce neuromuscular deficits associated with FAI (Meinyk et al., 2008; Moezy et al., 2008). However, no previous studies to our knowledge, have evaluated the effects of WBV on neuromuscular function in individuals with FAI.

The purpose of this investigation was to determine the acute effects of WBV on dynamic stabilization and lower extremity muscle activity in individuals with FAI. Ross and colleagues demonstrated a measure of dynamic stability known as time to stabilization (TTS), is greater in individuals with FAI compared to healthy subjects. (Ross & Guskiewicz, 2003; Ross et al., 2005). We hypothesized that TTS would decrease immediately post WBV treatment, and remain significantly decreased 30 minutes post-treatment. We also hypothesized that mean EMG amplitudes of muscles previously demonstrated to be altered by FAI would be significantly increased during the preparatory and loading phase of the TTS procedure immediately and 30 minutes post-WBV treatment.

Methods

Experimental Design

This study utilized a counterbalanced crossover design to evaluate the acute effects of WBV on TTS and EMG of lower extremity musculature. Each subject completed two counterbalanced testing sessions separated by one week: Control and WBV. TTS and EMG amplitudes were evaluated at baseline and immediately, 15 minutes, and 30 minutes following the control or WBV interventions. All testing procedures were conducted barefoot.

Subjects

A priori power analysis using unpublished data from Ross et al. using a similar intervention (stochastic resonance electrical stimulation) in individuals with FAI, indicated that 13 subjects would be necessary to attain a power of 0.80 for $\alpha \leq 0.05$. Tihanyi and colleagues (2007) reported increases in quadriceps EMG activity following an acute WBV intervention in 16 stroke patients. Because the effects of WBV on neuromuscular function in individuals with FAI are unknown, we recruited 26 individuals with FAI (12 females, 14 males; age = 20.4 ± 1.33; height = 172.48 ± 8.94cm; mass = 72.75 ± 11.37kg). Two subjects failed to report for the 2nd (control) testing session making our total sample size for the control condition n = 24. Subjects were required to be 18 to 30 years of age and recreationally active, defined as participation in physical activity for at least 30 minutes, three times per week. All subjects displayed unilateral or bilateral FAI, defined as meeting each of the following criteria: 1) suffered at least two ankle sprains in the last year that resulted in swelling, ecchymosis, and/or decreased range of motion and 2) experienced at least two sensations of "giving way" or feelings of instability after injury in the 12 months prior to participation (Arnold et al., 2011; Freeman et al., 1965; Hertel, 2000, 2002). Subjects were excluded if they participated in ankle rehabilitation within 3 months prior to participation; displayed acute signs of ankle sprain at time of injury (e.g. swelling, ecchymosis); reported a history of lower extremity fracture, significant knee or hip injury requiring surgery, visual or vestibular impairments that would affect balance, or neurologic dysfunction. Subjects were also excluded if they had contraindications for WBV including, cardiovascular, metabolic, or neuromuscular diseases, epilepsy, osteoporosis, osteoarthritis, menstrual irregularities, or pregnancy (Mahieu et al., 2006; Pollock et al., 2011; Torvinen et al., 2002b). Subjects were required to sign an informed consent form approved by the University of North Carolina Institutional Review Board.

The Cumberland Ankle Instability Tool (CAIT) was administered online prior to testing and used to quantify the level of FAI. This survey instrument has been demonstrated as a reliable and valid tool for assessing ankle instability. Scores of 27 or lower are indicative of FAI (Hiller et al., 2006). In subjects with bilateral FAI, the side with the greater CAIT score was selected for testing. Upon reporting to the laboratory, subjects completed a 5-minute warm up on a stationary cycle ergometer at a self-selected pace. Surface EMG electrodes (Delsys Inc., Boston, MA; amplification factor=1000 (20-450Hz); CMRR at 60Hz > 80dB; input impedance > 10^{15}//.02 Ω//pF) were then secured over the gluteus medius (GM), rectus femoris (RF), tibialis anterior (TA), and peroneus longus (PL) of the affected side. Prior to electrode placement, the skin was shaved, lightly abraded, and cleaned with isopropyl alcohol. A reference electrode was positioned on the tibial tuberosity. Following electrode placement, three 5-second maximal voluntary isometric contractions (MVIC) were recorded for each respective muscle. Electrode placements and manual muscle test locations were determined based on SENIAM guidelines (Hermens HJ et al., 2000).

Dynamic postural stability was assessed via time to stabilization (TTS). Maximal vertical jump height was first measured three times with the subject standing 70cm away from a Vertec device, and the highest value was used to represent maximal vertical jump height. Subjects then performed a double leg jump while reaching to 50% of the maximum jump height and landed in the center of a force plate (model #NC4060 Bertec Corporation, Columbus OH). Only the Vertec vanes representing 50% of maximal vertical jump height ± 0.5 inches were exposed and subjects were instructed to jump and touch the vanes, then land on the affected leg and stabilize as quickly as possible for 20 seconds while positioning the hands on the hips. Subjects were allowed 3-5 practice trials to familiarize themselves with the procedure. Trials were discarded and repeated if the subject touched down with the contralateral leg or bounced on the affected leg while trying to stabilize. Subjects were allowed a maximum of 7 errors per testing session. Ground reaction forces (GRF) and lower extremity EMG data were sampled simultaneously during the TTS task at 1000Hz.

Immediately following baseline TTS measurements, subjects moved to the WBV device (PowerPlate® Pro 5, Power Plate International B.V., Badhoevendorp, The Netherlands). For both the control and WBV conditions, subjects maintained an isometric squat position (~40^{o} knee flexion) for 1 minute followed by a 2-minute rest period, which was repeated 6 times (Tihanyi, Horvath, Fazekas, Hortobagyi, & Tihanyi, 2007). During the WBV condition, a vibratory stimulus (30Hz, 2g) was provided while subjects maintained this position. During the control condition subjects performed the same procedures on the WBV device, but the vibratory stimulus was not provided. The aforementioned TTS procedures were then repeated immediately, 15 minutes, and 30 minutes following the respective interventions.

