Whole-Body Vibration Transmission Barefoot and with Shoes in Athletes and Sedentary Individuals

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ABSTRACT

Whole-Body Vibration Transmission Barefoot and with Shoes in Athletes and Sedentary Females

Nour Saade

Whole-Body Vibration (WBV) is used in various settings; a lack of consistency is noted in the set-up of individuals on these machines. Whether or not to wear shoes and which parameters to select are difficult questions to answer due to the lack of detailed biomechanical analysis of these conditions. The effects of footwear (shoe or barefoot) and athletic level (varsity athletes or sedentary) on acceleration were analyzed for the lower extremity and at the neck under different parameters (frequency and amplitude) while subjects performed a single-leg squat exercise. Thirty healthy college and university level athletes or sedentary females volunteered in this study. A two-by-two counterbalanced set-up was performed. The measures of acceleration at the different locations were analysed and compared using ANOVAs with a significance of $p \leq 0.05$. *Results found variation of the acceleration between conditions to be dependent on parameters of vibration (amplitude and frequency). Footwear condition and level of training caused multiple differences in acceleration of certain axis at different locations without showing a consistent effect.* These findings aid our understanding of vibration parameter effects on the human body and their interaction within each other. Further studies are warranted to improve our understanding of the global effects of vibration parameters.

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ABBREVIATIONS

BF:	Bare Footed
EMG:	Electromyography
Hz:	Hertz
mm:	millimetre
MVC:	Maximal Voluntary Contraction
RV:	Rotational Vibration
SW:	Shoe Wearing
TPD:	Two-Point Discrimination
TVR:	Tonic Vibration Reflex
VV:	Vertical Vibration
WBV:	Whole-Body Vibration
WBVT:	Whole-Body Vibration Training

PREFACE

This thesis was prepared using the guidelines from the *Thesis Preparation and Thesis Examination Regulations* of Concordia University's school of graduate studies for the manuscript-based thesis. The manuscript included in this thesis represents a portion of the entire work of this thesis. All the results are available in the front portion of the thesis including the information which is presented in the manuscript.

The manuscript presented is in preparation for submission to the *Journal of Strength and Conditioning Research*. All the figures are available in the content of the thesis and the relevant items will also be prepared as a separate document for the submission of the manuscript. An overlap of information from the thesis is noted in the manuscript section of this document.

The *Journal of Strength and Conditioning Research requires* the authors to format the document in a specific manner for their journal and hence these guidelines may differ from the *Thesis Preparation and Thesis Examination Regulations* of Concordia University's. Hence, the manuscript section differs slightly from the format of the front portion of the thesis.

THESIS COMPOSITION

An overview and description of each chapter of this manuscript-based thesis.

INTRODUCTION: Introduction to whole-body vibration. Descriptions of fields which use the modality and objective of this research.

CHAPTER I: Definition of whole-body vibration, literature review relating to research.

CHAPTER II: Rationale, study objectives and hypothesis for current research.

CHAPTER III: Methodology description (participants, equipment, procedures) for research.

CHAPTER IV: Results for acceleration by axis and joint between conditions, arch drop and two point discrimination. Discussion on acceleration ordered by joint, then arch and two-point discrimination.

CHAPTER V: Manuscript – Introduction to whole-body vibration, rationale, objectives, methods, result and discussion. Focus on acceleration at the foot and knee, between footwear condition and training levels.

CONCLUSION: Summary of the study and emphasis on practical applications of results. Suggestions for future research on the topic.

AUTHOR CONTRIBUTIONS FOR THE MANUSCRIPT

Nour Saade is the primary author of the manuscript as he was responsible for the literature review and the composition of the entire manuscript. Mr. Saade was responsible for the complete operation of the study including subject recruitment, data collection, data analysis and the interpretation of the results.

Dr. Richard DeMont is the main supervisor of Mr. Saade and was responsible for overseeing the study. He was also actively involved in the editing of the thesis.

Dr. Subhash Rakheja provided the laboratory space for data collection and provided assistance regarding mechanical engineering knowledge pertinent to the thesis in addition to helping with the machinery used in the lab. In addition, he provided general comments on the thesis.

INTRODUCTION

Whole-body vibration (WBV) which was initially termed as “rhythmic neuromuscular stimulation” in the 1960s was brought to interest when a study demonstrated the stimulus could affect trunk flexion (Biermann 1960). Since then, several beneficial claims associated with WBV have warranted continuous research on the use of vibration platforms in multiple domains. In the strength and conditioning domain, whole-body vibration training (WBVT) is promoted by research indicating improvements in muscular strength, power and flexibility (CARDINALE 2003, Delecluse C 2003, Nele N. Mahieu 2006, Annino G 2007, Jacobs 2009, Rønnestad 2009, Rønnestad 2009, Petit PD 2010, Turner AP 2011). Use of WBV could forge a way into rehabilitation clinics to assist patient healing following anterior cruciate ligament surgery, to increase cartilage density during bed-rest bound individuals or with cystic fibrosis patients (Moezy A 2008, Rietschel E 2008, Liphardt AM 2009). Overweight populations might be attracted to claims that WBV can reduce visceral adipose tissue accumulation (Vissers D 2010). From the first WBV publications in the 1960s, research on the topic has increased in number; in 2002 we can count 30 vs. 2012 we can count 143 (4.7x more), new publications when searching “whole-body vibration” in Pubmed. Vibration platforms have become increasingly accessible for use by the general public in gyms and training facilities and certain models are designed for home use. The popularity gained by WBVT should be matched by explanations of the mechanisms causing the benefits of WBVT yet a discrepancy is present. In order to complement the knowledge we possess on WBV investigating the mechanical properties of vibration transmission in humans, would increase the understanding of certain WBV characteristics and confirm the foundations of the many theories currently assumed about the topic.

The transmission of vibration through the body is influenced by internal and external elements. The musculoskeletal system, an internal element, responds to dampen vibrations of the body's soft tissues with increased muscle activation and contractions (Wakeling JM 2002). Correspondingly, the maximum degree of vibration damping has also been associated to the highest level of muscle activity (Cardinale M 2005). There is no certainty on which muscular properties are the main causes of vibration damping. However, when damping was measured in children the results indicated that they transmit a higher percentage of vibration through the ankle and knee joint than adults (Bressel E 2010). An explanation could be the difference in muscular structure and mass of these two populations. Therefore, individuals who are more muscular and athletic might be better at damping vibrations than their sedentary counterparts but no vibration damping research has compared athletes to untrained individuals. Comparing the damping between trained and untrained individuals would provide insight on whether muscular composition affects the way vibration travels through the body. Any differences in the damping would then be important for the way WBVT is prescribed to trained and untrained individuals.

More so, the arch type of the individual subjected to vibration is another internal factor which might affect vibration damping. We are aware that arch height affects the transmission of forces through the body and the amount of acceleration which reaches the lower back during running (Nachbauer W 1992, Ogon M 1999). Considering that the arch types affects the damping of forces caused by running, verifying if the same occurs during WBV would be beneficial for developing WBVT usage guidelines.

Vibration damping is also affected by external sources, such as footwear. Wearing shoes seems to relate to a higher activation of the gastrocnemius muscle whereas being barefoot relates to higher activation of the vastus lateralis muscle (Marín PJ 2009). Although, research has been done to measure the effect of wearing shoes or being barefoot on muscle activity during WBV exposure; none looked at the effect they have on damping the vibration. If there are significant differences between being barefoot or wearing shoes on the damping of vibration the instructions for WBVT would then differ according to the amount of vibration desired to be transmitted to the individual.

There should also be so caution involved when WBV is used. A study has indicated adverse effects such as temporary decrease in cutaneous sensation following WBV (Pollock RD 2011). Verifying whether there are any relationships between WBV transmission and cutaneous sensation would be helpful in understanding how to use the platforms in a safer manner.

The users of WBVT might be interested in identifying the sources of variations in vibration transmission between individuals. Training on vibration platforms has shown greater performance increase for sedentary individuals compared to athletes (Rønnestad 2009, Rønnestad 2009). Meanwhile, vibration damping between training levels has never been measured. Determining if there are differences between athletes and sedentary individuals would provide substance to WBV usage guidelines and the knowledgebase of

WBVT. By comparing shoes versus barefoot and the foot arch component to the analysis we can confirm the specific implication of each of these constituents on the damping of WBV and adjust our vibration exposure guidelines to attain the desired efficiency. Therefore, the purpose of this study is to analyze the transmissibility of vibration between athletes and sedentary individuals while varying between barefoot or shoes and accounting for arch height and cutaneous sensation.

CHAPTER I: LITERATURE SURVEY

Defining Whole-Body Vibration

The term whole-body vibration (WBV) refers to an individual standing or sitting on a vibrating platform. The vibrations are generated through mechanical oscillations produced by the arrangement of the motor system in the platform. The vibrations are transmitted through the body of the individual standing on the platform and cause an interaction which is the basis of WBVT (PowerPlate 2013). The vibrations are qualified by their frequency (Hz), which corresponds to the number of cycles per second and amplitude (mm), which is the displacement from neutral to the highest point of the range the platform travels through (Vibraflex 2011). The vibratory stimulus resembles a sinusoidal wave because of the type of stimulus generated by the motors inside the platform (Fig. 1).

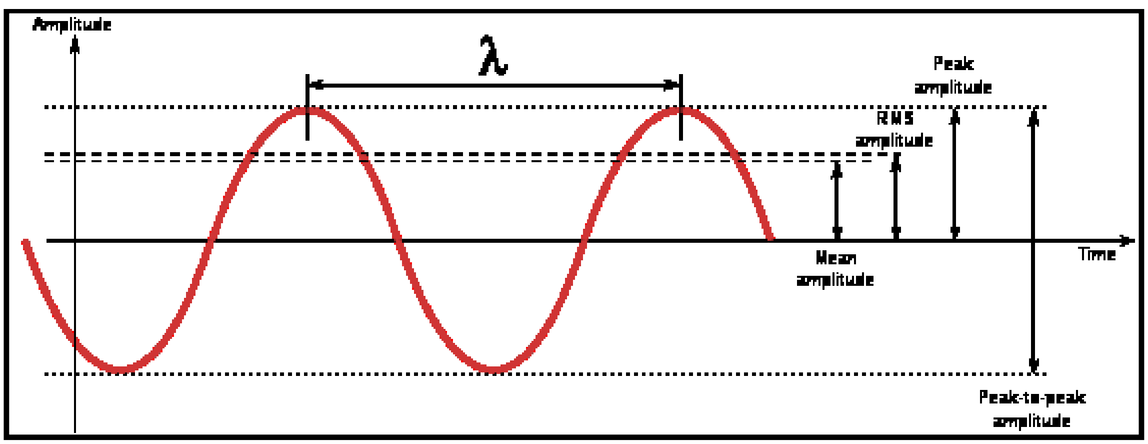

Figure 1: **Sinusoidal waveform**

Different types of vibration

Vertical Vibration (VV) vs. Rotational Vibration (RV)

The mechanisms used by the vibration platforms to generate oscillatory motion are different. Vibration platforms produce vertical, rotational or horizontal vibrations [figure 2 (Pel 2009)]. The vibration platforms are not necessarily limited to provide vibration through one of these axes, for example, rotational vibration combines vertical and rotational vibration output. Certain machine models emit the three previously mentioned vibrations combined. The main two types seen in commercial WBV platforms are vertical vibration (VV) and rotational vibration (RV) platforms. The horizontal vibration is seen in certain home designed models but it is not common for commercial platforms (Pel 2009). The VV is generated by a mechanism which produces a linear motion in the vertical (z-axis), whereas, RV is produced by a rotational mechanism which provides tilting movement to the platform around a central fulcrum (Pel 2009). The main difference between VV and RV is that VV oscillations generated by the motor are isolated in the vertical direction axis. Rotational vibrations (RV) encompass a rotational component along with the movement in the vertical axis, therefore, the platform moves like a seesaw or teeter-totter. In the case of the RV the position of the feet on the platform plays a role in determining the magnitude of the vibration amplitude and therefore need to be considered when using the machines.

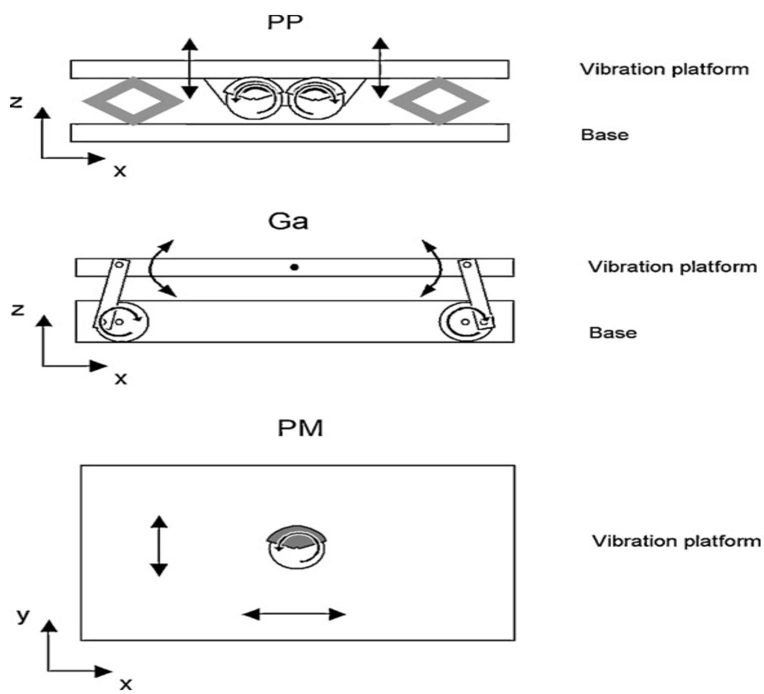

Figure 2: **Vertical, rotational and horizontal vibrations machine models.**

Vibration Transmission

Output of Different Machines

There are several brands and models of WBV platforms available on the market. The mechanical composition of each machine influences the amount of vibration transmitted to the body of the person standing on them (Pel 2009). Depending on the machine used, the vertical accelerations produced and measured differ. The Galileo generated about 15 units of g whereas the PowerPlate generated an estimated 8 units of g in the vertical direction while both machines were set at a common frequency of 25Hz and the feet positioned to obtain the same amplitude (Pel 2009). The difference in the accelerations measured indicate that the formula used to calculate accelerations account for frequency and amplitude, but not the type of machine. Therefore, the results obtained by using one machine are specific to that machine.

How it works: Vibration response through the body

In muscle spindle and Golgi tendon organ

The muscle spindle endings are a special type of sensory receptor and are separated into categories. The purpose of the muscle spindle is to respond to lengthening of the muscle fibers by initiating a motor response to contract the muscle (Guyton 2006). There are primary muscle spindle endings which are sensory afferent endings encircling the central portion of each intrafusal fiber (Guyton 2006). The secondary muscle spindle endings are also afferent but they are less sensitive to stretch of the muscle and they innervate the receptor region on both sides of the primary ending (Guyton 2006). Vibration of the tendon stimulates a response from both primary and secondary spindle fibers (EKLUND 1971, EKLUND 1972, Burke D 1976).

The Golgi tendon organ is a receptor found in the tendons of muscles which perceives changes in tension along the muscle and responds by causing a contraction of that muscle (Guyton 2006). The primary and secondary spindle endings and the Golgi tendon organ all respond to the vibration of a non-contracting muscle (Burke D 1976). The role of the muscle spindles and the Golgi tendon organ become important when considering the implication of the tonic vibration reflex (TVR) which is believed to be induced during WBV.

Tonic Vibration Reflex (TVR)

While an individual is exposed to WBV their muscles contract to adapt and dampen the vibrations as they travel through the body. The tonic vibration reflex (TVR) is an explanation to the muscle contractions produced. To define the TVR we need to analyze what occurs at the platform and in the muscle while exposed to WBV. As the platform oscillates, the position of the foot is changed to maintain contact with the platform causing repeated lengthening and shortening of muscles along the chain. The lengthening of the muscle will activate the muscle spindles and in turn initiate the TVR through influx of information from primary spindle endings (Burke D 1976, Guyton 2006). The result of the TVR is contractions in the muscle being lengthened and a relaxation of their antagonist (Eklund 1966).

Therefore, the TVR is theorized to cause a synchronized response in the muscles which alternate through contracted and relaxed states. As the muscles respond to the vibration by contracting they dampen the vibration transmission through the body.

Post Activation Potentiation (PAP):

Post activation potentiation (PAP) is a phenomenon which causes an enhancement of the acute muscle force following previous activation of the same component (Robbins 2005). The PAP enhances muscular function either by causing a twitch potentiation (TP) or a reflex potentiation (RP) (Sale 2004, Hodgson M 2005, Prisby RD 2008, Cochrane DJ 2010). There is no consensus in the research on whether WBV causes PAP. A study on WBV noted no observable PAP or increase in muscle twitch torque related with the exposure to vibration (Jordan M 2010).

Neuromuscular Excitability

Following WBV exposure there seems to be an increase in the neuromuscular excitability of the body. Neuromuscular excitability was enhanced after exposure to WBV at 26Hz and 6mm on a platform while performing squats continuously until exhaustion compared to squats without vibration exposure (Rittweger J 2003). The increase in neuromuscular activity was measured by an increase in the patellar tendon tap amplitude following WBV (Rittweger J 2003).

Research suggests that there is a link between WBV and the neuromuscular system although some studies measured no increase in twitch torque (Jordan M 2010). The fact that an increase in patellar tendon tap amplitude is measured implies that WBV does affect the neuromuscular system.

WBV and neuromuscular activity

Muscle Activation EMG/ Effect of Shoes on EMG

As discussed previously, when exposed to WBV muscle contractions occur in order to absorb the vibration and allow the body to follow the platform. The activity of muscles can also be analyzed by measuring the electromyography (EMG) signal. When measuring EMG during WBV, the lower leg was the segment with the greatest stimulation as EMG reached 5-50% of maximum voluntary contraction (MVC) (Ross D. Polock 2010). The EMG was always higher with a higher amplitude setting; for example at 5.5mm compared with 2.5mm (Ross D. Polock 2010). Increasing the frequency in increments of 5Hz (from 5HZ to 30Hz) caused the EMG of the soleus, lateral gastroc, tibialis anterior and rectus femoris to increase linearly which did not occur with gluteus maximus and biceps femoris muscles (Ross D. Polock 2010). While EMG was compared during rotational (RV) and vertical (VV) WBV, the average EMG value at all knee angles was significantly higher in both vibration conditions then without vibration (Abercromby AF 2007). In the vastus lateralis and the gastrocnemius the neuromuscular activation was measured to be significantly higher during RV than VV, while for the tibialis anterior muscle was significantly higher in VV than RV (Abercromby AF 2007).

When comparing the integrated EMG following a 30second bout of WBV compared with no vibration, there were no significant differences while performing a squat jump (SJ), counter movement jump (CMJ) or isometric squat (Cormie P 2006).

Further considerations on muscle activation during WBV would involve analyzing whether being barefoot (BF) or wearing shoes (SW) will increase or decrease EMG in the participant. Comparing the EMG root mean squared (rms) signal between shoes and barefoot during an unloaded isometric half squat at a frequency of 30Hz and amplitude of 4mm indicated that being barefoot induced the highest EMGrms for the vastus lateralis; whereas, wearing shoes provoked the highest EMGrms for the gastrocnemius muscle (Marín PJ 2009). By measuring the acceleration at the ankle and knee during an isometric squat we would be able to compare those values to the results of EMGrms barefoot and with shoes. Therefore, measuring the damping of vibration at different settings would assist in understanding the phenomenon measured in the study comparing EMG for BF and SW.

Damping through the body

Difference between Child and Adult

The variations in damping differ between children and adults. Children have a higher transmissibility than adults at the ankle by 42% and the hip by 62% while exposed to a frequency of 33Hz (Bressel E 2010). Although, at different frequencies or above the hip joint there were no significant variations between children and adults.