Data Reduction & Analysis

Ground reaction forces were filtered using a second-order, recursive low-pass Butterworth digital filter with an estimated optimum cutoff frequency of 12.53Hz. During the final 10 seconds of each trial, the minimum range of the anterior/posterior (A/P) and medial/lateral (M/L) ground reaction forces was calculated (range-variation) and averaged across trials to provide the mean ± standard deviation (SD) variation for each ground reaction force component. Ground reaction force components were rectified and an unbounded third polynomial was then fit to each rectified ground reaction force time series. TTS was defined as the point at which the polynomial fell below the mean + 3SD of the range-variation (Ross et al., 2005).

EMG data were bandpass (20-350Hz) and notch filtered (59.5-60.5Hz) using a 4^{th} order Butterworth filter, and smoothed using a 25ms root mean square sliding window function. Mean EMG amplitudes were calculated prior to (preparatory) and following (loading) initial ground contact (IGC) via custom LabVIEW Software (11.0.1-32bit, National Instruments, Austin, TX). Initial ground contact was defined as the instant the vertical ground reaction force exceeded 10N. The preparatory phase was defined as 150ms prior to IGC, and the loading phase was defined as 150ms following IGC. EMG data were normalized as percentage of maximal voluntary isometric contraction (MVIC) recorded during manual muscle tests for each muscle. MVIC was determined with a 100ms moving average to calculate the largest 100ms interval.

Change scores for each dependent variable at each measurement point $\left(e.g. \%\Delta = \left(\frac{(15 \min post - Baseline)}{Baseline}\right) \times 100\right)$ were compared between conditions (Control vs. WBV) via 2(Condition) x 3(Time) repeated measures ANOVA. EMG data were evaluated separately for the preparatory and loading phases of the landing. Significant ANOVA models were evaluated *post hoc* via Bonferroni's procedure. Statistical significance was established *a priori* as $\alpha \leq 0.05$.

Results

There was no significant main effect of Condition ($F_0 = 0.042$, $p = 0.839$), Time ($F_2 = 0.524$, $p = 0.596$), or Time x Condition interaction effect ($F_2 = 0.009$, $p = 0.991$; Figure 1) for TTS in the A/P direction. Similarly, the main effect for Condition ($F_0 = 0.192$, $p = 0.665$) and the Time x Condition interaction effect ($F_2 = 0.386$, $p = 0.682$) for TTS in the M/L direction were non-significant. However, there was a significant main effect of Time for TTS in the M/L direction ($F_2 = 3.665$, $p = 0.033$). *Post hoc* analysis identified a significant difference between M/L TTS Immediately and 15 minutes post WBV ($t_{49} = 2.281$, $p = 0.027$). Given the similarity of these changes in each group, this result is likely indicative of a learning effect.

No significant Time or Condition main effects or Time x Condition interaction effects were identified for the preparatory or loading phase EMG amplitudes for any muscle. Table 3 illustrates the statistical results for these analyses.

Discussion

The purpose of this study was to investigate the acute effects of WBV on dynamic postural stability and lower extremity muscle activity in individuals with FAI. Based on previous research identifying acute changes in muscle spindle sensitivity, proprioception, and muscle activity with WBV (Bosco et al., 2000; Cardinale & Lim, 2003; Tihanyi et al., 2007), we hypothesized that TTS would decrease and EMG amplitudes would increase following exposure to WBV. However, we did not observe any acute effects of WBV on these variables.

The effects of WBV are not widely understood, as the literature is conflicting regarding its physiologic effects. Our findings are supported by several studies that found no significant effect of WBV on EMG, strength, or balance (Cormie et al., 2006; Martinez et al., 2013; Pollock et al., 2011). Martinez et al. (2013) studied the effects of a 6-week WBV intervention on the reflex responses of the peroneus longus, peroneus brevis, and anterior tibialis when exposed to a sudden inversion mechanism, and found no significant changes in any of their dependent variables in their sample of healthy, recreationally active individuals in which neuromuscular deficits were not present. Pollock and colleagues (2011) investigated the effects of low vs. high amplitude vibration on balance, joint position sense, and cutaneous sensation in young, healthy individuals, but found no significant effects of WBV. Lastly, Cormie et al. (2006) reported an increase in vertical jump height, but no changes in isometric squat strength or EMG of the biceps femoris and quadriceps muscle groups following acute WBV exposure in healthy individuals.

In contrast to our findings, several studies have reported significant improvements in strength, power, EMG amplitude, and stability following acute WBV exposure (Abercromby et al., 2007; Bosco et al., 2000; Cormie et al., 2006; Moezy et al., 2008; Ronnestad, Holden, Samnoy, & Paulsen, 2012; Tihanyi et al., 2007). In a group of healthy power lifters, Ronnestad et al. (2012) found acute increases in power output and EMG amplitudes during a squat jump following acute WBV (Ronnestad et al., 2012). Moezy et al. (2008) reported significant increases in postural stability and joint reposition sense after 12 sessions of WBV exposure in subjects following ACL reconstruction. Abercromby et al. (2007) investigated the acute effect of contraction type, subject positioning, and the type of vibration (rotational versus vertical) on EMG of the lower extremity in healthy adults. They reported significant improvements in EMG of the vastus lateralis, gastrocnemius, and tibialis anterior during the WBV treatment using a smaller knee angle and isometric contractions. Lastly, Tihanyi et al. (2007) reported acute improvements in eccentric and isometric knee extension strength in stroke patients following WBV.