Effects of Posture and Vibration Frequency and Amplitude

The stance and posture individuals adopt while on a WBV platform affects the amount of acceleration that can be measured at different locations on their body (Abercromby AF 2007, Berschin G 2010, Cook DP 2011). Most studies agree that the straighter the standing position the individual assumes the more vibration will reach the head compared with being semi-squatting (40°) (Matsumoto 1998, Abercromby AF 2007). A separate study measured that a semi-squatting position will enhance force transmission through the body as compared with a standing position (Blair Crewther 2004). At a setting of 30Hz and 4mm regardless of the squatting angle, more head acceleration is measured during a bipedal stance than standing on one foot (Abercromby AF 2007). The comparisons of body positioning indicate the variability of results within WBV studies. Considering that we will be measuring the transmissibility differences between trained and untrained individuals; engaging the muscles and using a squatting position rather than a more relaxed standing position becomes essential.

While measuring vertical acceleration in the shank, the greatest values are obtained when the amplitude is higher (3mm vs. 1.5mm), the frequency is lower (20Hz vs. 40Hz) and a deeper squat position is engaged (40° vs. 30°) (Cook DP 2011). The same occurs in the thigh with regards to obtaining the highest vertical acceleration values. Although, the depth of squat does not cause a significant difference in thigh (Cook DP 2011).

A slight difference in the results obtained from previous studies on the frequency producing the highest accelerations through the body is noted. Two experiments pinned down 20Hz (Blair Crewther 2004, Cook DP 2011) as being the frequency causing the highest accelerations above the knee; whereas one experiment measured the frequency to be 15Hz (Ross D. Polock 2010). Therefore, selecting a frequency close to the range of 15Hz to 20Hz would be necessary because these frequencies are related to higher levels of vibration transmissibility.

Damping through the Body

The transmission of vibration through the human body has been examined on multiple occasions and consensus is made that vibration will be dampened and absorbed as it travels up through the body and further away from the platform (Blair Crewther 2004, Kiiski J 2008, Ross D. Polock 2010). The frequency of the platform has an effect on the transmission of acceleration through the body (Kiiski J 2008, Cook DP 2011). With settings between 10-40Hz there is a significant amplification of the peak acceleration at the ankle, whereas, this only occurs at 10Hz for the spine. Consequently, the higher the frequency the less significant the amplification seems to be at a point measured further from the platform (Kiiski J 2008).

Another factor which seems to be affecting the damping of vibration through the body is the natural frequency of soft tissue. The natural frequency of soft tissue can be defined as the frequency at which transmissibility of vibration from the source to the soft tissue reaches a maximum. Exposure at the said frequency causes the tissue to resonate (Wakeling JM 2002, Yue 2004). The value of the natural frequency increases from 10Hz to 50Hz when the muscles contract versus being relaxed as measured in the triceps surae, quadriceps and tibialis anterior muscles (Wakeling JM 2001).The body responds by an increase in the damping of vibration when the frequency of the platform is closer to the natural frequency of the soft tissue (Wakeling JM 2002). Therefore, the natural frequency of certain tissues can cause higher vibration measures in different tissues when those parameters are selected. The natural frequency can explain why certain settings produce measured acceleration different from the expected patterns discussed above.

General effects on body

Impaired Sensation

Vibration exposure has not always been categorized as a potentially beneficial condition. Vibration white finger which is brought on by maneuvering vibrating hand held machinery (BANISTER 1972) caused caution and provided arguments to the use of vibration as a modality. As we analyze WBV the question of the safety of using these machines for training still trigger some debate. In a recent study, on the use of WBV as a training modality, cutaneous sensation was measured through pressure aesthesiometry and results indicated that WBV at 30Hz and 4mm amplitude reduced sensation at the foot and ankle immediately after exposure, however, the sensation would return 15min post-exposure. At an amplitude of 8mm, the decreased sensation at the foot, ankle and posterior shank remained for the entire length of the procedure (Pollock RD 2011). The measurement of cutaneous sensation during WBV is a temporary effect, however, possible dangers might occur with excessive exposure. Hence, such result should be further investigated to understand whether there is a similar reduction in sensation for barefoot and shoe wearing individuals. Such a comparison can eventually be utilized to determine whether individuals should be advised to perform WBVT under one condition rather than the other.

Body Composition/ Fat

Athletes are attracted to use WBVT because of the purported performance benefits produced; however, a more sedentary population might also find interest from the possible effects of WBV on body composition. There is no consensus on the effects of WBV on body composition. While comparing visceral adipose tissue levels in 61 obese individuals, the area (cm^2) of visceral adipose tissue was significantly lower following WBVT than the control and fitness groups (Vissers D 2010). Meanwhile, in another comparison a group of 151 post-menopausal women aged above 65yo incorporated WBVT for 15min into their 60min training. There were no significant improvements in lean body mass, total body fat, and abdominal fat for the trained group compared to a wellness control group. Although, beneficial differences were still present for leg trunk flexion strength (von Stengel S. 2010). These results indicate that there is a possibility that WBVT can be a valuable addition to training programs depending on the population who uses the modality if the objective is to decrease visceral adipose tissue or increase leg trunk flexion strength.

Cartilage

The exposure to WBV significantly increased cartilage thickness in the weight-bearing portions of the tibia in individuals bound to 6° “head-down-tilt-bed-rest” for 14days compared to a control group for which the thickness decreased (Liphardt AM 2009). Therefore, WBV is a modality that could gain popularity for use in a rehabilitation setting and the understanding of vibration transmission through the body would complement the rehabilitative techniques.

Acute Effect of Vibration

The acute effects of WBV are considered to be any change in body function which can be perceived or measured immediately following one bout of exposure.

On 1RM/Strength

The use of WBV in conjunction with overload training at a setting of 50Hz and 3mm on a VV platform significantly increases 1RM in untrained and recreationally trained individuals compared with overload but no-vibration (Rønnestad 2009). However, with a frequency of 20Hz, 30Hz or 35Hz the effects of WBV on strength or 1RM were non-significant (Da Silva M.E. and Garcia-Manso J.M. 2006, Rønnestad 2009). Furthermore, at a frequency of 40Hz at 4mm the strength had a tendency to decrease for the WBV group although not significantly (Da Silva M.E. and Garcia-Manso J.M. 2006). No differences were found in peak force following 30seconds of WBV at 30Hz and 2.5mm compared to a sham condition (Cormie P 2006).

The measure of isokinetic torque for a WBV group which underwent 1min gradual increase to 26Hz and maintained the frequency for another 5min was significantly higher than a leg cycle ergometer group who pedaled for 6min constantly (Jacobs 2009).

On Power

The power output is evaluated to increase following the exposure to WBV at 50Hz and 3mm as determined by the rise of peak average power during SJ and CMJ in trained and untrained individuals compared to a no-vibration condition (Rønnestad 2009).

Frequencies of 20Hz and 35Hz do not have an acute effect on power in either trained or untrained individuals compared with no-vibration conditions (Rønnestad 2009). No differences were found in peak power following 30seconds of WBV at 30Hz and 2.5mm compared with sham condition (Cormie P 2006). A significant increase in maximal power is achieved with settings of 20Hz and 30Hz at 4mm (Da Silva M.E. and Garcia-Manso J.M. 2006).

The settings to achieve power using WBV are not unanimous. Most settings show no effect on measures of peak power, although, some show an increase in maximal power. Therefore, the results from these studies indicate that WBV benefits are very specific to setting chosen and we should carefully adjust parameters to obtain the desired results for the users.

On CMJ/SJ

The jump height (JH) during CMJ immediately following WBV at 30Hz and 2.5mm was significantly higher than following the sham condition (Cormie P 2006). There is a significant increase in SJ for the frequencies of 20Hz and 30Hz at 4mm compared with no vibration, and there was a slight but insignificant decrease for 40Hz (Da Silva M.E. and Garcia-Manso J.M. 2006). For the CMJ there was a significant increase at 30Hz and there was a significant decrease at 40Hz at 4mm compared with no-vibration (Da Silva M.E. and Garcia-Manso J.M. 2006). In another study, 5min WBV at 20Hz and 4mm showed a significant increase in SJ, whereas, at 40Hz and 4mm there was a significant decrease (CARDINALE 2003). The 40Hz frequency was tried at 8mm in another study and they found significant increases in CMJ at those settings whereas no differences were found with 30Hz and 35Hz and no-vibration (Turner AP 2011).

Therefore, when using a frequency of 40Hz with 4mm the effects might be insignificant or detrimental whereas at 8mm they generate beneficial increases to CMJ.

On Flexibility

The hamstring flexibility was significantly increased with WBV at 20Hz and 4mm, yet there were no significant benefits at 40Hz and 4mm as compared with the no-vibration condition (CARDINALE 2003). In a protocol where vibration was gradually increased during the first minute to 26Hz and maintained at that setting for 5 minutes, the sit and reach test produced significantly higher results in the WBV group compared with a leg cycling ergometer group (Jacobs 2009).

Muscle Stiffness

A specific research compared baseline measures with post warm-up measures of leg stiffness following WBV at 26Hz and 6mm for 6 bouts of 60sec and found no significant differences in measures of stiffness (John B. Cronina 2004).

Warm-up Effect

A review article analyzing the possible uses of WBV suggests that muscular blood flow is increased following exposure and that WBV prepares the muscle for performance by increasing flexibility and strength (Cook DP 2011). Therefore, suggesting WBV can be used as a warm-up prior to sports participation (Cook DP 2011).

Joint Position Sense/ Balance

In young and healthy individuals WBV did not produce any significant effect on joint position sense or balance at a setting of 30Hz and 4mm or 8mm. Although, there was a minimal increase in balance in the vertical plane which was significant at 30min post exposure (Pollock RD 2011).

These results indicate that the effect of WBV on body function might not always be spontaneous and that we might obtain delayed responses. Thus, when using WBV the individuals should adjust their use specifically based on the results desired. For example, an individual who will perform a task requiring balance, should time their WBVT use so that they perform their task 30min following exposure.

Long term Effect of Vibration

On Bone Mineral Density (BMD)

A significant BMD gain was measured in the lumbar spine while using RV, meanwhile VV did not produce an increase compared to the control group (Stengel SV 2010). The values in the neck were non-significant for BMD increase with both RV and VV (Stengel SV 2010).

On Strength

During a 13-week trial, participants trained 3x a week for 20min with WBV while alternating 1:1min on: off ratio; the results demonstrated significant strength gains only in the vibration group where a locked knee position was maintained (Mikhael M 2010). A 6-week trial attempted to determine the difference between 30Hz at 2mm and 50Hz at 4mm settings on strength gains and found that only the 50Hz at 4mm setting significantly increased the knee extensor eccentric voluntary torque and the knee flexor isometric voluntary torque (Petit PD 2010). There is an agreement between different studies that WBV would significantly increase isometric and dynamic knee strength compared to a control group but so does a resistance training group (Delecluse C 2003, Nele N. Mahieu 2006).

On Power/ Explosive Strength Production

The treatment effect is significantly larger for vertical vibration platforms, compared with rotational vibration platform, especially when measuring chronic changes in power output (Marín PJ 2009). A group of ballerinas training with WBV three times a week prior to their ballet practices obtained a significant increase in leg-press power and velocity following WBVT compared to a control group (Annino G 2007).

Adhering to a WBVT program comprising of bouts prior and intermittently during training was compared to resistance training and an active control group. A significant increase in the rate of force development while measuring peak force was noted in the WBVT whereas the differences were non-significant in the other two groups (Lamont HS 2010). By comparing when WBV exposure is beneficial during the training the same study concludes that WBV exposure between exercises may be a viable alternative to vibration during the exercise when trying to increase explosive isometric strength (Lamont HS 2010). Therefore, there were significant benefits from WBV compared to the control group even if the individual did not perform their exercise during WBV but stepped onto the platform in between the exercises. In another study, a group of skiers boasted a significant increase in explosive strength as measured by a high box jump test and plantar-flexor strength after 6 weeks compared with an equivalent strength and training program without vibration (Nele N. Mahieu 2006).

On Balance/Postural Control

A WBVT program for skiers seemed to have no significant impact on the postural control test as performed with a Balance Master platform after 6 weeks of training (Nele N. Mahieu 2006). Since the same group gained measurable increases in strength, the result of postural control might be due to the fact that the vibration occurs in the vertical axis and the balance testing was done in horizontal planes.

On SJ/CMJ

Jumping performance for both SJ and CMJ significantly increased after a 6 week training period with WBV at a setting of 50Hz at 4mm (Petit PD 2010). In a study comparing WBV with resistance training, a control group and a placebo group, the WBV group was the only one to significantly increase the CMJ jump height (Delecluse C 2003). A group of ballerinas was exposed to WBVT 3x a week prior to ballet and then their performance was compared with a control group; following the training the WBVT group significantly increased their CMJ compared to the control group (Annino G 2007). Similarly, training with vibration while doing squats produces significant increases in CMJ while squats without vibration had no effect (Rønnestad 2004). When measuring SJ, there was a significant improvement over a period of 8 weeks in the individualized vibration group, the fixed vibration and control group; yet, the individualized vibration group was the only group to reach significant increase in jumping height, mechanical power and flight time compared with the other two groups (Di Giminiani R 2009).

In the long term training condition, WBV generally produces gains in both SJ and CMJ. The results demonstrating significant gains are repeated over various studies, slightly reducing the controversy on the inconsistent results which accompany some of the other performance gains that are reported with WBVT.

On 1RM

A training program performing squats with vibration and a group performing squats without vibration indicated that both groups significantly increased their 1RM strength; there were no significant differences between the groups (Rønnestad 2004).

In Rehabilitation

The usage of WBV is slowly defining the rehabilitation protocols of certain injuries. Many studies supporting the benefits of WBV to facilitate or aid the healing of certain diseased conditions and injured individuals will be required in order to ensure the presence and use of WBV as a rehabilitation tool.

Proprioception Post-ACL Surgery

Anterior cruciate ligament (ACL) reconstruction can benefit from WBV during the rehabilitation. The use of WBVT during rehab compared with the conventional protocols caused the WBV group to have significantly greater improvements in the reconstructed knee for postural stability(Moezy A 2008). Significant differences were measured in absolute angular error results for the WBV group compared to conventional group when asked to move the knee from 90° to 60° while blindfolded on the Biodex (Moezy A 2008).

Cystic Fibrosis

Individuals with cystic fibrosis were exposed to a WBVT protocol composed of 3x3min session twice a day repeated 5days a week for 3 months at a frequency of 20Hz-25Hz which resulted in significant improvements in all components of the chair rising test, chair-rising time, maximal force, maximal power and velocity (Rietschel E 2008). The peak jump force and velocity also significantly increased following WBVT while the increases during the one-leg jump were non-significant (Rietschel E 2008). The results demonstrate certain benefits of WBVT in the cystic fibrosis population. Although, there were no comparison groups to see whether these effects are greater than any other therapy they still demonstrate the potential of WBV alone compared to no treatment at all.

Difference Between Trained/Untrained

1RM

While exercising with WBV trained and untrained individuals have both been able to significantly increase their strength (Rønnestad 2009, Rønnestad 2009). The untrained individuals increased their strength to a greater extent than what trained individuals were able to achieve (Rønnestad 2009). Although untrained individuals had a greater benefit than trained individuals, both groups improved their strength significantly which promotes using WBV as a training tool regardless of training level.

ISO Standards

Vibration Dose Value

The positive effects of vibration on performance or other body characteristics have been researched. There are certain publications on the adverse effect and the detrimental changes related to excessive vibration exposure on the human body. In the ISO 2631-1 document on vibration exposure WBV is differentiated from vibration provided directly to the limbs as the body responds differently to each. Generally, individuals exposed to high magnitudes of vibration for long durations such as for work have been associated with: several vertebral disc degeneration problems, hearing, visual and balance problems (Abercromby AF 2007). An important consideration on the effects outlined above is that they occur in seated WBV and after long exposure times. Nonetheless, these effects cannot be undermined when dealing with vibration exposure even in a standing position such as for WBVT and ISO 2631-1 attempts to quantify and limit the vibration time based on exposure dosage. The term used is estimated vibration dose value (eVDV) which uses direction, frequency, magnitude and duration of the vibration to calculate the amount which is not recommended to be exceed [ISO]. The current regimens of WBVT do not necessarily confine to the ISO standards as a setting of 30Hz at 4mm for 10min exceeds the eVDV suggested by the ISO 2631-1 and yet several sources use these settings (Abercromby AF 2007). As previously discussed, knee angle and posture do affect the transmission of the vibration through the body (Abercromby AF 2007, Berschin G 2010, Cook DP 2011) which is a component not accounted for in ISO 2631-1. Another criterion to account for when setting parameter and guidelines for WBV is that different machines do not always produce the same acceleration through the body even though they might be set to the same values (Pel 2009).

Current Suggestion for Guidelines

Frequency, Amplitude and Rest Patterns

Usage guidelines for WBV differ between sources and no unanimous settings are found for training. By reviewing the research, we come across certain trends and we can begin forming what is essential to increase certain performance aspects. Generally, we notice that high frequencies are more effective when combined with high displacement amplitudes and when low frequencies are combined with low displacement amplitudes (Adams JB 2009). The time delay during which the benefits of WBV occur or last should be adapted to the specific goal of each individual and ensure that they use WBV during a reasonable time frame in order to obtain the most out of the exposure. For example, the greatest improvements in peak power occur at 1min post-exposure and last up to 5min (Adams JB 2009). A different approach was to use individualized frequencies and determine what the most beneficial setting for WBV would be. Using individualized frequencies was performed by testing individuals under frequencies going from 20Hz to 55Hz in increments of 5Hz and measuring EMG activity at each setting in order to pick the frequency which caused the highest EMG activity for the individual (Di Giminiani R 2009). Using the individualized frequency technique produced greater gains in performance when compared with a fixed vibration setting across the population tested (Di Giminiani R 2009). The individualized setting protocol has not been used in other experiments. Therefore, the results seem promising and further inspection of these claims is required. Following individualized guidelines provides insight on which parameters to use when training with WBV.

Based on Neuromuscular activity

The measure of neuromuscular activity helps estimate the muscle response to the vibration. Based on neuromuscular activity, the 4mm setting caused higher EMGrms than 2mm at a frequency of 30Hz for the medial gastroc and vastus lateralis muscles(Marín PJ 2009). We should also consider that when users were provided with an individualized setting based on the frequency that produced the highest neuromuscular activity they benefitted more from the WBV training than individuals who were exposed to a standardized setting. Therefore, WBV guidelines are sensitive to the individual and the settings should reflect those differences.

Based on Acceleration/ G-forces

Guidelines could also be set based on the acceleration measured through the body under different settings. In that case a 20Hz frequency resulted in significantly higher G-forces than 10Hz and 30Hz. Thus, suggesting the use of the 10Hz and 30Hz frequencies for novice users of vibration and incorporating the 20Hz for people who are conditioned to tolerate higher G-forces (Blair Crewther 2004). Certain studies suggest that the pattern of vibration transmission magnitude seems to decrease as the frequency is increased above the 20Hz setting (Harazin 1998, Blair Crewther 2004). Concurrently, increasing the amplitude appears to cause an increase of the G-forces (Blair Crewther 2004). Consequently, to control the amount of acceleration measured by WBV an understanding of parameter interactions is warranted and should be further considered. Similarly, if differences exist between measured accelerations in trained and untrained individuals, the guideline for usage based on acceleration would need to be modified for these populations.

Based on performance

When analyzing performance based on recovery times 1min and 2min rest times, both permitted significant increases to jump ability, muscle power and strength in acute and long-term training protocols (Da Silva-Grigoletto 2009). There was a slight difference because 2min rest allowed greater improvement than 1min during acute training but it was the 1min rest that produced greater improvement during the long term training (Da Silva-Grigoletto 2009). Therefore, individuals need to select their rest time based on whether they are training for a distant event or if they are to perform immediately.

Effect of Arch Type

Arch type effect on damping

The foot-arch has been analyzed when dealing with ground reaction forces in walking and running. Differences in arch type cause the propagation of forces traveling through the body to be different. The initial medial force peak in the low arch group occurred significantly later than normal and high arched groups (Nachbauer W 1992). The anterior force peak in the low flattening group was significantly lower compared with medium and high flattening group (Nachbauer W 1992). When comparing the acceleration a significantly lower acceleration amplitude and rate was measured in the low back for the high arch group compared with the low arch (Ogon M 1999). Since there might be differences in shock absorbance and force transmission depending on arch type, this factor should be inspected in conjunction with WBV to see if similar relationships exist.

CHAPTER II: RATIONALE &OBJECTIVES

Whole-body vibration is used to achieve various ergogenic benefits. The type of machine used and the parameters selected are factors which determine the effectiveness of WBV. Certain studies have looked at the benefits on trained athletes and untrained or sedentary individuals and found differences. Therefore, performing a study on WBV is affected by several components. We designed a study considering the training level of individuals, different parameters and footwear in order to cover WBV more effectively. The goal was to provide WBV users with a reference in parameter selection and footwear based on desired goal of usage.

We selected one high and one low, frequency and amplitude. The parameters chosen allow us to perform four different combinations. The population was divided into athletic and non-athletic and participants had to undergo WBV with shoes and barefoot. The primary objective was to compare the relationship of the parameters, training level and footwear to the acceleration through the body. Since arch type was related to vibration transmission during running, the second objective was to determine whether the arch had an influence on acceleration during WBV. In the upper body a link was seen between exposure to vibration and decreased sensation. Thus, the third objective was to measure two-point discrimination following WBV.

Our hypothesis was that acceleration would decrease as the location was further from the platform. We also hypothesized, the higher accelerations at the platform would cause higher acceleration in the individual being exposed to them. Wearing shoes was expected to absorb some of the vibration and cause a slightly lower value in the lower extremity (ankle and knee) but similar values for the trunk (ASIS and neck). The athletes were hypothesized to absorb greater amount of vibration due to their better trained muscular system and they were expected to have lower acceleration values at the lower extremity (ankle and knee) with similar values for the trunk (ASIS and neck).

Our second hypothesis, that the arch would affect acceleration similar to running and hence the individuals with higher arches would absorb greater levels of vibration at the ankle and knee. We theorized the arch would absorb some of the vibration while the platform oscillates and would dissipate the vibration mildly before getting to the accelerometers placed on the individual. Finally, we hypothesized WBV exposure would decrease two-point discrimination measures in individuals as seen in the upper extremity. Previous studies have mentioned alterations in the lower extremity using pressure and we wanted to verify if the same occurred to two-point discrimination values.

CHAPTER III: METHODOLOGY

Experimental design

We performed a 2x4 repeated measure trial on trained and untrained female participants to determine if there are differences in the vibration dampening through the body. We collected measurements during one-legged squat with shoes and barefoot. The one-legged squat posture was chosen to reduce the rotational vibration component from a RV platform whereas; a two-legged stance would maximize the rotational component. The independent variables included the vibration frequencies and amplitudes, the level of physical activity and the footwear. The dependent variable are the amount of vibration at various segments of the human body, navicular height change and cutaneous sensation measures.

Participants

Thirty volunteer based female participants were used in the study. They were split into two groups (15 trained, 15 untrained). Measuring acceleration in 15 participants per group would be sufficient according to similar studies which have made these measurements with fewer participants (Arkady 1983, Harazin 1998, Wakeling JM 2001, Kiiski J 2008, Pel 2009, Marín PJ 2009 , Bressel E 2010, Ross D. Polock 2010). The inclusion criteria for trained individuals were to be in-season athletes who train 3 times per week minimum and participate at university or college division 1 level of competition. Untrained individuals were selected from the university population. The inclusion criteria were: they do not perform regular physically demanding tasks, do not exercise, and not enrolled in any leisure sports participation. Exclusion criteria were any condition affecting the tolerance or the transmissibility of the vibration such as: lower extremity injuries in the past year, back pain at time of experiment, acute musculoskeletal inflammation, epilepsy, cancer, gallstones and kidney or bladder stones as per recommendation of the manufacturer of the vibration platform used (Vibraflex 2011).

Vibration System

The vibration platform was a Vibraflex 600 (Naples, Florida Orthometrix, Inc.), which produces vertical vibration around a central fulcrum. Therefore, the vibration produced would be considered rotational vibration (RV). The Vibraflex 600 model can be set from 5Hz to 30Hz for the frequency and from 0mm to 6.4mm for the amplitude of the vibration and allows for a maximal plate acceleration of 22G's according to the manufacturer (Vibraflex 2011).

Acceleration

The acceleration at the joints was measured using tri-axial accelerometers (Boulder, CO, Sparkfun Electronics, ADXL3xx). Since there are no standard techniques to attach the accelerometers to the skin, we chose a method which has been used previously. The accelerometers were attached to the subject using double sided tape (Kiiski J 2008, Pel 2009) and then the boxes and cables were further secured using elastic tape (Kiiski J 2008). The accelerometers provided a measure of g-force (m/s^2). The attachments to the body were at the medial malleolus, the medial epicondyle of the femur, the anterior superior iliac spine and the spinous process of C7 vertebrae. One bi-axial accelerometer was placed on the vibration platform in order to compare the vibrations as they pass through the body with the amount being emitted directly at the surface of the platform.

Cutaneous Sensation

We used two-point discrimination (TPD) for the measurement of cutaneous sensation. The measure of TPD provides a more accurate assessment of change in cutaneous sensation compared to the depth sense perception measurement in patients with hand-arm vibration syndrome (Coughin P.A. 2001). We measured TPD before and immediately after cessation of vibration exposure. We marked down six points on the patient's lower extremity and then used an esthesiometer tool to measure their sensation. The six points chosen were: over 5th metatarsal, over 1 - 2 metatarsal interspace, tip of great toe, plantar surface of first metatarsal head, over Medial Arch of foot, midway between the popliteal fossa and calcaneus (NOLAN 1983, Periyasamy R. 2008, Pollock RD 2011). We adjusted the two-pins to the closest position and then increased the distance by 1mm until the participant felt they were being poked by two-pins. We then repeated the measure while randomly alternating between one and two points until they get eight correct sensations out of ten (NOLAN 1983). The pre-vibration value was compared to the value following the first vibration and the value at the end of the second exposure.

Postural positioning, shoes and foot type

A standard Nike shoe was provided to all participants for the measurement with shoes. The assessment of the foot type and arch was made using the Feiss' Line test. We marked the apex of the medial malleolus, the navicular tubercle and the plantar aspect of the 1st MTP joint while the athlete sits with his feet of the edge of the table (University

2011). We then placed a string between the apex of the medial malleolus and the plantar aspect of the 1st MTP joint and using a tape measure (1mm markings) we marked down the distance between the navicular tubercle and the reference line. The measurement was repeated during weight-bearing. In addition, we marked down the value from the ground to the navicular tubercle of each individual. Noting the deviation of the navicular tubercle in the weight-bearing and non-weight-bearing positions provides a value identified as the navicular drop (University 2011). A fixed goniometer measured the knee angle at 40° during the time data was recorded on the subject (Matsumoto 1998, Abercromby AF 2007). Verbal cues were provided for the individual to maintain the testing position and if they were out of position for more than two seconds the trial would be discarded.

Procedures

Participants were asked to attend the lab on one occasion for the data collection. During the session, participants performed the test with shoes and barefoot. The shoe and barefoot conditions were randomized to negate the order effects. During the visit, the participant were advised of the procedures and were provided with consent forms. Personal statistics of participants such as height, weight and age were collected. Then, leg dominance was determined by asking them to stand and let themselves fall forward three times. The leg which they selected to step forward with twice or more was considered to be their dominant leg. There is no general consensus on methods for determining leg dominance, but the technique selected has been used in previous studies (Hoffman 1998, Todd A. McLoda 2000, Cornelis Jo de Ruiter and Sander Schreven 2010). The participants then had the accelerometers attached at the locations mentioned above.

Before the application of the vibration stimulus the Feiss' Line test and the measurement of cutaneous sensation were completed for a first time. Then the individuals were asked to step onto the vibration platform and undergo vibration either barefoot or while fitted in the standardized shoe. The participants were exposed to four combinations of vibration (15Hz/2mm = 1.8g, 15Hz/4mm = 3.6g, 30Hz/2mm = 7.2g and 30Hz/4mm = 14.5g) for 30 seconds. Between each setting the participants were given 1 min of rest, which is enough to recuperate and avoid fatigue while at the current exposure time (Da Silva-Grigoletto 2009) and has been used in other protocols (Da Silva-Grigoletto 2009, Pel 2009, Marín PJ 2009). Participants maintained the one-legged squat at 40° while they were subjected to vibration on the platform for 30 seconds (Fig. 3). During resting time, the individuals were asked to sit in a chair until the next setting. Immediately at the end of the vibration exposure, the individual stepped off the platform and had their cutaneous sensation measure taken followed by the Feiss' Line test. The vibration was then repeated using the second footwear condition and followed by the same post exposure measurements.

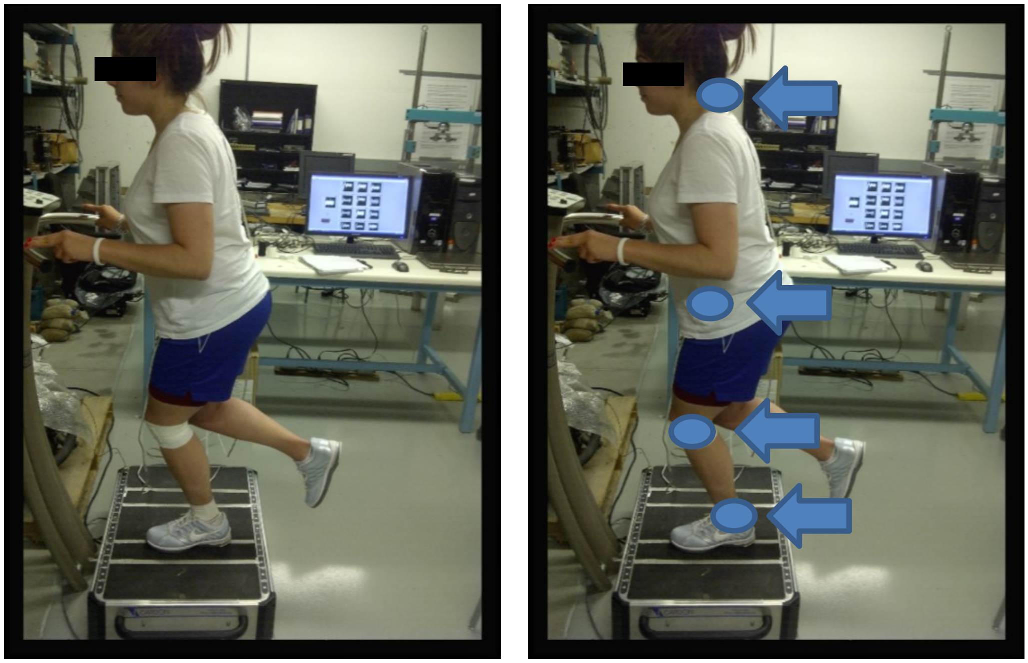

Figure 3: 1-leg squat at 40°

<u>Treatment of Data</u>

The signal from the accelerometers were transmitted to LabView after passing through a power supply box. Vibration signals were analyzed in time, frequency and amplitude domains. The data was normalized by comparing the acceleration recorded at each receptor with the accelerometer placed directly on the platform. The acceleration was determined as the normalized value measured by the accelerometer at each site.

Figure 4: Vibration platform used during the experiment. *Vibraflex ® 600*

Figure 5: Athletic footwear used during the study for both men and women

Statistical Analysis

The statistical analysis was performed using IBM SPSS Statistics 20.0 Release 20.0.0 (Armonk, NY, USA).

Acceleration: Athlete vs. Sedentaty/Shoe vs. Barefoot

An ANOVA was used for comparing shoes to barefoot measures, trained to untrained individuals, pre and post feiss line measures and pre and post cutaneous sensation measures. The statistical measures were performed to see whether the current parameters are significant with α-level of 0.05. The data was divided into a comparison between the four different vibration settings for all other variables. There was an analysis of response to vibration damping between trained and untrained individuals. Then individuals were compared to wearing shoes vs. being barefoot. Another measure was navicular tubercle position to ground. Using navicular position we measured if there were any relationships between the exposure to WBV and the navicular position or navicular drop in the subjects. We also verified if there were any effects on cutaneous sensation as measured prior to WBV exposure compared with post-exposure values.

CHAPTER IV: RESULTS & DISCUSSION

Results

Ankle

To measure acceleration at the ankle an accelerometer was placed at the medial malleolus of the participants.

Vertical

Shoe vs. Barefoot:

Following analysis using a repeated measure ANOVA, the acceleration at the ankle in the vertical axis was significantly ($F = 43.056$, $p < 0.001$) lower in SW than BF (Fig. 6).

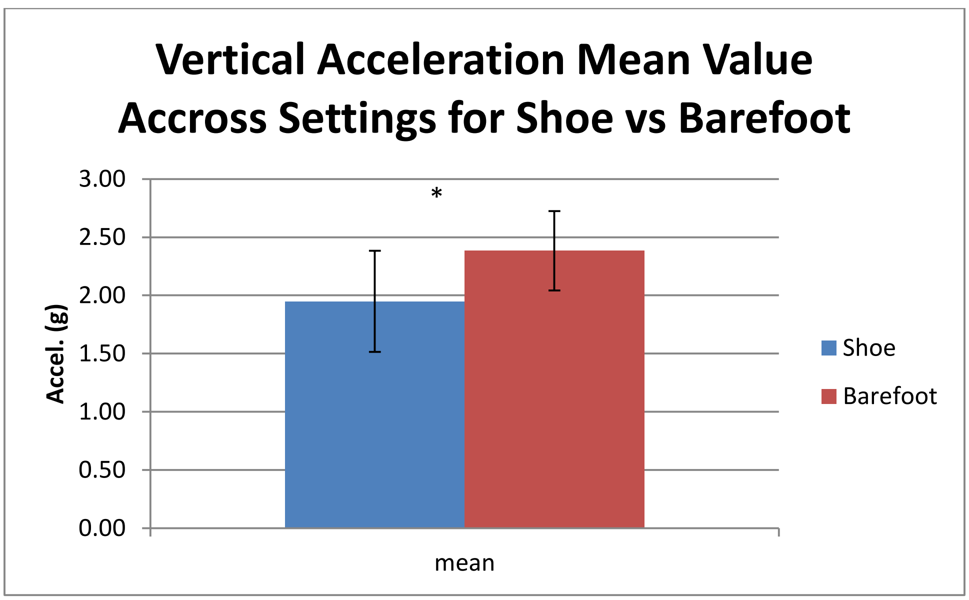

Figure 6: Ankle in vertical direction mean acceleration. The shoe causes significantly less vibration to be measured in the vertical direction then being barefoot.

A repeated measure ANOVA was done to determine the effect of each parameter (frequency/amplitude) on the acceleration at the ankle between SW and BF. The acceleration at the ankle in the vertical direction was significantly lower in SW than BF at the different frequency (F= 6.461, p=0.014) and amplitude (F= 8.939, p=0.004).

The comparison between SW and BF was performed at each setting to determine the relationship of footwear to the acceleration at the ankle during the various settings. The acceleration was significantly lower in SW through all settings at the ankle vertical axis [(2mm15hz: F=17.445, p<0.001), (2mm30hz: F=27.751, p<0.001), (4mm15hz: F=9.409, p=0.003), (4mm30hz: F=13.685, p<0.001)] compared to BF (Fig. 7).

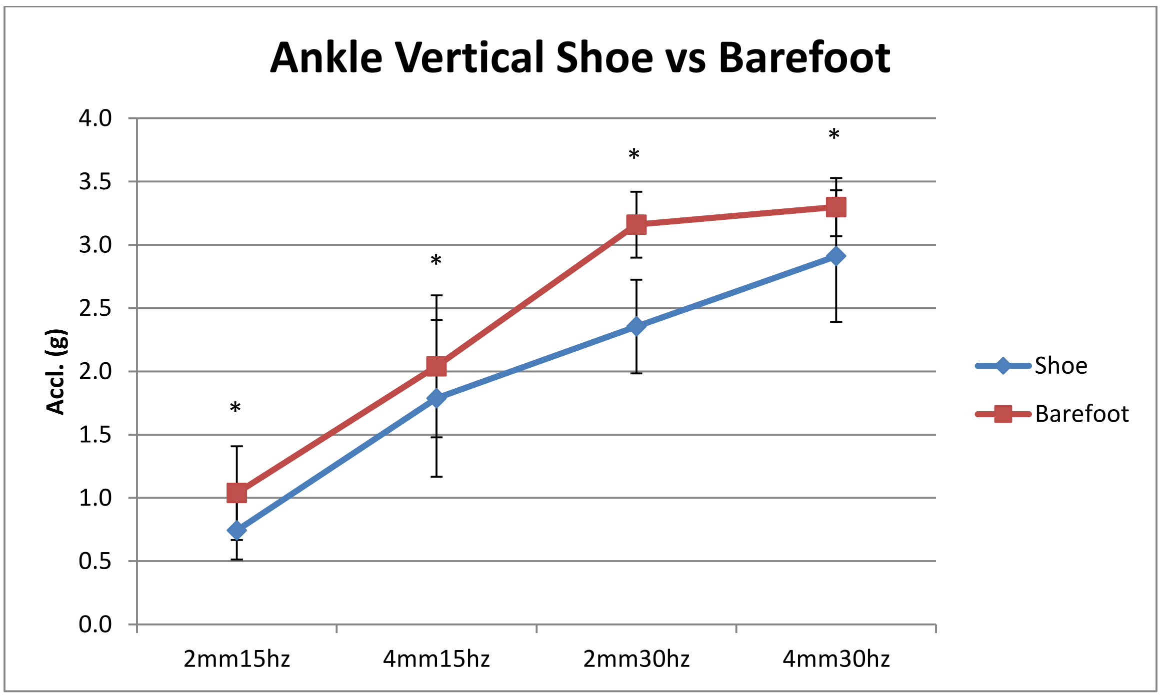

Figure 7: Ankle in vertical direction at the different settings. The shoe causes significantly (2mm15hz, 2mm30hz, 4mm30hz p<0.01 and 4mm15hz p=0.03)less vibration to be measured in the vertical direction then being barefoot.

Coronal

Shoe vs. Barefoot:

A repeated measure ANOVA was used to determine the difference between SW and BF at the coronal axis of the ankle. The total acceleration at the ankle in the coronal axis was significantly (F=24.733, p<0.001) lower in BF than SW (Fig 8).

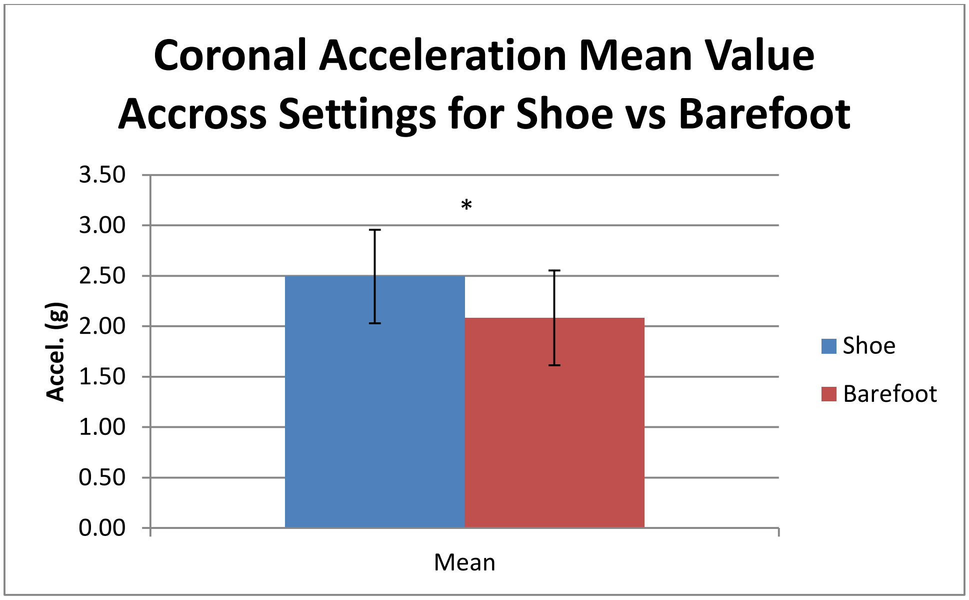

Figure 8: Ankle in vertical direction at the different settings. The shoe causes less vibration to be measured in the vertical direction then being barefoot.