These conflicting findings depend largely on the varying parameters of the WBV stimulus, duration of exposure to WBV in a single session, and acute vs. chronic/longitudinal WBV exposure (Brunetti et al., 2006b). Several studies investigated the effects of acute WBV exposure with varying results. One study found significant differences between rotational and vertical oscillations (Abercromby et al., 2007). Another study found significant increases in quadriceps EMG amplitude during knee extension after an acute exposure to WBV at 20Hz (Tihanyi et al., 2007), while another found no change in quadriceps EMG during a countermovement jump after acute exposure to WBV at 30Hz (Cormie et al., 2006), and yet another study found acute increases in quadriceps EMG during a squat jump following WBV exposure at 50Hz (Ronnestad et al., 2012). Because of the high variability in WBV parameters across investigations, it was difficult to determine which to utilize in our intervention. Our WBV parameters (30Hz, 2g) were determined based off the study by Tihanyi and et al. (2007), who found significant increases in eccentric and isometric torque of the knee extensors following an acute WBV session in stroke patients. These parameters were chosen in order to achieve the greatest impact on EMG amplitude, however, our study found no significant effect of WBV on mean EMG amplitude. This could have been due to the different sample used in comparison to the study by Tihanyi et al. (2007), or the fact that the TTS task inherently requires a smaller summation of motor units than an MVIC knee extension with a dynamometer as measured by Tihanyi et al.

The varying WBV parameters cause different neuromuscular responses. While none of these studies attempted to improve dynamic postural control, these studies evaluated effects of WBV on strength, EMG, and static postural control following WBV. Cormie et al. (2006) used 30Hz frequency and 2.5mm amplitude (low) and found improved countermovement jump height, but no changes in EMG activity. Ronnestad et al. (2012) used 50Hz frequency and 3mm amplitude and found increased quadriceps EMG during a power movement. Tihanyi et al. (2007) used 20Hz frequency and high amplitude vibration and find increases in quadriceps EMG during an maximal isometric and eccentric knee extension motion. Because TTS is predicated on an appropriate neuromuscular response, the lack of significant EMG findings in this study indicated a weak neuromuscular response, and explains the lack of improvement in TTS.

In addition to the varying parameters and frequencies for WBV intervention, conflicting results may be due to the heterogeneous patient populations varying from young healthy subjects and elite level athletes, to stroke patients, multiple sclerosis patients, and elderly populations (Cormie et al., 2006; Mahieu et al., 2006; Schuhfried et al., 2005; Tihanyi et al., 2007; Torvinen et al., 2002a). Another possible reason for the lack of significant findings could have been the position of the subject on the WBV platform. As one study noted, subject positioning could have an effect on muscle spindle activation with smaller knee flexion angles (~20 degrees for isometric vibration) eliciting a greater neuromuscular response due to the lengthened position (Abercromby et al., 2007). Our investigation had the subject positioned at 40^{o} isometric knee flexion. While the most beneficial subject positioning is unclear, there is the potential that the squat position used in our study displayed too much knee flexion to optimize neuromuscular stimulation.

With respect to musculoskeletal injury, research has investigated the effects of WBV in subjects following ACL reconstruction and found significant improvements in postural stability, strength, and joint reposition sense (Brunetti et al., 2006a; Fu et al., 2013; Moezy et al., 2008). To the authors' knowledge, only one study has investigated the effects of WBV in individuals with FAI and demonstrated improvements in single-leg balance after a 6-week progressive vibration program. They did not, however, find any significant difference in mean EMG amplitude or power of the peroneus longus (Cloak et al., 2010). The study indicated that longitudinal WBV may have implications for improving static balance, but dynamic postural control as assessed by TTS may be too demanding to be affected by a single WBV exposure. Martinez et al. (2013) examined the potential of using WBV as a preventative therapy to ankle injury. However, after a 6-week intervention they found no significant difference in reaction time, peak EMG, or time to peak EMG in their healthy population. The authors concluded that the lack of improvements in reflex response was that the WBV stimulus was not sufficient to induce neuromuscular adaptions in healthy individuals.

Another factor in this study that was different than other research on WBV was the sampling of an injured, yet functional population. Subjects in this study were required to answer a CAIT questionnaire as part of the inclusion criteria. Hiller et al. (2006) validated the CAIT scoring system and concluded that subjects with a score of 28 or higher were unlikely to have FAI, and subjects with a score of 27 or lower were likely to have FAI. As Martinez et al. (2007) found, WBV did not induce neuromuscular changes in a healthy population and some subjects with higher CAIT (>25) scores may not have been as receptive to WBV as individuals with lower CAIT scores (<10). Although every subject in our investigation scored below 27 on the CAIT questionnaire, there was wide range of scores (range = 6-25, mean = 16.35 ± 4.82). Our mean CAIT score was well below the classification of FAI by Hiller et al. (2006), and less than the mean CAIT score (19 ± 4) reported by Arnold and colleagues study on FAI and quality of life (Arnold et al., 2011). Our mean scores were also less than the reported CAIT scores (18.4 ± 1.3) by Cloake et al. (2010), in their study investigating the effects of 6-week vibration training on single-leg balance in dancers with FAI. This would suggest our subjects did, in fact, possess FAI, however the wide range of scores could potentially skewed our mean. Subjects who displayed more severe levels of instability could have been affected by the WBV intervention, but their results were potentially confounded by virtue of being grouped with more functional individuals. However, we evaluated the relationships between CAIT scores and the magnitude of change in each TTS or EMG variable immediately following WBV, and none of these correlations were statistically significant. This suggests that the lack of significant effects of acute WBV was not influenced by the level of FAI.

Limitations of the study include the subjective self-reported history of ankle sprains. Similarly, the subjects in this study were all at different stages in the spectrum of FAI, as is displayed by the wide range of CAIT scores. Another limitation was that the total exposure to the vibration was six minutes, while other studies have utilized longer treatment sessions ranging 6 to 16 minutes of WBV exposure (Moezy et al., 2008; Tihanyi et al., 2007). The positioning of our subject could have also been an important factor. If our subject performed the WBV intervention in a single-leg stance mimicking the TTS procedure, the neuromuscular response could have been greater. Increasing the dorsiflexed position could have increased stretch on the plantarflexor and peroneal musculature, thus potentially improving transmission of the WBV stimulus and causing a greater neuromuscular response. Our study also only examined the acute effects of WBV, thus it is unclear if repeated exposure to WBV with the same parameters would have similar results.