The comparison between SW and BF for each setting at the ankle in the coronal axis were significant at 2mm15hz ($F=16.663$, $p<0.001$), 2mm30hz ($F=30.988$, $p<0.001$) and 4mm15hz ($F=10.425$, $p=0.002$). The values for acceleration in the coronal axis at the ankle were not significant at 4mm30hz ($F=0.784$, $p=0.379$) (Fig. 9).

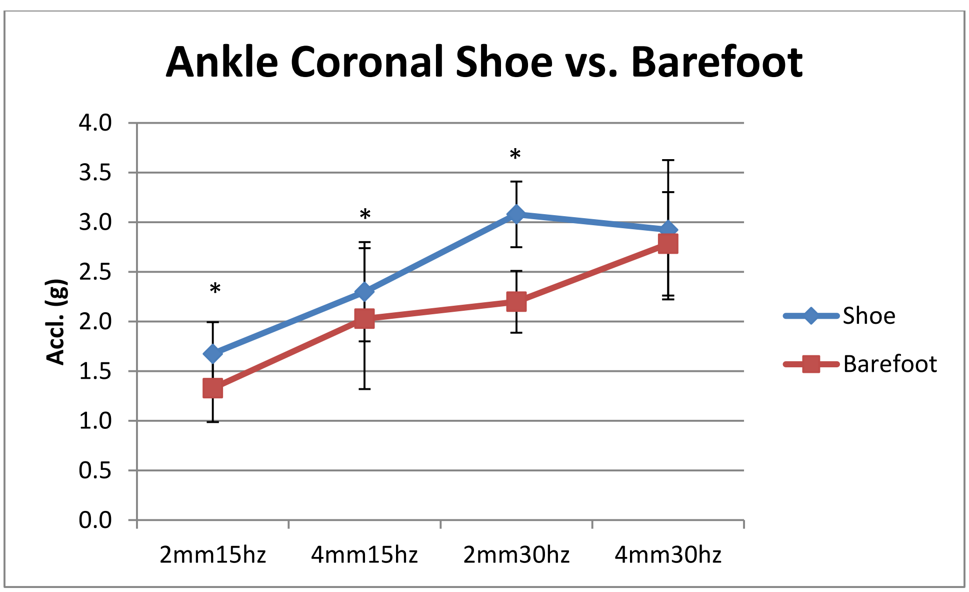

Figure 9: Ankle in vertical direction at the different settings. The shoe causes less vibration to be measured in the vertical direction then being barefoot.

Athlete vs. Non-Athlete:

The total acceleration at the ankle in the coronal axis was significantly (F=5.701, p=0.02) lower in untrained then trained individuals (Fig. 10).

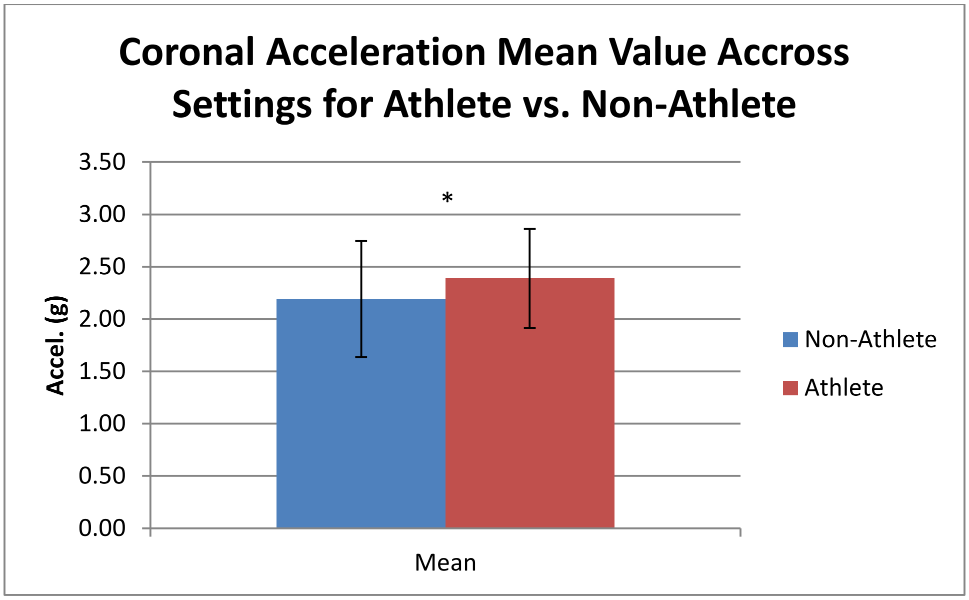

Figure 10: Ankle in coronal direction. The non-athletes have less vibration at the coronal direction then athletes.

Although, comparing the acceleration at the ankle in the coronal direction individually between the two training levels at each setting was not significantly different (Fig. 11).

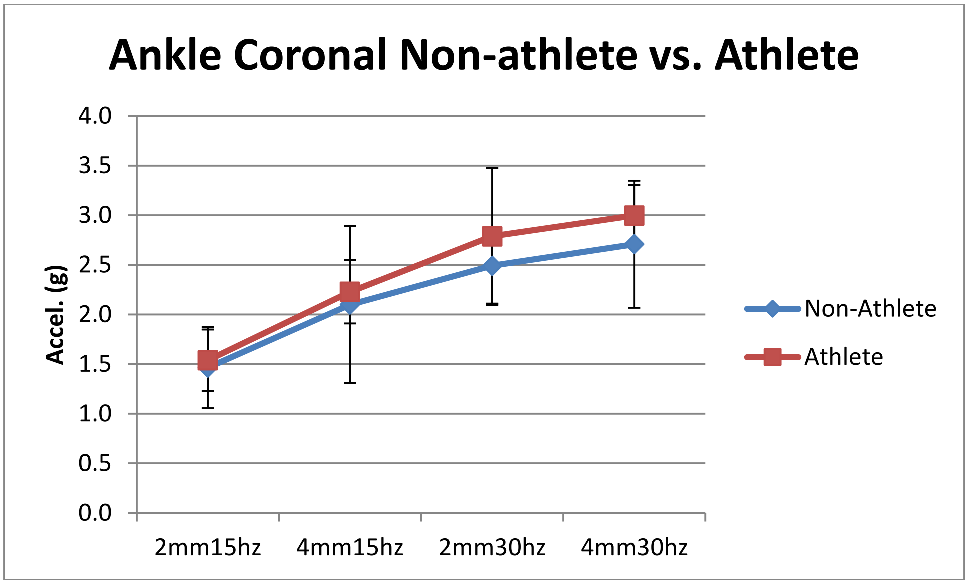

Figure 11: Ankle in coronal direction at the different settings. The non-athletes transmit less vibration in the coronal direction then athletes.

Sagittal

Shoe vs. Barefoot:

Total sagittal acceleration at the ankle between SW and BF was significantly ($F=19.416$, $p<0.001$) lower in SW then BF (Fig. 12).

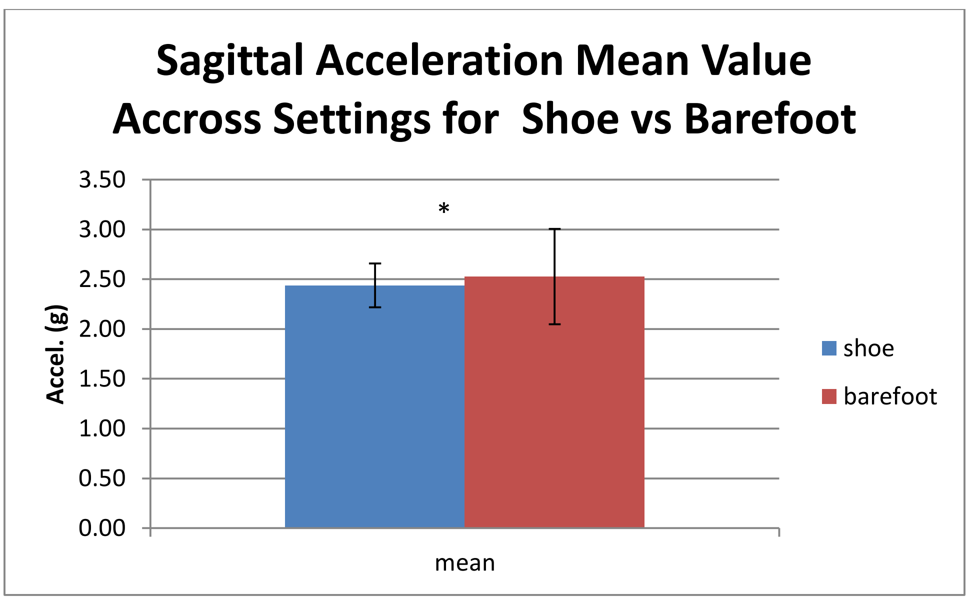

Figure 12: Total acceleration in ankle sagittal shoe vs. barefoot.

The acceleration at the ankle in the sagittal direction between SW and BF was compared to each setting (frequency/amplitude) (Fig. 13).There acceleration measured at the ankle in the sagittal direction was significantly lower for SW than BF at 2mm15hz (F=11.035, p=0.002) and 4mm15hz. (F=8.167, p=0.006). The sagittal acceleration was significantly higher for SW then BF at 4mm30hz (F=10.071, p=0.002). The acceleration values were not significantly different between SW and BF at 2mm30hz.

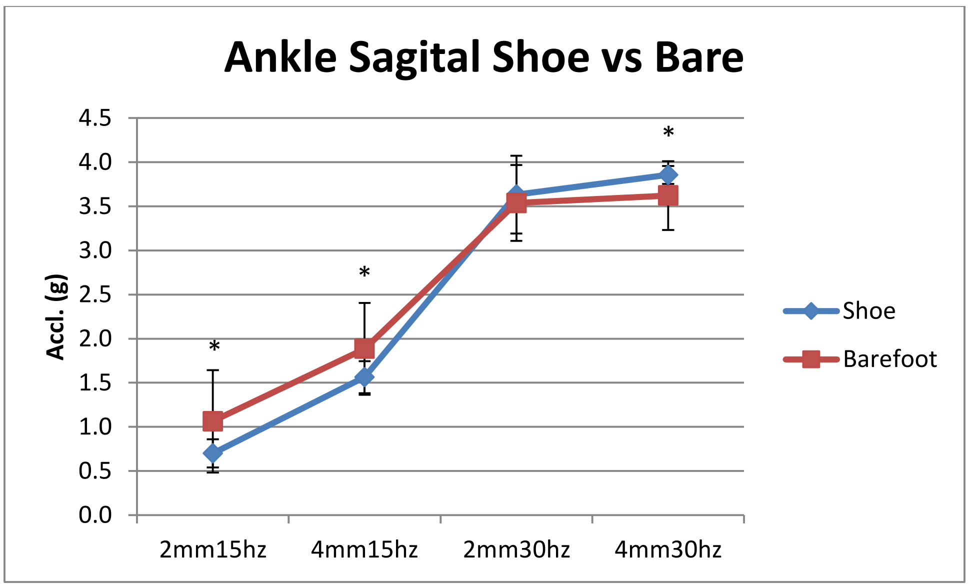

Figure 13: Acceleration at the ankle in the sagittal direction at the different settings. The shoe causes less vibration to be measured at 2mm15hz and 4mm15hz. The shoe condition records greater acceleration at 2mm30hz and 4mm30hz.

Athlete vs. Non-Athlete:

The measure of total acceleration at the ankle in the sagittal direction was significantly (F=5.523, p=0.022) different depending on frequency between the athlete and non-athlete group.

Knee

To measure acceleration at the knee an accelerometer was placed at the medial femoral epicondyle.

Vertical

Athlete vs. Non-Athlete:

A comparison was made between the acceleration at the knee in the vertical axis and training level at each setting (frequency/amplitude). The results were significantly higher in athletes at 2mm15hz (F=16.757, $p<0.001$) and 4mm15hz (F=9.219, p=0.004) than non-athletes (Fig. 14).

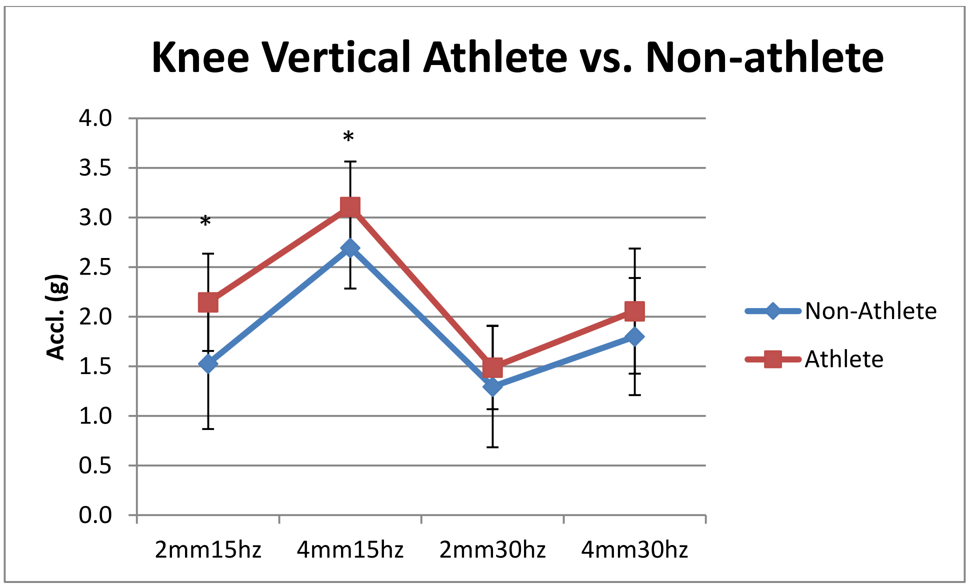

Figure 14: Knee in vertical direction at the different settings. The non-athletes transmit less vibration in the coronal direction then athletes.

Coronal

Shoe vs. Barefoot:

The measures of acceleration at the knee in the coronal direction were compared between SW and BF at each setting. The acceleration at the knee in the coronal axis was a significantly lower at 2mm30hz (F=6.088, p=0.017) SW then BF (Fig. 15).

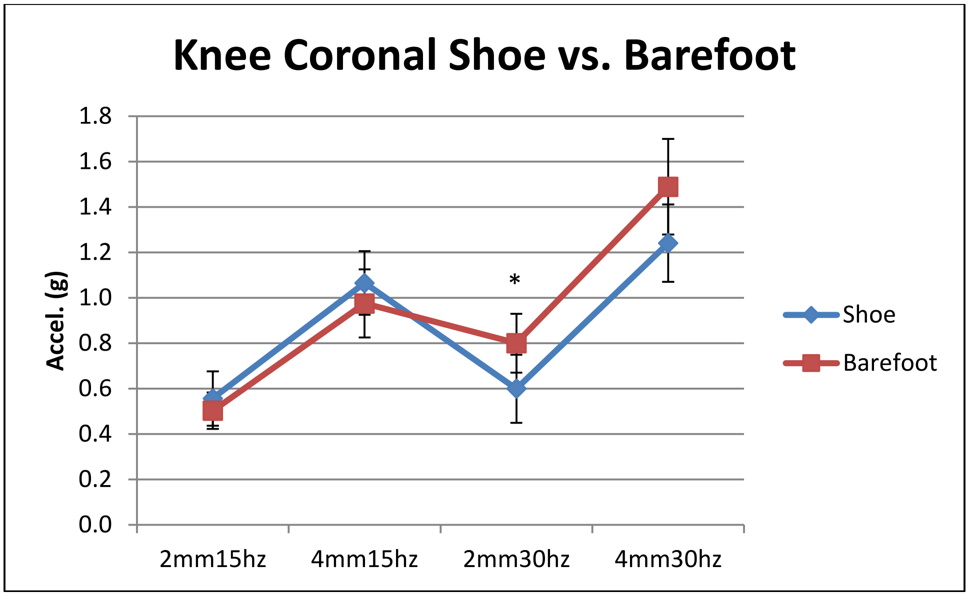

Figure 15: Knee in coronal direction at the different settings. Combined effect of displacement and shoe are significantly different within subjects. There was also a significant group difference between shoe and no shoe at 2mm30hz.

Sagittal

Shoe vs. Barefoot:

The measure of acceleration at the knee in the sagittal plane was compared between SW and BF using a repeated measure ANOVA. The results were significantly different ($F=4.681 p=0.035$) depending on frequency and shoe combined (Fig. 16).

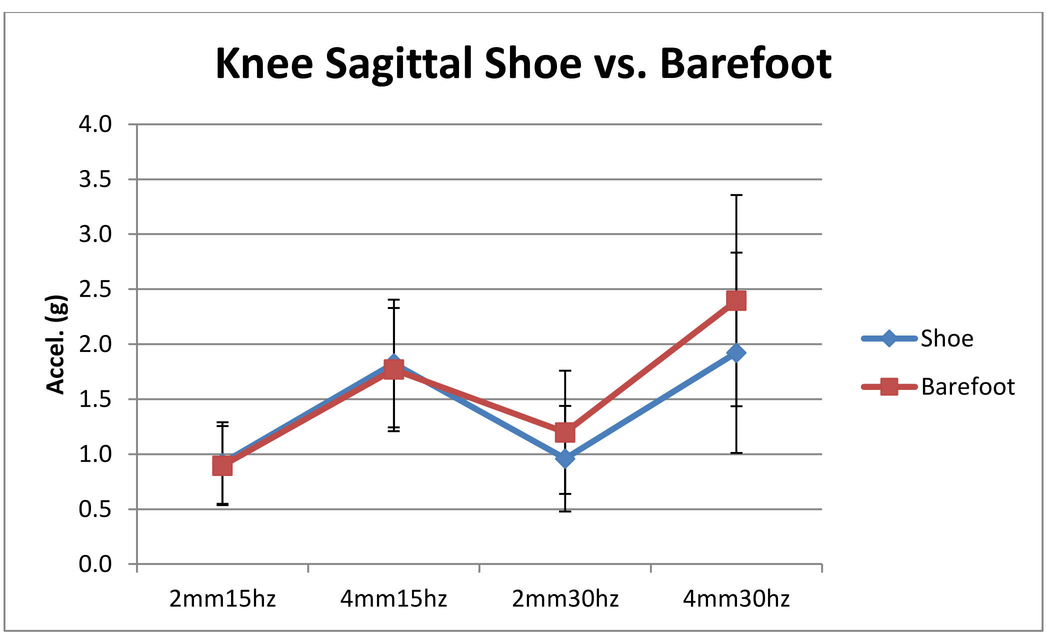

Figure 16: Knee in sagittal direction at the different settings. Combined effect of displacement and shoe are significantly different within subjects.

Athlete vs. Non-Athlete:

The measures for athletes and non-athletes were compared for each setting at the knee. The results were significantly lower for the knee in the sagittal direction at 2mm15hz ($F=7.148$, $p=0.01$) and at 4mm15hz ($F=4.712$, $p=0.034$) for non-athletes compared to athletes (Fig. 17).