The results of this study have implications for further research regarding WBV as a potential therapeutic intervention for FAI. Our study did not measure strength, proprioception, or joint reposition sense in our measures of neuromuscular changes. These variables contribute to dynamic stability and have demonstrated improvements following WBV (Moezy et al., 2008). Also, it is necessary to study the varying parameters of WBV and what their exact physiologic effects are in a healthy and injured population. Conducting a longitudinal study evaluating the effects of prolonged WBV intervention on individuals with FAI could be more beneficial due to neuromuscular adaptations that could occur from a longer intervention. There is also the potential of performing coordination-training tasks with acute WBV to optimize the neuromuscular response. With regard to FAI classification, further research should be conducted to quantify and distinguish between grades of FAI. A clearer definition of FAI to identify individuals who would benefit from this novel therapy is necessary.

Clinical Significance

In conclusion, the results of this study found no significant effect of acute WBV exposure on TTS and lower extremity EMG during single-leg landing. Although there are many studies showing WBV as a valuable adjunct for strength, proprioceptive, or balance training, the exact parameters of the study should be considered based on the desired therapeutic effect. As such, it is unclear if WBV is effective as an adjunct therapy for treating FAI.

APPENDICES

Appendix 1: Cumberland Ankle Instability Tool

Please tick the ONE statement in EACH question that BEST describes your ankles.

	LEFT	RIGHT	Score
1. I have pain in my ankle			
Never	☐	☐	5
During sport	☐	☐	4
Running on uneven surfaces	☐	☐	3
Running on level surfaces	☐	☐	2
Walking on uneven surfaces	☐	☐	1
Walking on level surfaces	☐	☐	0
2. My ankle feels UNSTABLE			
Never	☐	☐	4
Sometimes during sport (not every time)	☐	☐	3
Frequently during sport (every time)	☐	☐	2
Sometimes during daily activity	☐	☐	1
Frequently during daily activity	☐	☐	0
3. When I make SHARP turns, my ankle feels UNSTABLE			
Never	☐	☐	3
Sometimes when running	☐	☐	2
Often when running	☐	☐	1
When walking	☐	☐	0
4. When going down the stairs, my ankle feels UNSTABLE			
Never	☐	☐	3
If I go fast	☐	☐	2
Occasionally	☐	☐	1
Always	☐	☐	0
5. My ankle feels UNSTABLE when standing on ONE leg			
Never	☐	☐	2
On the ball of my foot	☐	☐	1
With my foot flat	☐	☐	0
6. My ankle feels UNSTABLE when			
Never	☐	☐	3
I hop from side to side	☐	☐	2
I hop on the spot	☐	☐	1
When I jump	☐	☐	0
7. My ankle feels UNSTABLE when			
Never	☐	☐	4
I run on uneven surfaces	☐	☐	3
I jog on uneven surfaces	☐	☐	2
I walk on uneven surfaces	☐	☐	1
I walk on a flat surface	☐	☐	0
8. TYPICALLY, when I start to roll over (or "twist") on my ankle, I can stop it			
Immediately	☐	☐	3
Often	☐	☐	2
Sometimes	☐	☐	1
Never	☐	☐	0
I have never rolled over on my ankle	☐	☐	3
9. After a TYPICAL incident of my ankle rolling over, my ankle returns to "normal"			
Almost immediately	☐	☐	3
Less than one day	☐	☐	2
1–2 days	☐	☐	1
More than 2 days	☐	☐	0
I have never rolled over on my ankle	☐	☐	3

Hiller CE, Refshauge KM, Bundy AC, Herbert ED, Kilbreath SL. 2005

Appendix 2: Foot and Ankle Disability Index

Score:	**The Foot & Ankle Disability Index (FADI) Score**	
Clinician Name:	Daniel Adelman ATC, LAT, CSCS, PES	
Subject ID:		
Date:		
	0 - Unable to Do	
	1 - Extreme Difficulty	
	2 - Moderate Difficulty	
	3 - Slight Difficulty	
	4 - No difficulty at all	
Question:	**Answer:**	**Score**
Standing		
Walking on even ground		
Walking on even ground without shoes		
Walking up hills		
Walking down hills		
Going up stairs		
Going down stairs		
Walking on uneven ground		
Stepping up and down curves		
Squatting		
Sleeping		
Coming up to your toes		
Walking initially		
Walking 5 minutes or less		
Walking approximately 10 minutes		
Walking 15 minutes or greater		
Home responsibilities		
Activities of daily living		
Personal care		
Light to moderate work (standing, walking)		
Heavy work (push/pulling, climbing, carrying)		
Recreational activities		
General level of pain		
Pain at rest		
Pain during your normal activity		
Pain first thing in the morning		
	Total FADI Score:	
Reference for Score:		
Martin RL, Burdett RG, Irrgang JJ. Development of the Foot and Ankle Disability Index (FADI). J Orthop Sports Phys Ther. 1999; 29: A32-A33		

Appendix 3: Foot and Ankle Disability Index Sport

Score:	**The Foot & Ankle Disability Index (FADI) Sport**	
Clinician Name:	Daniel Adelman ATC, LAT, CSCS, PES	
Subject ID:		
Date:		
	0 - Unable to Do	
	1 - Extreme Difficulty	
	2 - Moderate Difficulty	
	3 - Slight Difficulty	
	4 - No difficulty at all	
Question:	**Answer:**	**Score**
Running		
Jumping		
Landing		
Squatting and stopping quickly		
Cutting, lateral movements		
Low-impact activities		
Ability to perform activity with your normal technique		
Ability to participate in your desired sport as long as you would like		
	Total FADI Sport Score:	
Reference for Score:		
Martin RL, Burdett RG, Irrgang JJ. Development of the Foot and Ankle Disability Index (FADI). J Orthop Sports Phys Ther. 1999; 29: A32-A33		

REFERENCES

Abercromby, A. F. J., Amonette, W. E., Layne, C. S., Mcfarlin, B. K., Hinman, M. R., & Paloski, W. H. (2007). Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc, 39*(9), 1642-1650. doi: Doi 10.1249/Mss.0b013618093f551

Arnold, B. L., Wright, C. J., & Ross, S. E. (2011). Functional Ankle Instability and Health-Related Quality of Life. *J Athl Train, 46*(6), 634-641.