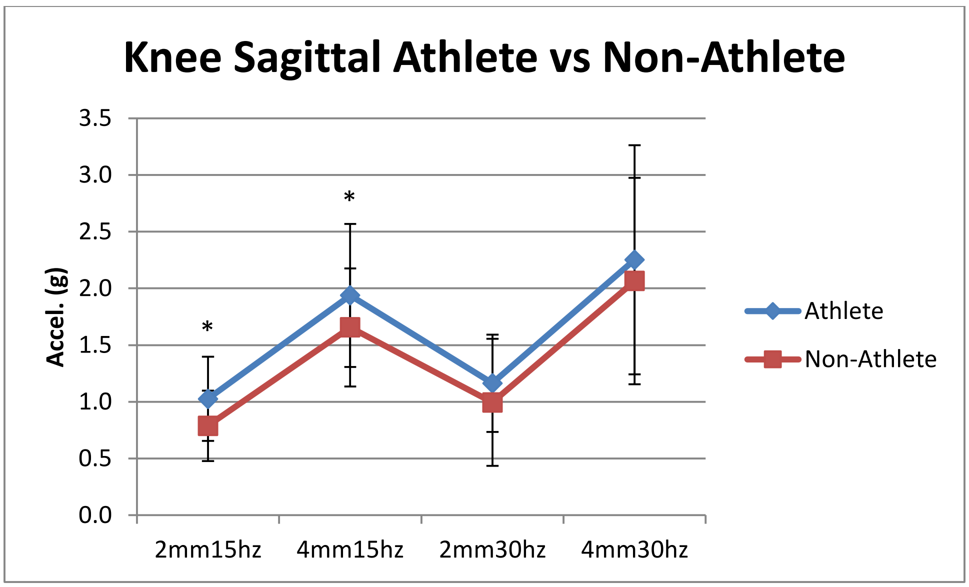

Figure 17: Knee in sagittal direction at the different settings. Significant difference between shoe and barefoot at 15Hz only.

Hip

Vertical

Shoe vs. Barefoot:

The acceleration at the hip in the vertical direction is significantly higher in non-athletes at 2mm15hz ($F=5.247$, $p=0.026$), 2mm30hz ($F=5.551$, $p=0.022$) and 4mm30hz ($F=8.103$, $p=0.006$) compared to athletes (Fig. 18).

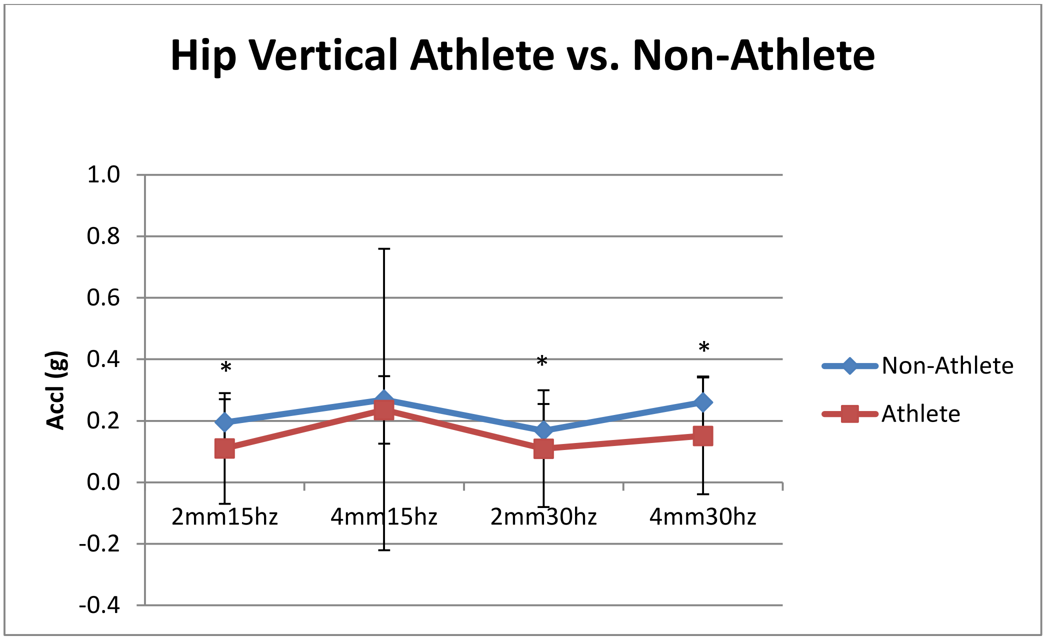

Figure 18: Hip in vertical direction at the different settings. The non-athletes transmit significantly more vibration than athletes at 2mm15hz, 2mm30hz and 4mm30hz.

Sagittal

Athlete vs. Non-Athlete:

The total acceleration in the sagittal direction at the hip accelerometer was significantly different with change in frequency ($F=83.864$, $p<0.001$) and displacement ($F=202.891$, $p<0.001$). Total acceleration at the hip in the sagittal direction was significantly ($F= 5.565$, $p=0.022$) lower in non-athletes then athletes (Fig. 19).

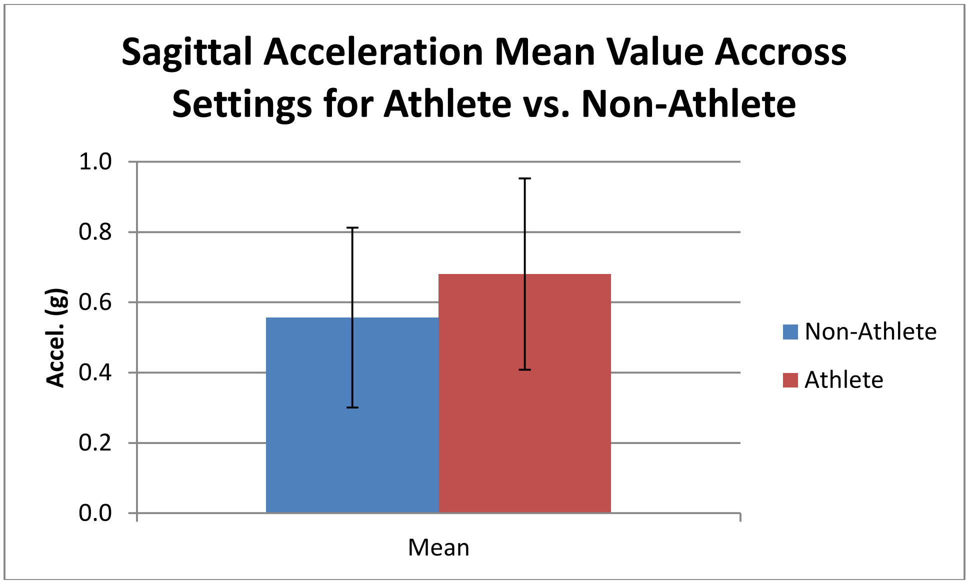

Figure 19: Total acceleration at hip sagittal between athletes and non-athletes. The non -athletes transmit less vibration in the sagittal direction then athletes.

The between group measure of sagittal acceleration at the hip was significantly (F= 4.912, p=0.031) higher in athletes than non-athletes at 2mm30hz (Fig. 20).

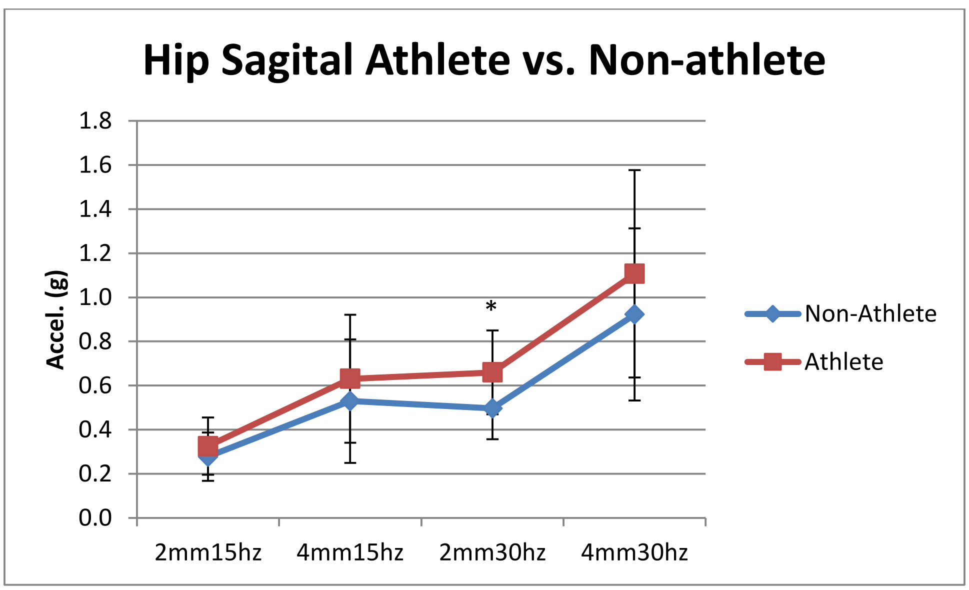

Figure 20: Hip in sagittal direction at the different settings, 2mm30hz is significantly lower in non-athletes.

Cervical

Vertical

Sagittal

All subjects:

The acceleration at the cervical in the sagittal direction is significantly different with changes in frequency (F=11.017, p=0.002) and displacement (F=56.331, p<0.001).

Athlete vs. Non-Athlete:

The between group measures at the cervical spine in the sagittal plane were significantly different at 2mm15hz (F=6.125, p=0.016) (Fig. 21).

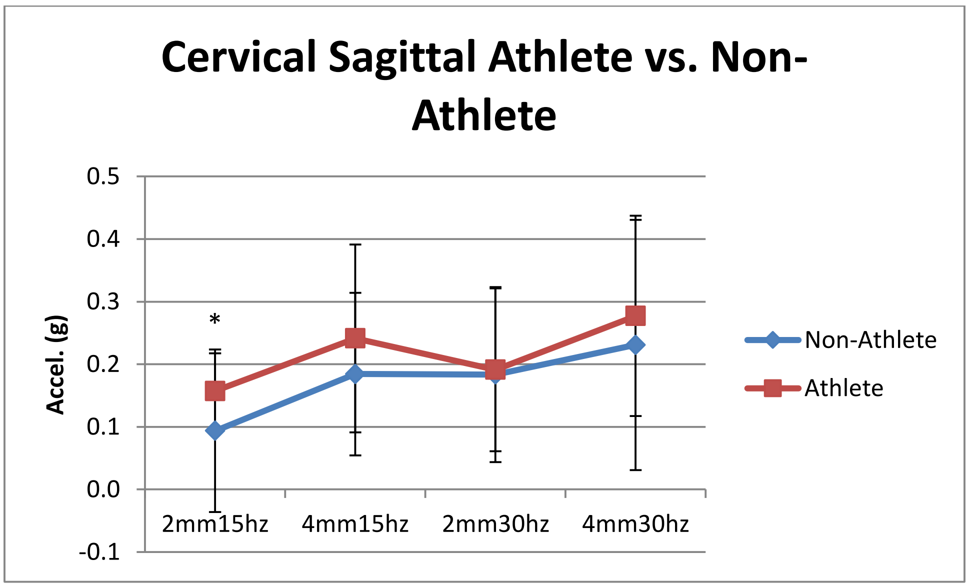

Figure 21: Cervical in sagittal direction at the different settings. The non-athletes transmit significantly less vibration in the sagittal direction then athletes at 2mm15hz.

Across Settings and Joints

The mean of the acceleration rms value was significantly (F= 3296.684, p<0.001) different within subjects at the four measured vertical locations (Fig. 22).

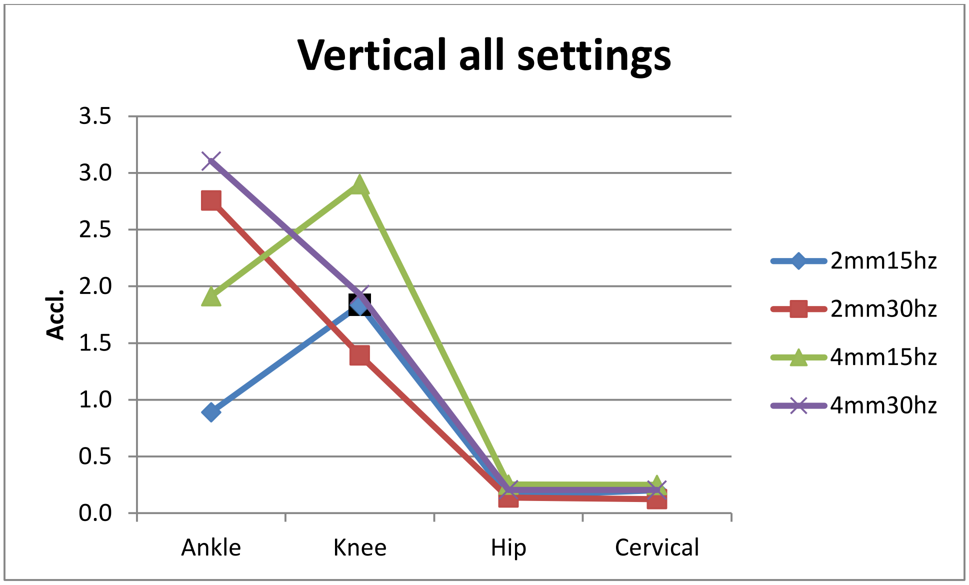

Figure 22:Vertical direction all settings at all joints. The frequency affects whether more vibration is picked up at the ankle or the knee. The displacement affects the amount of vibration picked up at the ankle or the knee.

The frequency causes an inverse relationship between acceleration at the knee and ankle. The 15hz frequency causes greater acceleration at the knee than the ankle, while the 30hz frequency causes higher displacement at the ankle than the knee ($F=624.086$, $p<0.001$) (Fig. 23).

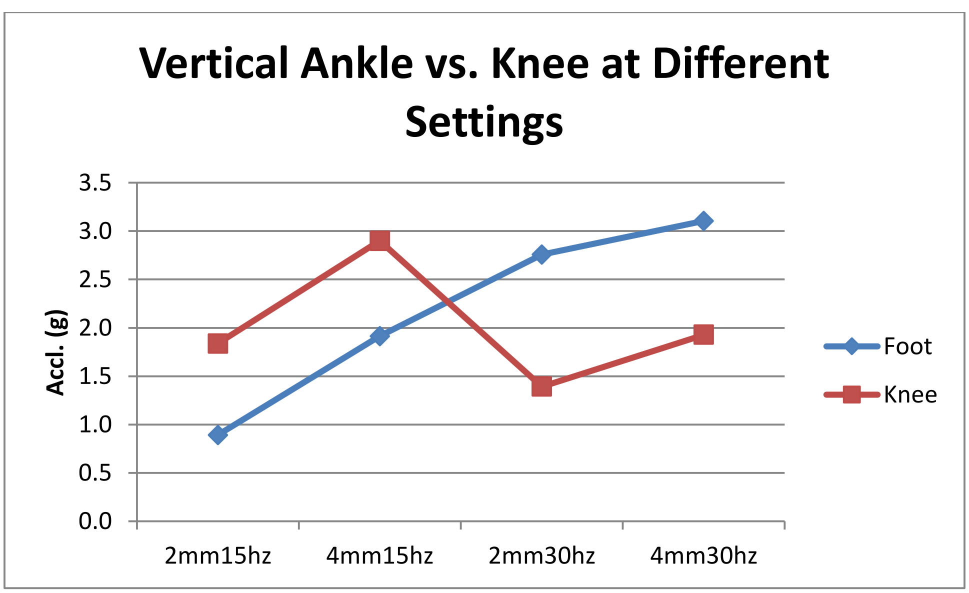

Figure 23: Vertical direction all settings at ankle and knee. The frequency affects whether more vibration is picked up at the ankle or the knee. The displacement affects the amount of vibration picked up at the ankle or the knee.

The total acceleration in the coronal plane is significantly different across frequency ($F=99.146$, $p<0.001$) and displacement ($F=475.36$, $p<0.001$) values (Fig 24). The acceleration at the 4 positions in the coronal axis are significantly ($F=1962.444$, $p<0.001$) different from one another.

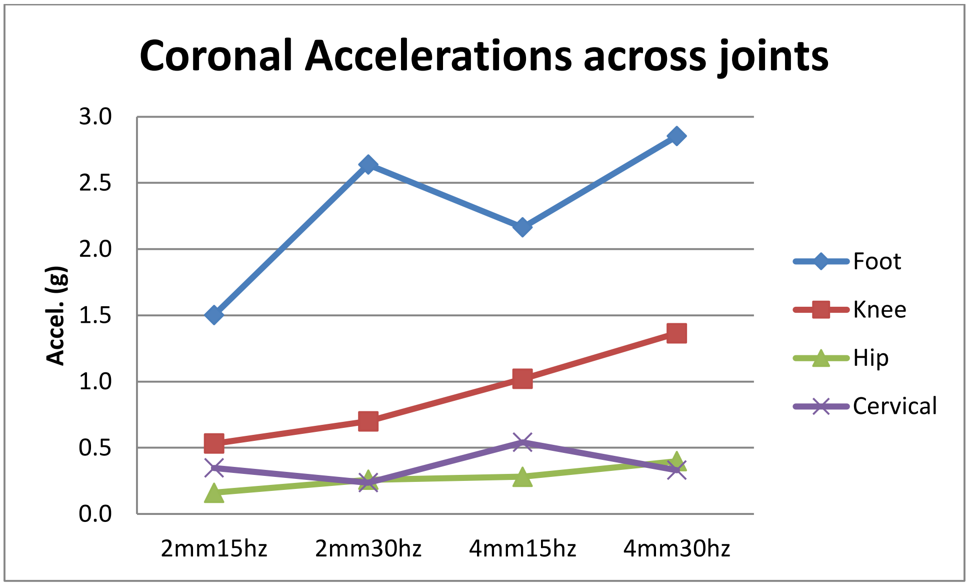

Figure 24: Coronal direction all settings at all joints.

The total acceleration in the sagittal plane is significantly different with changes in frequency ($F=475.616$, $p<0.001$) and displacement ($F=535.117$, $p<0.001$) (Fig. 25).

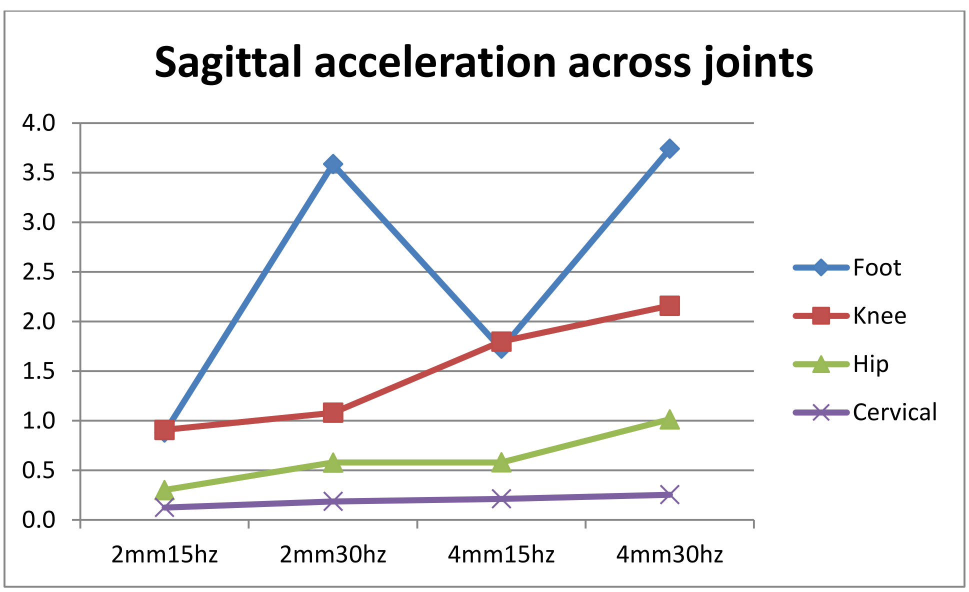

Figure 25: Sagittal direction all settings at all joints.