Bahr, R., & Bahr, I. A. (1997). Incidence of acute volleyball injuries: A prospective cohort study of injury mechanisms and risk factors. *Scandinavian Journal of Medicine & Science in Sports, 7*(3), 166-171.

Beckman, S. M., & Buchanan, T. S. (1995). Ankle Inversion Injury and Hypermobility - Effect on Hip and Ankle Muscle Electromyography Onset Latency. *Arch Phys Med Rehabil, 76*(12), 1138-1143.

Bernier, J. N., & Perrin, D. H. (1998). Effect of coordination training on proprioception of the functionally unstable ankle. *Journal of Orthopaedic & Sports Physical Therapy, 27*(4), 264-275.

Beynnon, B. D., Murphy, D. F., & Alosa, D. M. (2002). Predictive Factors for Lateral Ankle Sprains: A Literature Review. *J Athl Train, 37*(4), 376-380.

Bogaerts, A., Verschueren, S., Delecluse, C., Claessens, A. L., & Boonen, S. (2007). Effects of whole body vibration training on postural control in older individuals: A 1 year randomized controlled trial. *Gait Posture, 26*(2), 309-316. doi: Doi 10.1016/J.Gaitpost.2006.09.078

Bosco, C., Iacovelli, M., Tsarpela, O., Cardinale, M., Bonifazi, M., Tihanyi, J., . . . Viru, A. (2000). Hormonal responses to whole body vibration in men. *Eur J Appl Physiol, 81*(6), 449-454.

Brown, C. N., & Mynark, R. (2007). Balance deficits in recreational athletes with chronic ankle instability. [Research Support, Non-U.S. Gov't]. *J Athl Train, 42*(3), 367-373.

Brown, C. N., Padua, D. A., Marshall, S. W., & Guskiewicz, K. M. (2011). Hip Kinematics During a Stop-Jump Task in Patients With Chronic Ankle Instability. *J Athl Train, 46*(5), 461-467.

Brunetti, O., Filippi, G. M., Lorenzini, M., Liti, A., Panichi, R., Roscini, M., . . . Cerulli, G. (2006a). Improvement of posture stability by vibratory stimulation following anterior cruciate ligament reconstruction. *Knee Surgery Sports Traumatology Arthroscopy, 14*(11), 1180-1187. doi: Doi 10.1007/S00167-006-0101-2

**Brunetti, O., Filippi, G. M., Lorenzini, M., Liti, A., Panichi, R., Roscini, M., . . . Cerulli, G. (2006b). Improvement of posture stability by vibratory stimulation following anterior cruciate ligament reconstruction. [Randomized Controlled Trial
Research Support, Non-U.S. Gov't]. *Knee Surg Sports Traumatol Arthrosc, 14*(11), 1180-1187. doi: 10.1007/s00167-006-0101-2**

Bruyere, O., Wuidart, M. A., Di Palma, E., Gourlay, M., Ethgen, O., Richy, F., & Reginster, J. Y. (2005). Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil, 86*(2), 303-307.

Bullocksaxton, J. E. (1994). Local Sensation Changes and Altered Hip Muscle Function Following Severe Ankle Sprain. *Physical Therapy, 74*(1), 17-28.

Cardinale, M., & Lim, J. (2003). Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *Journal of Strength and Conditioning Research, 17*(3), 621-624.

Caulfield, B., & Garrett, M. (2004). Changes in ground reaction force during jump landing in subjects with functional instability of the ankle joint. *Clinical Biomechanics, 19*(6), 617-621. doi: Doi 10.1016/J.Clinbiomech.2004.03.001

Cheung, W. H., Mok, H. W., Qin, L., Sze, P. C., Lee, K. M., & Leung, K. S. (2007). High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil, 88*(7), 852-857. doi: Doi 10.1016/J.Apmr.2007.03.028

Cloak, R., Nevill, A. M., Clarke, F., Day, S., & Wyon, M. A. (2010). Vibration training improves balance in unstable ankles. [Randomized Controlled Trial]. *Int J Sports Med, 31*(12), 894-900. doi: 10.1055/s-0030-1265151

Cormie, P., Deane, R. S., Triplett, N. T., & McBride, J. M. (2006). Acute effects of whole-body vibration on muscle activity, strength, and power. *Journal of Strength and Conditioning Research, 20*(2), 257-261.

Delecluse, C., Roelants, M., & Verschueren, S. (2003). Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc, 35*(6), 1033-1041. doi: Doi 10.1249/01.Mss.0000069752.96438.B0

Dizon, J. M. R., & Reyes, J. J. B. (2010). A systematic review on the effectiveness of external ankle supports in the prevention of inversion ankle sprains among elite and recreational players. *Journal of Science and Medicine in Sport, 13*(3), 309-317. doi: Doi 10.1016/J.Jsams.2009.05.002

Docherty, C. L., Moore, J. H., & Arnold, B. L. (1998). Effects of strength training on strength development and joint position sense in functionally unstable ankles. *J Athl Train, 33*(4), 310-314.

Eils, E., & Rosenbaum, D. (2001). A multi-station proprioceptive exercise program in patients with ankle instability. *Med Sci Sports Exerc, 33*(12), 1991-1998.