Arch

Arch Change NWB to WB

The mean measure of the arch-change as the body went from non-weight bearing to weight bearing was not significantly different from pre-vibration to between-vibration (F=2.086, p=0.154), between-vibration to post-vibration (F=1.354, p=0.25) and pre-vibration to post-vibration (F=0.312, p=0.579).

The trend for the arch-change seems to be that the value prior to any vibration was lower than the post-vibration values (Fig 26).

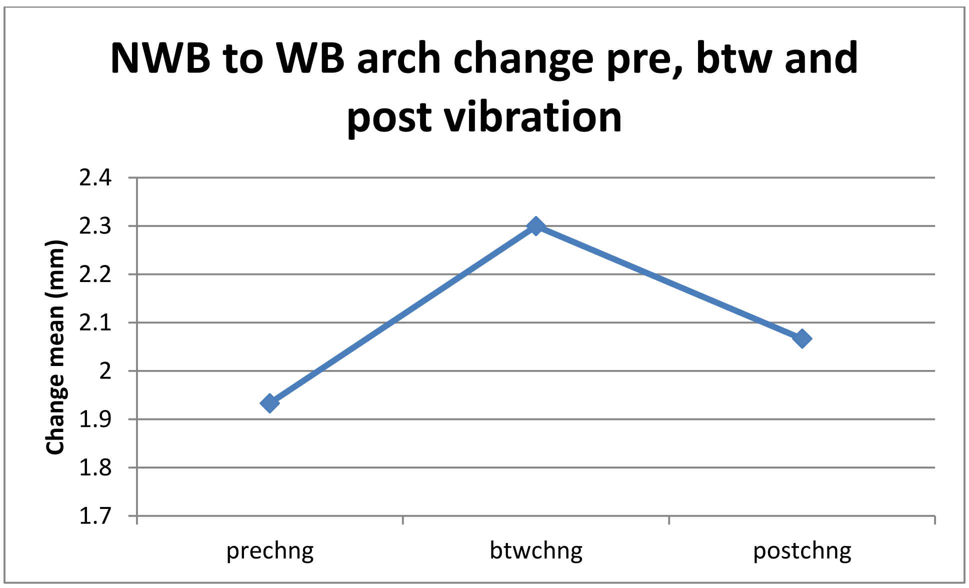

Figure 26: The amount of change the arch (navicular drop) produced before after first exposure to vibration and at the end of the experiment.

Arch Height

The change in arch height was significantly different from pre-vibration to between-vibration (F=8.7, p=0.005), between-vibration to post-vibration (F=5.796, p=0.019) and pre-vibration to post-vibration (F=16.776, p<0.001) (Fig. 27).

The ground height of the arch was significantly different between athletes to non-athletes for between-vibration to post-vibration ($F=4.232$, $p=0.044$) and pre-vibration to post-vibration ($F=5.055$, $p<0.029$). The athlete group had a higher arch height then the non-athlete group.

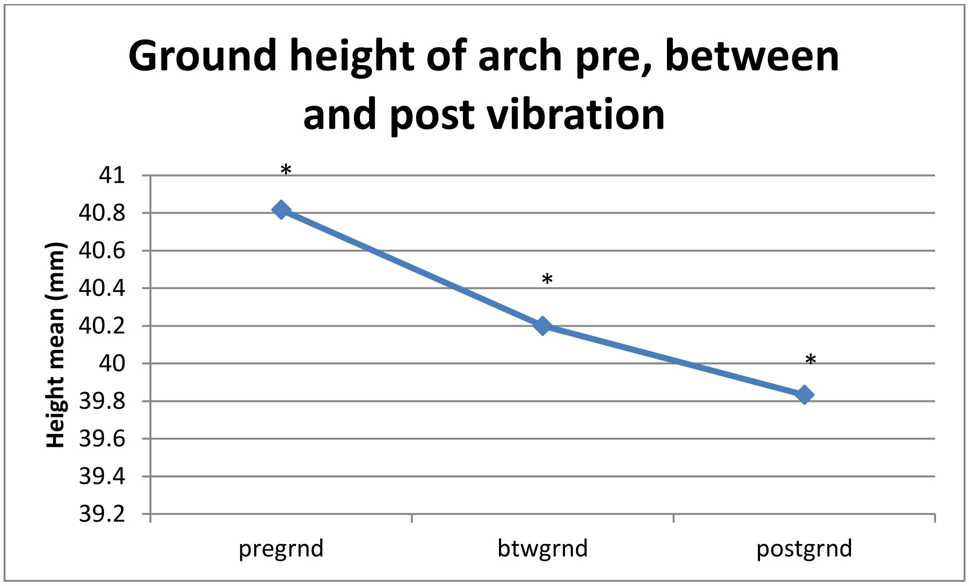

Figure 27: Arch height decreased following initial exposure to vibration and again following second exposure to vibration.

There seemed to be no effect of arch height or change on the amount of vibration transmitted through the body.

Two-point discrimination

The change in two point discrimination was not significant at any of the 6 locations measured following exposure to vibration.

Discussion

ANKLE

General

Vertical

In the vertical axis at the ankle, higher frequency and higher amplitude produces greater acceleration. The acceleration measured at the ankle from lowest value to highest value was 2mm15hz, 4mm15hz, 2mm30hz and then 4mm30hz. The frequency has a greater impact on the acceleration at the ankle then the amplitude. The parameters selected will influence the amount of vibrations transmitted through the ankle and depending on the objective they should be selected according to amount of force transmission desired.

Coronal

The acceleration at the ankle in the coronal axis is directly proportional to frequency and amplitude. These results are consistent with other studies (Cook DP 2011). The platform used in our study provided RV, hence the values measured in our study might be slightly higher in the coronal axis then what is expected on machines which generate VV. Although, the position chosen for our study was single-legged to reduce the coronal component. However, some acceleration in the coronal direction is inevitably transmitted due to the RV component.

Sagittal

The acceleration at the ankle in the sagittal plane is greater with higher frequencies and greater with higher amplitude. The results in our study were confounding with a study stating that acceleration was lower with higher frequency, although they only started measuring at 20hz and went up to 40hz (Cook DP 2011). The discrepancy between the studies might be due to the lack of the 15hz frequency which seems to cause increased vibration transmission through the knee (Ross D. Polock 2010).

Shoe vs. Barefoot:

<u>Vertical</u>

Less vibration was measured in the ankle vertically during SW as opposed to BF. The elastic properties of the shoe sole could act as a damping factor by absorbing some of the vibration. When the individual is barefoot, the vibration measured at the ankle does not benefit from the layer of cushioning provided by the shoe sole. Therefore, more vibration would be transmitted to the ankle under the barefoot condition.

The lower acceleration values measured while wearing a shoe can be explained by an EMG study of shoe vs. barefoot WBV exposure. The EMG signal measured a higher gastroc muscle activation when wearing a shoe during WBV compared to being barefoot (Marín PJ 2009). As a result of the gastroc muscle crossing the ankle joint, a higher activation could indicate an increased effort of the muscles to support or stabilize the ankle and explain the decreased vibration measured. Combining our findings with the EMG study, we can support the theory that the maximum degree of vibration damping is associated to the highest level of muscle activity (Cardinale M 2005).

In our study, the greatest difference between SW and BF acceleration measures were noted at 2mm30hz in the ankle. Furthermore, the EMG study measuring the gastroc during SW and BF found the greatest difference in the muscle activation at 2mm30hz (Marín PJ 2009). Although, the footwear EMG study did not perform WBV at 15hz, there is reason to believe that the gastroc activation levels between shoes and barefoot might be similar at the different frequencies. Further studies are required to determine the exact relationship between SW and BF conditions while exposed to WBV at different parameters.

Coronal

Higher coronal vibration levels were measured at the ankle while wearing a shoe under all settings. The shoe might alter the individual's medial-lateral balance and therefore cause a reduced stability in the coronal plane as opposed to being barefoot. The possible effect of decreased coronal (medial-lateral) stability in certain shoes has been documented (Menant, Perry et al. 2008). Even though different shoes have different coronal stability, our study used a standardized shoe for all participants and our results during WBV are specific to the type of shoe we used. In order to determine a general effect between different types of shoes, acceleration and shoe type should be compared in another study.

A previous study has compared vibration effects between shoe and barefoot conditions, but they analyzed EMG for the gastroc, rather than acceleration at different joints. (Marín PJ 2009) The EMG results during WBV should be further investigated in order to confirm the interactions of the shoe condition and the higher coronal acceleration at the ankle. The EMG should also be measured for muscles that influence the coronal stability of the foot such as peroneals, tibialis anterior and tibialis posterior muscles.

Sagittal

Wearing a shoe seems to cause less vibration at the sagittal accelerometer in the ankle at 15hz, whereas, the sagittal vibration while wearing a shoe is higher at the ankle sagittal at 30hz. The results were not significant at 2mm30hz. However due to the variations between accelerations at the ankle in the sagittal direction, the evidence is not sufficient to conclude the effect for the shoe condition at the foot in the sagittal plane. No previous studies analyze the difference between training level and acceleration in the sagittal direction. The results of our study, strongly suggest that the 15hz frequency generates differences between conditions at the knee. The effect of training level should be examined in more depth in order to determine which muscles react the most to vibration and why a difference can be measured at the 15hz frequency.

Knee

General:

Vertical

The vibration at the knee in the vertical direction is directly proportional to amplitude and inversely proportional to frequency. The highest vibrations were measured at 4mm15hz and the lowest at 2mm30hz. Therefore, considerations should be taken when WBV is used for the rehabilitation of the knee such as post-ACL repair (Moezy A 2008).

Coronal

The vibration in the coronal plane of the knee is directly proportional to frequency and amplitude which is similar to other studies (Cook DP 2011). As the frequency and amplitude increase the vibration in the coronal plane increases at the knee. A better understanding of the vibration damping would be concluded if muscle activation levels could be matched with the acceleration results we have obtained.

Sagittal

The results we obtained for the knee in the sagittal plane indicate that there are significant differences in the vibration based on the parameters selected. Displacement causes a greater influence on acceleration then frequency. The results we obtained are different form a previous study where they found acceleration at the knee in the sagittal direction to be inversely proportional (Cook DP 2011). The differences between the results of the two studies might be due to the different set-up and the different parameters used. These factors are both very important in determining the effects of WBV.

Athlete vs. Non-Athlete:

Vertical

The knee in non-athletes is exposed to lower acceleration values in the vertical direction compared to athletes. The acceleration values are significantly different between athletes and non-athletes for the knee at 15hz but not at 30hz. The vertical vibration in the knee is typically greatest at the 15hz setting (Ross D. Polock 2010). The difference measured in acceleration at the knee in the vertical direction at 15hz can explain why non-athletes experience greater benefit from vibration exposure then athletes. Using data from studies comparing vibration and muscle activation, lower acceleration values are measured at the ankle when muscles crossing the ankle have a higher activation (Marín PJ 2009). Several WBV studies have measured an increased EMG signal in muscles throughout the body when comparing vibration to no-vibration conditions (Abercromby AF 2007, Di Giminiani R 2009, Marín PJ 2009 , Ross D. Polock 2010). If the same occurs at the knee, the greater benefit in sedentary individuals (Rønnestad 2009) could be attributed to the greater muscle activation of muscles crossing the knee. Therefore, the increased muscle activation does reduce the amount of vibration measured which in turn works/trains the muscles involved. Further investigation is required to support these claims. The study measuring EMG and acceleration between different conditions was only performed at 30hz and their results were significant for the ankle yet a study should be performed at 15hz for the knee.

The findings mentioned above facilitate speculations pertaining to the athletes' tolerance to a vibratory stimulus such as WBV. Assuming athletes are more comfortable with a higher level of acceleration due to the stronger muscles and bones they attempt to dampen the vibration less at the knees. Whereas, sedentary individuals may be more apprehensive to the amount of acceleration perceived at their knee joints.

Sagittal

The results were only significant at 15hz for the knee in the sagittal plane between training levels. These results are similar to the finding we had in the vertical direction. The sagittal acceleration at the knee at 15hz is more influential and athletes allow more vibrations at their knees then non-athletes.

Although, no previous studies analyze the difference between training level and acceleration in the sagittal direction, the results of our study strongly suggest that the 15hz frequency causes differences between conditions at the knee. The effect of training level should be examined in more depth in order to determine which muscles react the most to vibration and why a difference can be measured at the 15hz frequency.

Shoe vs. No-Shoe:

Coronal

Less vibration is present at the knee in the coronal plane when the subject wears shoes. The difference is significant at 2mm30hz frequency only. The difference is not significant across the other parameters. Although, being aware that there are differences at the ankle between SW and BF in the coronal direction, further implications for these findings should compare the two conditions while elaborating with the EMG signals in order to better understand the results at the knee.

Sagittal

There were no significant differences between SW and BF conditions at the knee in the sagittal plane. At 15hz SW and BF conditions seem to be similar although a difference is noticeable at the 30hz where SW condition seems to be lower. Having found significant differences in other planes these results indicate that the sagittal plane at the knee is less influenced by the shoe condition.

Hip

Athlete vs. Non-Athlete

Vertical

The vertical hip accelerations were significantly higher in non-athletes then athletes at 2mm15hz, 2mm30hz and 4mm30hz. The vertical hip acceleration values are inversely related to the vertical acceleration at the knee. Athletes and non-athletes seem to use different strategies to dampen vibrations throughout their body. The relationship between training levels is valuable for designing future studies and deciding on whether to pick athletes or non-athletes. Studies comparing the muscle activation between athletes and non-athletes and the acceleration picked up at the different joints would consolidate the mechanism causing the differences.

Nonetheless, the acceleration at the hip is considerably lower than the values measured at the ankle and knee. The clinical significance of the measurements at the hip are debatable and possibly not as influential as the ones at the ankle and knee.

Sagittal

There weren't enough consistency between the results for athletes and non-athletes at the hip sagittal. The effect of vibration and the design of the study is mainly intended to cause a vertical plane effect and the lack of significance in the sagittal plane seems to be suggesting the same.

Across Joints

Vertical

The vertical acceleration recorded at the 30hz frequency was progressively dampened while passing through the ankle, knee, hip and neck accelerometers as expected. Our results confirm the findings of previous studies on WBV (Bressel E 2010, Cook DP 2011). We identified that the amplitude is directly related to acceleration in the vertical direction through the body.

The relationship between the vertical accelerations at the ankle and knee is affected by the parameters selected. The frequency caused changes in the damping of acceleration at the ankle and knee accelerometers. At 15hz vibration measured at the ankle is lower than at the knee, whereas at 30hz there is more vibration at the ankle than the knee. These finding are slightly different from the expectation of the highest measures to be found at the ankle regardless of frequency. Our result are similar to a study which measured higher vibration at the knee then at the ankle at 15hz and that higher frequencies would produce lower accelerations at the knee (Ross D. Polock 2010).

Arch

The results from our second objective suggest that the arch height decreases following WBV exposure. As the individual is exposed to vibration the arch height measured by the navicular tuberosity distance from the ground is reduced. The drop in the arch was about 1mm. Although, the value was statistically significant it might not be clinically significant as seen in navicular height studies using orthotics where the lowest difference provided by orthotics is 5mm (Craig Payne). The study design for the current experiment was meant to measure the acceleration while accounting for any change in arch. Our results indicate that the arch has changed after only 2min of exposure to WBV suggest that a higher and clinically significant change might occur with a longer exposure time. Our study only measured arch before and after exposure to vibration. However, the length of time these effects last would be worth investigating.

The arch has an effect on forces between non weight-bearing and weight-bearing condition (Nachbauer W 1992), but the effect of the arch when weight-bearing is maintained seems to be less influential. The arch changes between non-weight bearing and weight bearing positions, therefore, once and individual is weight bearing on the platform their foot remains in a continuous weight bearing position. Whether their arch is high or low or whether it is rigid or collapses would mainly affect the vibrations during the initial loading step onto the platform. Once the foot has been loaded and exposed to vibration the state of loading of the foot remains the same and does not seem to affect the acceleration through the body.

Two-point discrimination

The third objective to investigate differences in the measure of two-point discrimination was not significantly different across individuals. Therefore, when individuals are exposed to vibration for a small amount of time (2min), the effect of WBV on sensation cannot be measured by two-point discrimination. A study design aiming to confirm these finding should expose the individual to longer periods of vibration and use various sensory measurements to determine the effects of WBV on neurologic characteristics in the lower extremity.

Limitation

The accelerometers used had a measurement range of +/- 5g. Therefore, the values collected would have saturated when the measurement is higher than 5g. The main parameters which would cause vibrations higher than 5g are 2mm30hz which gives 7.2g and 4mm30hz which gives 14.5g. At the ankle there would likely be saturation at those values. At the knee the vibration is dampened and therefore the accelerometer would not always saturate at those values. Although, we know that the highest transmission at the knee occurs at 15hz and that the Due to these limitations we would not be able to make general statements regarding vibration damping. As for the comparison of vibration between athletes and non-athletes or SW and BF we were still able to detect certain differences but due to the risk of certain of the values being saturated the values would need to be verified.

CHAPTER V: MANUSCRIPT

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Effects of footwear and training level on acceleration during Whole-Body Vibration in the lower extremity

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ABSTRACT

Effects of footwear and training level on acceleration during Whole-Body Vibration in the lower extremity

This study examines acceleration at the ankle and knee in athletic and sedentary females, while being barefoot (BF) or wearing a shoe (SW) during a one-legged squat on a vibration platform. Thirty females volunteered for the study. Various parameters were selected for the comparison (2mm/4mm amplitude and 15hz/30hz frequency). Tri-axial (vertical, coronal, sagittal) accelerometers were placed at the ankle (medial malleolus) and knee (medial femoral condyle). The participants were exposed to four times 30sec bouts of vibration before the process was repeated with the other footwear condition. The testing was randomized to negate order. The data was analyzed using an ANOVA for the SW,BF and for the training levels. At the ankle, the shoe condition had a greater influence on vibration levels. The vertical vibration was lower for SW wearing conditions, whereas the coronal vibration was higher for SW. At the knee the training level had a greater effect. The non-athlete group had lower vibration at the knee in the vertical and sagittal directions at 15hz. Hence the training effect at the knee was only perceived at 15hz. These results suggest that the shoe has an effect at the ankle and the training level has effect at the knee. These results can be beneficial in prescribing exercises using vibration platforms.

Key Words: Frequency, Amplitude, Accelerometer, Ankle, Knee…

INTRODUCTION

Whole-body vibration (WBV) which was initially termed as "rhythmic neuromuscular stimulation" in the 1960s was brought to interest when a study demonstrated the stimulus could affect trunk flexion (Biermann 1960). Since then, several beneficial claims associated with WBV have warranted continuous research on the use of vibration platforms in multiple domains. In the strength and conditioning domain, whole-body vibration training (WBVT) is promoted by research indicating improvements in muscular strength, power and flexibility (CARDINALE 2003, Delecluse C 2003, Nele N. Mahieu 2006, Annino G 2007, Jacobs 2009, Rønnestad 2009, Rønnestad 2009, Petit PD 2010, Turner AP 2011). Use of WBV could forge a way into rehabilitation clinics to assist patient healing following anterior cruciate ligament surgery, to increase cartilage density during bed-rest bound individuals or with cystic fibrosis patients (Moezy A 2008, Rietschel E 2008, Liphardt AM 2009). Overweight populations might be attracted to claims that WBV can reduce visceral adipose tissue accumulation (Vissers D 2010). From the first WBV publications in the 1960s, research on the topic has increased in number; in 2002 we can count 30 vs. 2012 we can count 143 (4.7x more), new publications when searching "whole-body vibration" in Pubmed. Vibration platforms have become increasingly accessible for use by the general public in gyms and training facilities and certain models are designed for home use. The popularity gained by WBVT should be matched by explanations of the mechanisms causing the benefits of WBVT yet a discrepancy is present. In order to complement the knowledge we possess on WBV investigating the mechanical properties of vibration transmission in humans, would increase the understanding of certain WBV characteristics and confirm the foundations of the many theories currently assumed about the topic.

The transmission of vibration through the body is influenced by internal and external elements. The musculoskeletal system, an internal element, responds to dampen vibrations of the body's soft tissues with increased muscle activation and contractions (Wakeling JM 2002). Correspondingly, the maximum degree of vibration damping has also been associated to the highest level of muscle activity (Cardinale M 2005). There is no certainty on which muscular properties are the main causes of vibration damping. However, when damping was measured in children the results indicated that they transmit a higher percentage of vibration through the ankle and knee joint than adults (Bressel E 2010). An explanation could be the difference in muscular structure and mass of these two populations. Therefore, individuals who are more muscular and athletic might be better at damping vibrations than their sedentary counterparts but no vibration damping research has compared athletes to untrained individuals. Comparing the damping between trained and untrained individuals would provide insight on whether muscular composition affects the way vibration travels through the body. Any differences in the damping would then be important for the way WBVT is prescribed to trained and untrained individuals.

Vibration damping is also affected by external sources, such as footwear. Wearing shoes seems to relate to a higher activation of the gastrocnemius muscle whereas being barefoot relates to higher activation of the vastus lateralis muscle (Marín PJ 2009). Although, research has been done to measure the effect of wearing shoes or being barefoot on muscle activity during WBV exposure; none looked at the effect they have on damping the vibration. If there are significant differences between being barefoot or wearing shoes on the damping of vibration the instructions for WBVT would then differ according to the amount of vibration desired to be transmitted to the individual.

The users of WBVT would benefit by knowing the sources of variations in vibration transmissibility between individuals. Training on vibration platforms has shown greater performance increase for sedentary individuals compared to athletes (Rønnestad 2009, Rønnestad 2009). Meanwhile, vibration damping between training levels has never been measured. Determining if there are differences between athletes and sedentary individuals would provide substance to WBV usage guidelines and the knowledgebase of

WBVT. By comparing shoes versus barefoot and the foot arch component to the analysis we can confirm the specific implication of each of these constituents on the damping of WBV and adjust our vibration exposure guidelines to attain the desired efficiency. Therefore, the purpose of this study is to analyze the transmissibility of vibration between athletes and sedentary individuals while varying between barefoot and shoes.

METHODS

Experimental Approach to the Problem

We performed a 2x4 repeated measure trial on trained and untrained female participants to determine if there were any differences in the vibration dampening through the body. In order to address the question we collected measurements during one-legged squat with shoes (SW) and barefoot (BF). The one-legged squat posture was chosen to reduce the rotational vibration (RV) component from a RV platform whereas; a two-legged stance would maximize the rotational component. The independent variables included the vibration frequencies and amplitudes, the level of physical activity and the footwear. The frequencies and displacement selected were based on discussion from previous studies and included one high and one low setting for each parameter. The dependent variable was the amount of vibration at the ankle and the knee.

Subjects

Thirty volunteer based female participants were used in the study. They were split into two groups (15 trained, 15 untrained). Measuring acceleration in 15 participants per group would be sufficient based on similar studies which have made these measurements with fewer participants (Arkady 1983, Harazin 1998, Wakeling JM 2001, Kiiski J 2008, Pel 2009, Marín PJ 2009 , Bressel E 2010, Ross D. Polock 2010). The inclusion criteria for trained individuals were to be in-season athletes who train 3 times per week minimum and participate at university or college division 1 level of competition. Untrained individuals were selected from the university population. The inclusion criteria were: they do not perform regular physically demanding tasks, do not exercise, and not enrolled in any leisure sports participation. Exclusion criteria were any condition affecting the tolerance or the transmissibility of the vibration such as: lower extremity injuries in the past year, back pain at time of experiment, acute musculoskeletal inflammation, epilepsy, cancer, gallstones and kidney or bladder stones as per recommendation of the manufacturer of the vibration platform used (Vibraflex 2011).

Testing Procedures

Participants were asked to attend the lab for one data collection session. During the session they performed the testing with shoes and barefoot. The shoe and barefoot conditions were randomized to negate the order effects. During the visit the participant were advised of the procedures and provided with consent forms. Participant demographics such as height, weight and age were collected. Then leg dominance was determined by performing the balance recovery test and asking them to stand and let themselves fall forward three times. The leg which they selected to step forward with twice or more was considered to be their dominant leg. There is no general consensus on methods for determining leg dominance but the technique selected has been used in previous studies whether on its own or in conjunction with other tests (Hoffman 1998, Todd A. McLoda 2000, Cornelis Jo de Ruiter and Sander Schreven 2010). The participants then had the accelerometers attached at the ankle (medial malleolus) and knee (medial femoral condyle). Then the individuals were asked to step onto the vibration platform and undergo vibration either barefoot or while fitted in the standardized shoe. The participants were exposed to four combinations of vibration (15Hz/3mm = 2.7g, 15Hz/6mm = 5.4g, 30Hz/3mm = 10.9g and 30Hz/6mm = 21.7g) for 30 seconds. Between each setting the participants were given 1 min of rest, which is enough to recuperate and avoid fatigue while at the current exposure time (Da Silva-Grigoletto 2009) and has been used in other protocols (Da Silva-Grigoletto 2009, Pel 2009, Marín PJ 2009). Participants maintained the one-legged squat at 40° while they were subjected to vibration on the platform for the 30 seconds period for the trial to be retained. During resting time the individuals were be asked to sit in a chair and rest before the vibration is applied at the next setting. Immediately at the end of the vibration exposure the individual stepped off the platform and rested for five minutes. The vibration was then repeated using the second footwear condition and followed by the same post exposure measurements.

Acceleration

The acceleration at the joints was measured using tri-axial accelerometers. Since no standard technique has been documented to attach the accelerometers to the skin we used a method which has been used previously. The accelerometers were attached to the subject using double sided tape (Kiiski J 2008, Pel 2009), and then the boxes and cables were further secured using elastic bandages (Kiiski J 2008). The accelerometers provided a measure of acceleration (m/s^2) which was transformed to g-force (g). The attachments to the body were at the medial malleolus and the medial epicondyle of the femur. One bi-axial accelerometer was placed on the vibration platform in order to measure consistency in the vibration emitted directly at the surface of the platform.

Postural positioning and Shoes

Individuals performed and maintained a one-legged squat at 40° which was measured using a hand-held goniometer. A standard Nike shoe was provided to all participants for the measurement with shoes.

Statistical Analyses

The signal from the accelerometers were transmitted to an oscilloscope after passing through a power supply box. Vibration signals were analyzed in time, frequency and amplitude domains. The data was normalized by comparing the acceleration recorded at each receptor with the accelerometer placed directly on the platform. The acceleration was determined as the normalized value measured by the accelerometer at each site.

The statistical analysis was performed using IBM SPSS Statistics 20.0 Release 20.0.0 (Armonk, NY, USA).

Repeated measure ANOVA's were used for comparing shoes to barefoot measures and an ANOVA was used to compare trained and untrained individuals. The statistical measures were performed to see whether the current parameters are significant with α-level of 0.05. The data was divided into a comparison between the four different vibration settings for all other variables. There was an analysis of response to vibration damping between trained and untrained individuals. Then individuals were compared to wearing shoes vs. being barefoot.

RESULTS

Ankle

Vertical

All subjects:

To measure acceleration at the ankle an accelerometer was placed at the medial malleolus of the participants. The acceleration at the ankle in the vertical direction was significantly different with changes in frequency ($F=584.323$, $p<0.001$) and amplitude ($F=315.415$, $p<0.001$).

Shoe vs. Barefoot:

Following analysis using a repeated measure ANOVA, the acceleration at the ankle in the vertical axis was significantly ($F= 43.056$, $p<0.001$) lower in SW than BF.

A repeated measure ANOVA was done to determine the effect of each parameter (frequency/amplitude) on the acceleration at the ankle between SW and BF. The acceleration at the ankle in the vertical direction was significantly lower in SW than BF at the different frequency ($F= 6.461$, $p=0.014$) and amplitude ($F= 8.939$, $p=0.004$).

The comparison between SW and BF was performed at each setting to determine the relationship of footwear to the acceleration at the ankle during the various settings. The acceleration was significantly lower in SW through all settings at the ankle vertical axis [(2mm15hz: $F=17.445$, $p<0.001$), (2mm30hz: $F=27.751$, $p<0.001$), (4mm15hz: $F=9.409$, $p=0.003$), (4mm30hz: $F=13.685$, $p<0.001$)] compared to BF (Fig. 1).

Coronal

All subjects:

The acceleration measured at the ankle in the coronal direction was significantly different with changes in frequency (F=133.740, p<0.001) and displacement (F=146.071, p<0.001).

Shoe vs Barefoot:

A repeated measure ANOVA was used to determine the difference between SW and BF at the coronal axis of the ankle. The total acceleration at the ankle in the coronal axis was significantly (F=24.733, p<0.001) lower in BF than SW.

The comparison between SW and BF for each setting at the ankle in the coronal axis were significant at 2mm15hz (F=16.663, p<0.001), 2mm30hz (F=30.988, p<0.001) and 4mm15hz (F=10.425, p=0.002). The values for acceleration in the coronal axis at the ankle were not significant at 4mm30hz (F=0.784, p=0.379) (Fig. 2).

Athlete vs. Non-Athlete:

The total acceleration at the ankle in the coronal axis was significantly (F=5.701, p=0.02) lower in untrained then trained individuals. Although, comparing the acceleration at the ankle in the coronal direction individually between the two training levels at each setting was not significantly different.

Sagittal

All subjects:

The acceleration measured at the ankle in the sagittal direction is significantly different with changes in frequency (F=1681.906, p<0.001) and amplitude (F=448.429, p<0.001).

Shoe vs. Barefoot:

Total sagittal acceleration at the ankle between SW and BF was significantly (F=19.416, p<0.001) lower in SW then BF.

The acceleration at the ankle in the sagittal direction between SW and BF was compared to each setting (frequency/amplitude) (Fig. 3).There acceleration measured at the ankle in the sagittal direction was significantly lower for SW than BF at 2mm15hz ($F=11.035$, $p=0.002$) and 4mm15hz. ($F=8.167$, $p=0.006$). The sagittal acceleration was significantly higher for SW then BF at 4mm30hz ($F=10.071$, $p=0.002$). The acceleration values were not significantly different between SW and BF at 2mm30hz.

Athlete vs. Non-Athlete:

The measure of total acceleration at the ankle in the sagittal direction was significantly ($F=5.523$, $p=0.022$) different depending on frequency between the athlete and non-athlete group.

Knee

Vertical

All subjects:

To measure acceleration at the knee an accelerometer was placed at the medial femoral epicondyle. The acceleration at the knee in the vertical direction was significantly different with changes in frequency ($F=56.017$, $p<0.001$) and displacement ($F=350.993$, $p<0.001$).

Athlete vs. Non-Athlete:

A comparison was made between the acceleration at the knee in the vertical axis and training level at each setting (frequency/amplitude). The results were significantly higher in athletes at 2mm15hz ($F=16.757$, $p<0.001$) and 4mm15hz ($F=9.219$, $p=0.004$) than non-athletes (Fig. 4).

Coronal

All subjects:

The acceleration at the knee in the sagittal direction is significantly different with changes in frequency (F=19.371, p<0.001) and displacement (F=347.896, p<0.001).

Shoe vs. Barefoot:

The measures of acceleration at the knee in the coronal direction were compared between SW and BF at each setting. The acceleration at the knee in the coronal axis was a significantly lower at 2mm30hz (F=6.088, p=0.017) SW then BF (Fig. 5).

Sagittal

All subjects:

The acceleration at the knee in the sagittal direction was significantly different with changes in frequency (F=8.524, p<0.005) and displacement (F=333.112, p<0.001).

Shoe vs. Barefoot:

The measure of acceleration at the knee in the sagittal plane was compared between SW and BF using a repeated measure ANOVA. The results were significantly different (F=4.681p=0.035) depending on frequency and shoe combined.

Athlete vs. Non-Athlete:

The measures for athletes and non-athletes were compared for each setting at the knee. The results were significantly lower for the knee in the sagittal direction at 2mm15hz (F=7.148, p=0.01) and at 4mm15hz (F=4.712, p=0.034) for non-athletes compared to athletes (Fig. 6).

DISCUSSION

ANKLE

General

Vertical

In the vertical axis at the ankle, higher frequency and higher amplitude produces greater acceleration. The acceleration measured at the ankle from lowest value to highest value was 2mm15hz, 4mm15hz, 2mm30hz and then 4mm30hz. The frequency has a greater impact on the acceleration at the foot then the amplitude. Therefore, parameters selected influence the amount of vibrations transmitted through the ankle and depending on the objective they should be selected according to amount of force desired.

Coronal

The acceleration at the foot in the coronal axis is directly proportional to frequency and amplitude. These results are consistent with other studies (Cook DP 2011). The platform used in our provided RV, hence the values measured in our study might be slightly higher in the coronal axis then what would be expected on machines which generate VV. Although, the position chosen for our study was single leg to reduce the coronal component, there is inevitably some acceleration in the coronal direction that is transmitted.

Sagittal

The acceleration at the ankle in the sagittal plane is greater with higher frequencies and greater with higher amplitude. The results measured in our study are confounding with a study which stated that acceleration was lower with higher frequency, although they only started measuring at 20hz and went up to 40hz (Ross D. Polock 2010). The difference in patterns between lower and higher frequency in relation to acceleration might be due to not having the 15hz frequency which seems to cause higher vibration traveling up through the lower extremity(Ross D. Polock 2010).

Shoe vs. Barefoot:

Vertical

Less vibration was measured in the foot vertically while wearing a shoe as opposed to being barefoot on the platform. The elastic properties of the shoe sole could act as a damping factor by absorbing some of the vibration. Hence, when the individual is barefoot the vibration measured at the foot does not possess the layer of cushioning provided by the shoe sole. Therefore, more vibration would be transmitted to the ankle under the barefoot condition.

The lower vibration measured while wearing a shoe can be supplemented with an EMG study of shoe vs. barefoot WBV exposure. The EMG signal measured is higher in the gastroc muscle when wearing a shoe during WBV compared to being barefoot (Marín PJ 2009). The gastroc muscle crosses the ankle joint and a higher activation could indicate an increased effort of the muscles to support or stabilize the specific joint and hence explain the decreased vibration measured. Combining our findings with the EMG study, we can support the theory that the maximum degree of vibration damping is associated to the highest level of muscle activity (Cardinale M 2005).

The greatest difference we measured between the means of vibration for the different footwear at the ankle accelerometer was at 2mm30hz. The study on EMG of the gastroc during shoe vs. barefoot also found the greatest difference in the muscle activation between shoe and no shoe at 2mm30hz (Marín PJ 2009).Although, the footwear EMG study did not perform WBV at 15hz, there is reason to believe that the gastroc activation levels between shoes and barefoot might be similar at the different frequencies. Further studies are required to determine the exact relationship between shoes and barefoot conditions while exposed to WBV at different parameters.

Coronal

Higher coronal vibration levels were measured at the ankle while wearing a shoe under all settings. The shoe might alter the individual's medial-lateral balance and therefore cause a reduced stability in the coronal plane as opposed to being barefoot. The possible effect of decreased coronal (medial-lateral) stability in certain shoes has been documented (Menant, Perry et al. 2008). Even though, different shoes have different coronal stability our study used a standardized shoe for all participants and hence our results during WBV are specific to the type of shoe we used. In order to determine a general effect between different types of shoes they should be compared in another study.

Other studies have compared vibration effects between shoe and barefoot conditions but they analyzed EMG for the gastroc, rather than acceleration at different joints. The EMG results during WBV should be further investigated in order to confirm the interactions of the shoe condition and the higher coronal acceleration at the ankle. The EMG should also be measured for muscles that influence the coronal stability of the foot such as peroneals, tibialis anterior and tibialis posterior muscles.

Sagittal

Wearing a shoe seems to cause less vibration at the sagittal accelerometer in the ankle at 15hz, whereas, the sagittal vibration while wearing a shoe is higher at the ankle sagittal at 30hz. The results were not significant at 2mm30hz. The variations between accelerations at the ankle in the sagittal direction indicate a that the amplitude has a main effect at 15hz, whereas the frequency causes an interaction between the footwear conditions at 4mm in the ankle. Although, there seems to be certain interactions between the shoe and the parameters selected, further comparisons should be made while using different settings along the ones chosen in order to determine the effect of frequency and amplitude on vibration in the sagittal direction at the ankle. Hence trying to find the cut-off frequency by including values within the 15hz and 30hz values.

Knee

General:

Vertical

The vibration at the knee in the vertical direction is directly proportional to amplitude and inversely proportional to frequency. The highest vibrations were measured at 4mm15hz and the lowest at 2mm30hz. Therefore, these considerations are important when the purpose of using WBV will be for the rehabilitation of the knee such as suggested in certain studies (Moezy A 2008).

Coronal

The vibration in the coronal plane of the knee is directly proportional to frequency and amplitude which is similar to other studies (Cook DP 2011). Therefore, as the frequency and amplitudes increase the vibration in the coronal plane are increased at the knee. The vibration information would be more conclusive if muscle activation levels could be matched with the results we have obtained.

Sagittal

The results we obtained for the knee in the sagittal plane indicate that there are significant differences in the vibration based on the parameters selected. Displacement causing a greater influence on acceleration then frequency. The results we obtained are different form a previous study where they found acceleration at the knee in the sagittal direction to be inversely proportional (Cook DP 2011). The differences between the results of the two studies might be due to the different set-up used in each and the different parameters. These factors are both very important in determining the effects of WBV.

Athlete vs. Non-Athlete:

Vertical

The knee in non-athletes seems to be exposed to less vibration then the knee of athletes is in the vertical direction. The ANOVA is significant for differences between athletes and non-athletes for the knee at the 15hz frequency whereas it is not at 30hz. The vertical vibration in the knee is typically greatest at the 15hz setting (Ross D. Polock 2010). Therefore, measuring a difference in the vertical vibration at the knee at 15hz depending on training level can provide insight on why non-athletes experience greater benefit from vibration exposure then athletes. Using data from studies comparing vibration and muscle activation, lower vibration is measured at the ankle when muscles crossing the ankle record a higher activation (Marín PJ 2009). Hence if the same occurs at the knee the reasoning for greater benefit in sedentary individuals (Rønnestad 2009) could be related to the greater muscle activation of muscles crossing the knee. Therefore, the increased muscle activation does reduce the amount of vibration measured and works/trains the muscles involved. Further investigation is required to support such a theory because the study measuring EMG and acceleration was only performed at 30hz and hence their results were significant for the ankle yet a study should be performed at 15hz for the knee.

The findings mentioned above facilitate speculations pertaining to the athletes' tolerance to a vibratory stimulus such as WBV. Assuming athletes are more comfortable with a higher level of vibration due to the stronger muscles and bones they have they attempt to dampen the vibration less at the knees compared to sedentary individuals who may be more apprehensive to the amount of acceleration perceived at their knee joints.

Sagittal

The results were only significant at 15hz for the knee in the sagittal plane between training levels. These results are similar to the finding we had in the vertical direction. Hence, at the knee 15hz seem to be the frequency of choice and there seems to be a pattern for athletes to allow more vibrations at their knees then non-athletes.

Although, no previous studies analyze the difference between training level and acceleration in the sagittal direction, the results we have found strongly suggest that the 15hz frequency might be the one where differences might arise between conditions at the knee. The effect of training level should be examined in more depth in order to determine which muscles react the most to vibration and why a difference can be measured at the 15hz frequency.