Erskine, J., Smillie, I., Leiper, J., Ball, D., & Cardinale, M. (2007). Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men. *Clinical Physiology and Functional Imaging, 27*(4), 242-248. doi: Doi 10.1111/J.1475-097x.2007.00745.X

Fallat, L., Grimm, D. J., & Saracco, J. A. (1998). Sprained ankle syndrome: prevalence and analysis of 639 acute injuries. *J Foot Ankle Surg, 37*(4), 280-285.

Freeman, M. A. (1965). Instability of the foot after injuries to the lateral ligament of the ankle. *J Bone Joint Surg Br, 47*(4), 669-677.

Freeman, M. A., Dean, M. R., & Hanham, I. W. (1965). The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br, 47*(4), 678-685.

Friel, K., McLean, N., Myers, C., & Caceres, M. (2006). Ipsilateral hip abductor weakness after inversion ankle sprain. *J Athl Train, 41*(1), 74-78.

Fu, C. L. A., Yung, S. H. P., Law, K. Y. B., Leung, K. H. H., Lui, P. Y. P., Siu, H. K., & Chan, K. M. (2013). The Effect of Early Whole-Body Vibration Therapy on

Neuromuscular Control After Anterior Cruciate Ligament Reconstruction. *American Journal of Sports Medicine, xx*(x), 1-11. doi: DOI: 10.1177/0363546513476473

Garn, S. N., & Newton, R. A. (1988). Kinesthetic Awareness in Subjects with Multiple Ankle Sprains. *Physical Therapy, 68*(11), 1667-1671.

Garrett, M., Kerr, T., & Caulfield, B. (1999). Phase-dependent inhibition of H-reflexes during walking in humans is independent of reduction in knee angular velocity. *Journal of Neurophysiology, 82*(2), 747-753.

Garrick, J. G. (1977). The frequency of injury, mechanism of injury, and epidemiology of ankle sprains. *Am J Sports Med, 5*(6), 241-242.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force Platform Measures for Evaluating Postural Control - Reliability and Validity. *Arch Phys Med Rehabil, 70*(7), 510-517.

Goldie, P. A., Evans, O. M., & Bach, T. M. (1994). Postural Control Following Inversion Injuries of the Ankle. *Arch Phys Med Rehabil, 75*(9), 969-975.

Gribble, P. A., Hertel, J., Denegar, C. R., & Buckley, W. E. (2004). The effects of fatigue and chronic ankle instability on dynamic postural control. *J Athl Train, 39*(4), 321-329.

Gross, M. T. (1987). Effects of Recurrent Lateral Ankle Sprains on Active and Passive Judgments of Joint Position. *Physical Therapy, 67*(10), 1505-1509.

Guskiewicz, K., & Perrin, D. H. (1996). Research and clinical applications of assessing balance. *Journal of Sport Rehabilitation, 5*, 45-63.

Gutierrez, G. M., Knight, C. A., Swanik, C. B., Royer, T., Manal, K., Caulfield, B., & Kaminski, T. W. (2012). Examining Neuromuscular Control During Landings on a Supinating Platform in Persons With and Without Ankle Instability. *American Journal of Sports Medicine, 40*(1), 193-201. doi: Doi 10.1177/0363546511422323

Hale, S. A., & Hertel, J. (2005). Reliability and Sensitivity of the Foot and Ankle Disability Index in Subjects With Chronic Ankle Instability. *J Athl Train, 40*(1), 35-40.

Harrington, K. D. (1979). Degenerative Arthritis of the Ankle Secondary to Long-Standing Lateral Ligament Instability. *Journal of Bone and Joint Surgery-American Volume, 61*(3), 354-361.

Hermens HJ, Merletti R, Rau G, Disselhorst-Klug C, Stegerman DF, & GM, H. (2000) Retrieved April 3, 2012, 2012, from www.seniam.org

Hertel, J. (2000). Functional instability following lateral ankle sprain. *Sports Medicine, 29*(5), 361-371.

Hertel, J. (2002). Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train, 37*(4), 364-375.

Hertel, J., & Denegar, C. R. (1998). A Rehabilitation Paradigm for Restoring Neuromuscular Control Following Athletic Injury. *Athletic Therapy Today, 3*(5), 12-16.

Hiller, C. E., Refshauge, K. M., Bundy, A. C., Herbert, R. D., & Kilbreath, S. L. (2006). The Cumberland ankle instability tool: a report of validity and reliability testing. [Research Support, Non-U.S. Gov't]. *Arch Phys Med Rehabil, 87*(9), 1235-1241. doi: 10.1016/j.apmr.2006.05.022

Hudson, Z. (2009). Rehabilitation and return to play after foot and ankle injuries in athletes. [Review]. *Sports Med Arthrosc, 17*(3), 203-207. doi: 10.1097/JSA.0b013e3181a5ce96

Hughes, T., & Rochester, P. (2008). The effects of proprioceptive exercise and taping on proprioception in subjects with functional ankle instability: A review of the literature. *Physical Therapy in Sport, 9*(3), 136-147. doi: Doi 10.1016/J.Ptsp.2008.06.003

Issurin, V. B., Liebermann, D. G., & Tenenbaum, G. (1994). Effect of vibratory stimulation training on maximal force and flexibility. *Journal of Sports Sciences, 12*(6), 561-566.

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

Konradsen, L., Olesen, S., & Hansen, H. M. (1998). Ankle sensorimotor control and eversion strength after acute ankle inversion injuries. *American Journal of Sports Medicine, 26*(1), 72-77.

Konradsen, L., & Ravn, J. B. (1990). Ankle Instability Caused by Prolonged Peroneal Reaction-Time. *Acta Orthopaedica Scandinavica, 61*(5), 388-390.

Konradsen, L., Voigt, M., & Hojsgaard, C. (1997). Ankle inversion injuries - The role of the dynamic defense mechanism. *American Journal of Sports Medicine, 25*(1), 54-58.