Shoe vs. No-Shoe:

Coronal

Less vibration is present at the knee in the coronal plane when the subject wears shoes. The difference is significant at 2mm30hz frequency only. Therefore, the difference is not significant across the other parameters and hence make a conclusion difficult to extract from such results. Although, being aware that there are differences at the ankle between shoes and no-shoes in the coronal direction, there are further implications for these findings and further studies should compare the two conditions while elaborating with the EMG signals in order to better understand the results at the knee.

Sagittal

There were no significant differences between shoe and barefoot conditions at the knee in the sagittal plane. At 15hz the shoe and barefoot conditions seem to be similar although a difference is noticeable at the 30hz where the shoe condition seems to be lower. Having found significant differences in other planes these results indicate that the sagittal plane at the knee is less influenced by the shoe condition.

PRACTICAL APPLICATION

The current results indicate that shoe wearing and training level have an influence on the damping of vibrations through the body. Shoes seem to be a good method to reduce vertical vibration at the ankle or elicit a greater response of the muscles surrounding the ankle joint vertically. Being barefoot seems to reduce the coronal vibration at the ankle and by using similar approach we can assume that the medial-lateral stabilizers at the ankle would be elicited more; although such an assumption should be further investigated using EMG studies in conjunction with acceleration measures.

When discussing training levels our main conclusions are related to the knee in the vertical and sagittal planes. Sedentary individuals had lower vibration levels at the knee at in the vertical and sagittal planes at 15hz compared to trained individuals. These results support studies indicating higher improvements in untrained individuals compared to trained individuals. The differences between training levels can be associated to the greater muscle activation when the vibration recorded at the joint is lower (Cardinale M 2005). In order to complement these results a study combining both acceleration and EMG measures would be ideal while accounting for training level and footwear.

Appendix1 Figures

Fig. 1

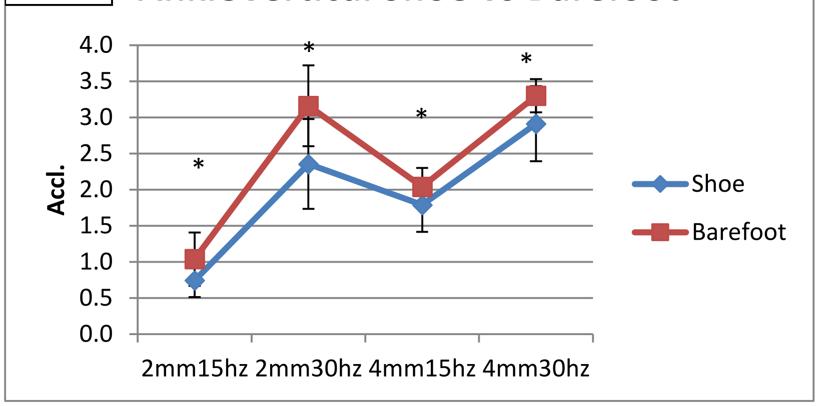


Fig. 2

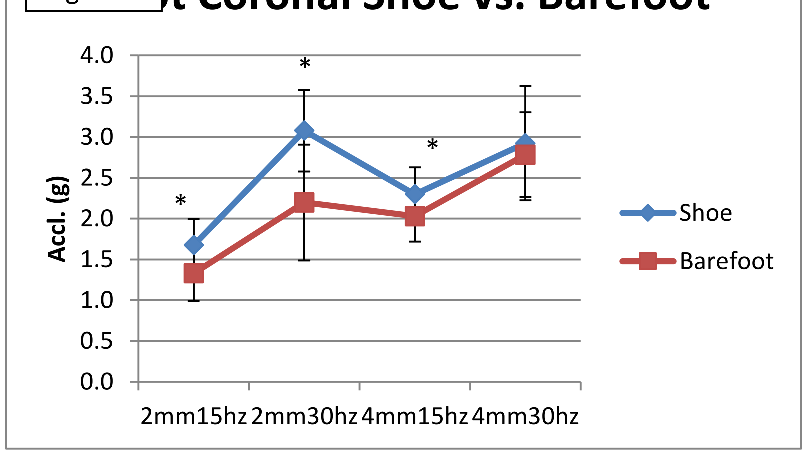


Fig. 3

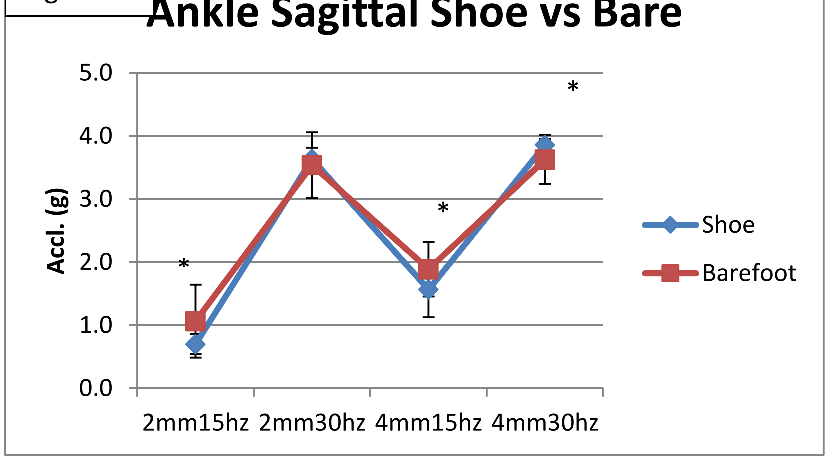


Fig. 4

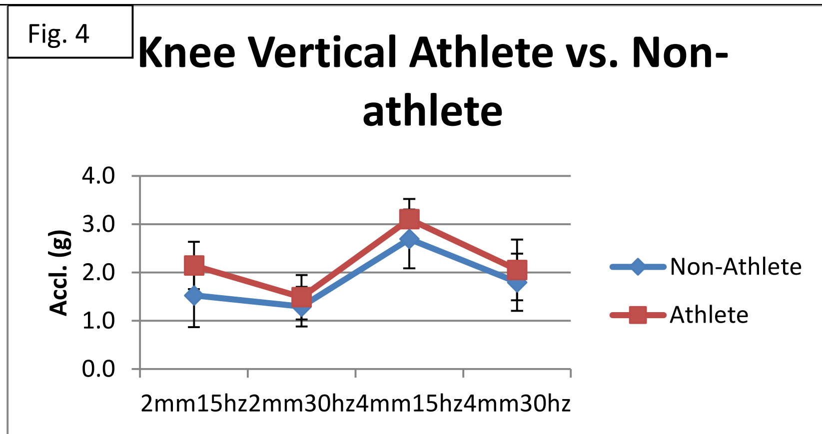


Fig.5

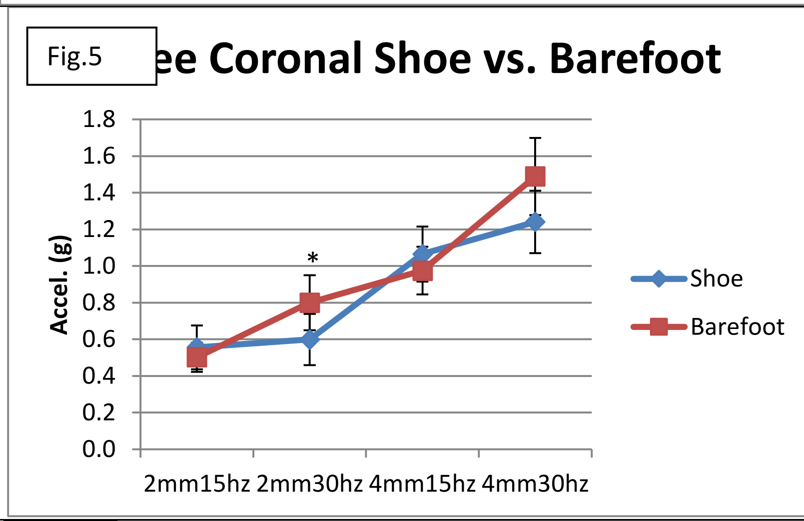
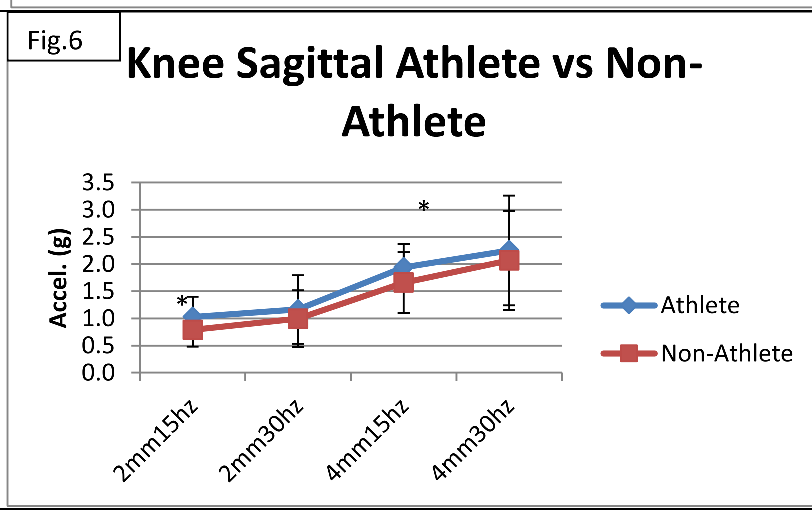


Fig.6



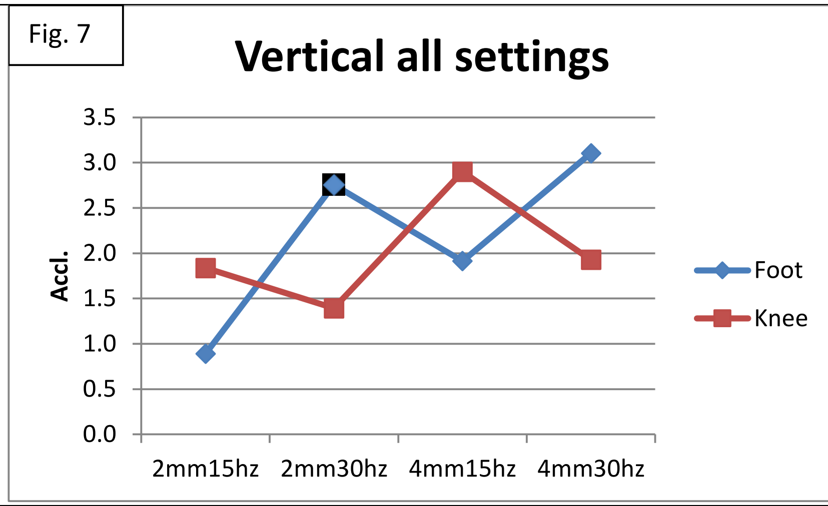


Fig. 7
Vertical all settings
Accl.
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2mm15hz
2mm30hz
4mm15hz
4mm30hz
Foot
Knee

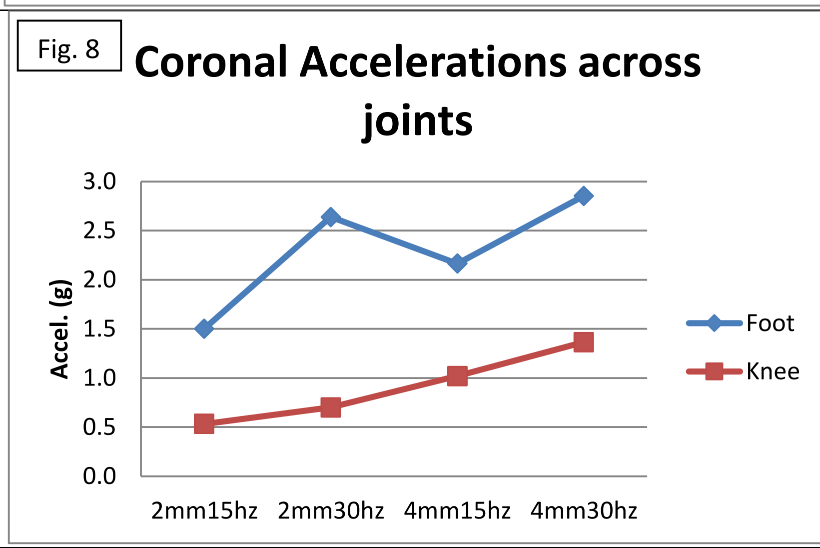


Fig. 8
Coronal Accelerations across joints
Accel. (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2mm15hz
2mm30hz
4mm15hz
4mm30hz
Foot
Knee

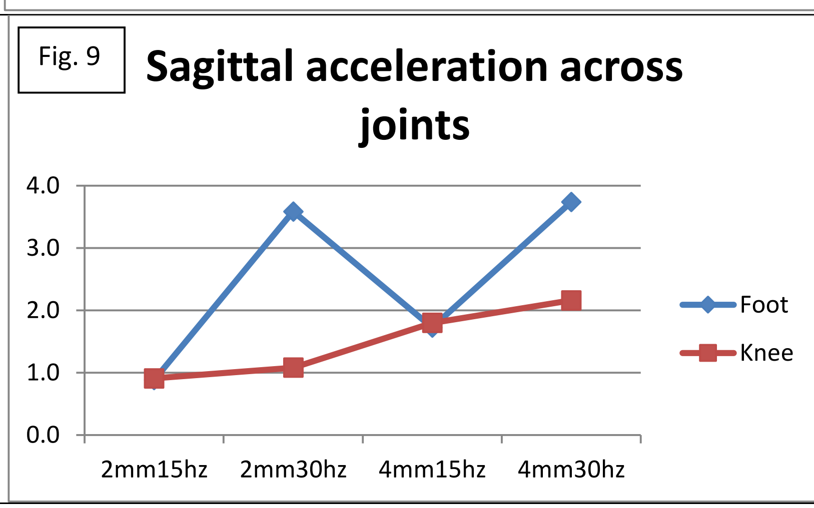


Fig. 9
Sagittal acceleration across joints
4.0
3.0
2.0
1.0
0.0
2mm15hz
2mm30hz
4mm15hz
4mm30hz
Foot
Knee

CHAPTER VI: Conclusions

Our studies first objective was to clarify patterns of vibration damping through the body at different parameters while wearing shoes (SW), being barefoot (BF) and for different levels of athletic training. While wearing shoes, we measured a lower acceleration level at the ankle in the vertical direction and a higher acceleration at the ankle in the coronal plane. Furthermore, we measured greater acceleration at the ankle at the 30hz frequency and a greater effect at the knee at the lower 15hz frequency. Greater amplitudes seem to cause greater vibrations at the lower extremity (ankle and knee).

The acceleration at the ankle was mainly affected by the footwear. The vertical acceleration is lower during SW. The lower acceleration coincides with higher levels of gastroc muscle contraction during SW in an EMG study (Marín PJ 2009). The coronal results for SW indicated higher acceleration at the ankle. Similar results were measured without WBV which indicates that shoes cause a lower coronal stability then being barefoot (Menant, Perry et al. 2008). In summary, footwear plays a role in the amount of vibration at the ankle depending on parameters selected. The general effect of the shoe is to decrease the amount of vibration measured in the vertical direction while increasing the amount of vibration measured in the coronal direction. At a frequency of15hz, footwear has a main effect on the sagittal acceleration with amplitude causing lower acceleration with SW. At an amplitude of 4mm, there is an interaction when varying the frequency: SW is lower at 15hz and higher at 30hz. Shoes seem to be a good method to reduce vertical vibration at the ankle or elicit a greater response of the muscles surrounding the ankle joint vertically. Being barefoot reduces the coronal acceleration at the ankle. Based on knowledge that higher muscle activation accompanies higher vibration damping (Cardinale M 2005); we can assume that during BF the medial-lateral stabilizers at the ankle are elicited more than SW. Although such an assumption should be further investigated using EMG studies in conjunction with acceleration measures.

When discussing training levels, our main conclusions are related to the knee in the vertical and sagittal planes. Sedentary individuals had lower vibration levels at the knee in the vertical and sagittal planes at 15hz compared to trained individuals. Our results support studies indicating greater improvements in untrained individuals compared to trained individuals (Rønnestad 2009, Rønnestad 2009); by causing greater muscle activation when the vibration recorded at the joint is lower (Cardinale M 2005). In order to complement these results a study combining both acceleration and EMG measures would be ideal.

Our study measured a decrease in arch height from the ground although the values were not strong enough to suggest any clinical relevance. Yet a study design exposing the individual to longer duration vibratory stimulus might be better at determining the relevance of such a measure. The same applies to sensory measures such as two-point discrimination.

Future studies should combine EMG measures with accelerometer data in order to define a clear relationship of muscular activation and vibratory differences under different footwear conditions and between different levels of training. As for the arch and sensation, a longer exposure to vibration should also be implemented in the study design.

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APPENDIX A
Consent to Participate in the Study

CONSENT TO PARTICIPATE IN:

Transmissibility of WBV in sedentary and athletic population, considering parameters at the foot and cutaneous sensation

This is to state that I agree to participate in a program of research being conducted by Nour Saade from the Exercise Science Department of Concordia University (***contact info*:** no.saade@gmail.com) under the supervision of Dr. Richard DeMont (***contact info*:** **(**514)848-2424 ext. 3329, *rgdemont@gmail.com*)

A. Purpose of the Experiment

I have been informed that the purpose of the research is to obtain measures related to the transmission of vibrations through the body under vertical Whole-Body vibration while holding a one leg squat position on a vibration platform. This research study is an important step in the understanding of the effect of vertical whole-body vibration on the human body.

B. Procedures

I understand that I am volunteering to participate in this study which will be carried out in the CONCAVE laboratory. There will be two data collecting sessions lasting approximately 45 minutes, with 48 hours between sessions. One session will be performed barefoot and the other while wearing shoes which will be provided to me. All procedures will be explained to my satisfaction. My foot arch will be classified by marking down three points on my foot with a pen and determining their relationship to one another with a measuring tape. The sensation in my lower extremity will be measured at eight different landmarks using a two-point aesthesiometer pressed against my skin. I will be asked to identify whether one or two pointers are being used. The arch and sensation measures will be taken before and after the exposure to vibration. The acceleration at four landmarks of my body will be measured non-invasively using accelerometers. The accelerometers will be adhesively attached to my skin. I will then do a one leg squat while standing on a vibration platform for 30 seconds. After 1 minute of rest, I will repeat this activity four times. Each session will include four squats. I will return after 48 hours do repeat the same procedure.

C. Risks and Benefits

To our knowledge there is no risks linked to this study. You will be screened for the following conditions, and if absent, you will be declared fit to participate in the study: acute or chronic back injury, acute inflammation in the musculoskeletal system, acute migraine attack, acute or chronic musculoskeletal injury in the dominant leg, acute thrombosis, and recent surgery. (The manufacturer of the vibration platform also cautions against, cancer, epilepsy, gallstones, kidney or bladder stones, open wounds in the dominant leg, pregnancy, rheumatoid arthritis & arthropathy, and diabetes.)

All procedures are completely non-invasive. It is possible you will experience minor skin irritation from the tape holding the accelerometer equipment in place. Due to the squatting exercise and vibration, there is a possibility of minor effects including irritation or itchiness to the skin of the foot in contact with the vibration platform, nausea and dizziness, quick but temporary fall of blood pressure, and hypoglycaemia (if diabetic). Muscle soreness is possible following the experiment. ***These are unlikely temporary side effects with no known long term risk, but please inform the experimenter if you feel any discomfort.*** A certified athletic therapist will be present during the testing procedures. There are no direct benefits or compensation from your participation in this study. This research will aid both the rehabilitation and fitness communities.

D. Conditions of Participation

- I understand that I am free to withdraw my consent and discontinue my participation at any time without negative consequences.
- I understand that my participation in this study is CONFIDENTIAL (i.e., the researcher will know, but will not disclose my identity)
- I understand that the data from this study may be published.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

Name (please print)

____

SIGNATURE

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If at any time you have questions about your rights as a research participant, please contact Kyla Wiscombe, Research Ethics Assistant, Concordia University, at (514)848-2424 x4888 or by email at <kwiscomb@alcor.concordia.ca>.