Lentell, G., Baas, B., Lopez, D., Mcguire, L., Sarrels, M., & Snyder, P. (1995). The Contributions of Proprioceptive Deficits, Muscle Function, and Anatomic Laxity to Functional Instability of the Ankle. *Journal of Orthopaedic & Sports Physical Therapy, 21*(4), 206-215.

Mahieu, N. N., Witvrouw, E., Van de Voorde, D., Michilsens, D., Arbyn, V., & Van den Broecke, W. (2006). Improving strength and postural control in young skiers: Whole-body vibration versus equivalent resistance training. *J Athl Train, 41*(3), 286-293.

Martin, B. J., & Park, H. S. (1997). Analysis of the tonic vibration reflex: Influence of vibration variables on motor unit synchronization and fatigue. *European Journal of Applied Physiology and Occupational Physiology, 75*(6), 504-511.

Martinez, F., Rubio, J. A., Ramos, D. J., Esteban, P., Mendizabal, S., & Jimenez, F. (2013). Effects of 6-week whole body vibration training on the reflex response of the ankle muscles: a randomized controlled trial. *Int J Sports Phys Ther, 8*(1), 15-24.

Mattacola, C. G., & Dwyer, M. K. (2002). Rehabilitation of the Ankle After Acute Sprain or Chronic Instability. *J Athl Train, 37*(4), 413-429.

McGuine, T. A., & Keene, J. S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine, 34*(7), 1103-1111. doi: Doi 10.1177/0363546505284191

McKay, G. D., Goldie, P. A., Payne, W. R., & Oakes, B. W. (2001). Ankle injuries in basketball: injury rate and risk factors. *British Journal of Sports Medicine, 35*(2), 103-108.

Meinyk, M., Kofler, B., Faist, M., Hodapp, M., & Gollhofer, A. (2008). Effect of a Whole-Body Vibration Session on Knee Stability. *Int J Sports Med, 29*(10), 839-844. doi: Doi 10.1055/S-2008-1038405

Melnyk, M., Schloz, C., Schmitt, S., & Gollhofer, A. (2009). Neuromuscular Ankle Joint Stabilisation after 4-weeks WBV Training. *Int J Sports Med, 30*(6), 461-466. doi: Doi 10.1055/S-0028-1112141

Michell, T. B., Ross, S. E., Blackburn, J. T., Hirth, C. J., & Guskiewicz, K. M. (2006). Functional balance training, with or without exercise sandals, for subjects with stable or unstable ankles. *J Athl Train, 41*(4), 393-398.

Michelson, J. D., & Hutchins, C. (1995). Mechanoreceptors in Human Ankle Ligaments. *Journal of Bone and Joint Surgery-British Volume, 77B*(2), 219-224.

Mickel, T. J., Bottoni, C. R., Tsuji, G., Chang, K., Baum, L., & Tokushige, K. A. (2006). Prophylactic bracing versus taping for the prevention of ankle sprains in high school athletes: a prospective, randomized trial. [Randomized Controlled Trial
Research Support, Non-U.S. Gov't]. *J Foot Ankle Surg, 45*(6), 360-365. doi: 10.1053/j.jfas.2006.09.005

Milgrom, C., Shlamkovitch, N., Finestone, A., Eldad, A., Laor, A., Danon, Y. L., . . . Simkin, A. (1991). Risk-Factors for Lateral Ankle Sprain - a Prospective-Study among Military Recruits. *Foot & Ankle, 12*(1), 26-30.

Moezy, A., Olyaei, G., Hadian, M., Razi, M., & Faghihzadeh, S. (2008). A comparative study of whole body vibration training and conventional training on knee proprioception and postural stability after anterior cruciate ligament reconstruction. *British Journal of Sports Medicine, 42*(5). doi: Artn 373
Doi 10.1136/Bjsm.2007.038554

Nazarov, V., & Spivak, G. (1985). Development of athlete's strength abilites by means of biomechanical stimulation method. *Theory Prac Phys Culture, 12*, 445-450.

Palmieri-Smith, R. M., Hopkins, J. T., & Brown, T. N. (2009). Peroneal Activation Deficits in Persons With Functional Ankle Instability. *American Journal of Sports Medicine, 37*(5), 982-988. doi: Doi 10.1177/0363546508330147

Perlman, M., Leveille, D., DeLeonibus, J., Hartman, R., Klein, J., Handelman, R., . . . Wertheimer, S. (1987). Inversion lateral ankle trauma: differential diagnosis, review of the literature, and prospective study. [Comparative Study]. *J Foot Surg, 26*(2), 95-135.

Pollock, R. D., Provan, S., Martin, F. C., & Newham, D. J. (2011). The effects of whole body vibration on balance, joint position sense and cutaneous sensation. *Eur J Appl Physiol, 111*(12), 3069-3077. doi: 10.1007/s00421-011-1943-y

Prentice, W. (2009). *Arnheim's Princples of Athletic Training: A Competency Based Approach* (13th ed.). New York, NY: McGraw Hill.

Rasool, J., & George, K. (2007). The impact of single-leg dynamic balance training on dynamic stability. *Physical Therapy in Sport, 8*(4), 177-184. doi: Doi 10.1016/J.Ptsp.2007.06.001

Rees, S. S., Murphy, A. J., & Watsford, M. L. (2009). Effects of whole body vibration on postural steadiness in an older population. *J Sci Med Sport, 12*(4), 440-444. doi: 10.1016/j.jsams.2008.02.002

Refshauge, K. M., Kilbreath, S. L., & Raymond, J. (2000). The effect of recurrent ankle inversion sprain and taping on proprioception at the ankle. *Med Sci Sports Exerc, 32*(1), 10-15.

Rittweger, J. (2010). Vibration as an exercise modality: how it may work, and what its potential might be. *Eur J Appl Physiol, 108*(5), 877-904. doi: Doi 10.1007/S00421-009-1303-3

Rittweger, J., Beller, G., & Felsenberg, D. (2000). Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clinical Physiology, 20*(2), 134-142.

Rittweger, J., Mutschelknauss, M., & Felsenberg, D. (2003). Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. *Clinical Physiology and Functional Imaging, 23*(2), 81-86.

Ronnestad, B. R., Holden, G., Samnoy, L. E., & Paulsen, G. (2012). Acute effect of whole-body vibration on power, one-repetition maximum, and muscle activation in power lifters. *J Strength Cond Res, 26*(2), 531-539. doi: 10.1519/JSC.0b013e318220d9bb

Ross, S. E., & Guskiewicz, K. M. (2003). Time to stabilization: A method for analyzing dynamic postural stability. *Athletic Therapy Today, 8*(3), 37-39.

Ross, S. E., & Guskiewicz, K. M. (2004). Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clinical Journal of Sport Medicine, 14*(6), 332-338.

Ross, S. E., & Guskiewicz, K. M. (2006). Effect of coordination training with and without stochastic resonance stimulation on dynamic postural stability of subjects with functional ankle instability and subjects with stable ankles. *Clinical Journal of Sport Medicine, 16*(4), 323-328.

Ross, S. E., Guskiewicz, K. M., & Yu, B. (2005). Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train, 40*(4), 298-304.

Rozzi, S. L., Lephart, S. M., Sterner, R., & Kuligowski, L. (1999). Balance training for persons with functionally unstable ankles. *Journal of Orthopaedic & Sports Physical Therapy, 29*(8), 478-486.

Ryan, L. (1994). Mechanical Stability, muscle strength and proprioception in the functionally unstable ankle. *Australian Physiotherapy, 40*(1), 41-47.

Santilli, V., Frascarelli, M. A., Paoloni, M., Frascarelli, F., Camerota, F., De Natale, L., & De Santis, F. (2005). Peroneus longus muscle activation pattern during gait cycle in athletes affected by functional ankle instability - A surface electromyographic study. *American Journal of Sports Medicine, 33*(8), 1183-1187. doi: Doi 10.1177/0363546504274147

Schaap, G. R., Dekeizer, G., & Marti, K. (1989). Inversion Trauma of the Ankle. *Archives of Orthopaedic and Trauma Surgery, 108*(5), 273-275.

Schuhfried, O., Mittermaier, C., Jovanovic, T., Pieber, K., & Paternostro-Sluga, T. (2005). Effects of whole-body vibration in patients with multiple sclerosis: a pilot study. *Clinical Rehabilitation, 19*(8), 834-842. doi: Doi 10.1191/0269215505cr919oa

Sitja Rabert, M., Rigau Comas, D., Fort Vanmeerhaeghe, A., Santoyo Medina, C., Roque i Figuls, M., Romero-Rodriguez, D., & Bonfill Cosp, X. (2012). Whole-body vibration training for patients with neurodegenerative disease. [Meta-Analysis
Review]. *Cochrane Database Syst Rev, 2,* CD009097. doi: 10.1002/14651858.CD009097.pub2

Takebayashi, T., Yamashita, T., Minaki, Y., & Ishii, S. (1997). Mechanosensitive afferent units in the lateral ligament of the ankle. *Journal of Bone and Joint Surgery-British Volume, 79B*(3), 490-493.

Tihanyi, T. K., Horvath, M., Fazekas, G., Hortobagyi, T., & Tihanyi, J. (2007). One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke. *Clinical Rehabilitation, 21*(9), 782-793. doi: Doi 10.1177/0269215507077814

Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T. A. H., Pasanen, M., Kontulainen, S., . . . Vuori, I. (2002a). Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clinical Physiology and Functional Imaging, 22*(2), 145-152.

Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T. A. H., Pasanen, M., Kontulainen, S., . . . Vuori, I. (2002b). Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc, 34*(9), 1523-1528. doi: Doi 10.1249/01.Mss.0000027713.51345.Ae

Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T. A. H., Pasanen, M., Kontulainen, S., . . . Vuori, I. (2003). Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: A randomized controlled study. *Journal of Bone and Mineral Research, 18*(5), 876-884.

Tropp, H., Eckstrand, J., & Gillquist, J. (1984). Factors Affecting Stabiliometry recordings of single limb stance. *Am J Sports Med, 12,* 185-188.

Tropp, H., Ekstrand, J., & Gillquist, J. (1984). Stabilometry in Functional Instability of the Ankle and Its Value in Predicting Injury. *Med Sci Sports Exerc, 16*(1), 64-66.

Tropp, H., & Odenrick, P. (1988). Postural Control in Single-Limb Stance. *Journal of Orthopaedic Research, 6*(6), 833-839.

Verhagen, R. A. W., Dekeizer, G., & Vandijk, C. N. (1995). Long-Term Follow-up of Inversion Trauma of the Ankle. *Archives of Orthopaedic and Trauma Surgery, 114*(2), 92-96.

Wakeling, J. M., Nigg, B. M., & Rozitis, A. I. (2002). Muscle activity damps the soft tissue resonance that occurs in response to pulsed and continuous vibrations. *Journal of Applied Physiology, 93*(3), 1093-1103. doi: Doi 10.1152/Japplphysiol.00142.2002

Wikstrom, E. A., Fournier, K. A., & McKeon, P. O. (2010). Postural control differs between those with and without chronic ankle instability. *Gait Posture, 32*(1), 82-86. doi: Doi 10.1016/J.Gaitpost.2010.03.015

Wilkerson, G. B. (2002). Biomechanical and neuromuscular effects of ankle taping and bracing. *J Athl Train, 37*(4), 436-445.

**Winter, D. A., Patla, A. E., & Frank, J. S. (1990). Assessment of balance control in humans. [Research Support, Non-U.S. Gov't
Review]. *Med Prog Technol, 16*(1-2), 31-51.**

Yeung, M. S., Chan, K. M., So, C. H., & Yuan, W. Y. (1994). An epidemiological survey on ankle sprain. *Br J Sports Med, 28*(2), 112-116.