

THE EFFECT OF HIGH AND LOW AMPLITUDES
DURING WHOLE BODY VIBRATION ON
LOWER LEG ARTERIAL BLOOD FLOW

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ABSTRACT

THESIS: The Effect of High and Low Amplitudes During Whole Body Vibration on Lower Leg Arterial Blood Flow
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Whole body vibration (WBV) is a technique that has been shown to induce positive blood flow changes, however little is known about the effect of different vibration amplitudes on arterial blood flow. **Purpose.** The purpose of this study was to determine the effect of 2 different amplitudes during an acute bout of WBV on blood flow through the popliteal artery. **Methods.** Thirty healthy, recreationally active subjects (15 women, 15 men) aged 19-34 years performed two, 10 - minute bouts of vibration at a frequency of 30 Hz and high amplitude (6 mm) or low amplitude (3 mm) in random order after a period of prone rest. Doppler ultrasound was used to assess changes in blood flow. Mean blood flow velocity, peak velocity, end-diastolic velocity, pulsatility index, and resistive index measures were taken immediately before vibration and immediately after. **Results.** Mean blood flow velocity increased after 10 minutes of WBV. Mean velocity increased more in the 6mm trial (pre= 21.6 ± 4.74 cm/s, post= 25.3 ± 6.11 cm/s) than in the 3mm trial (pre= 22.3 ± 4.33 cm/s, post= 23.5 ± 5.94 cm/s). Peak blood flow velocity increased following 10 minutes of WBV and increased more in the 6mm trial (pre= 37.1 ± 9.78 cm/s, post= 43.7 ± 10.95 cm/s) than in the 3mm trial (pre= 37.8 ± 8.92 cm/s, post= 39.4 ± 10.5 cm/s) following 10 minutes of passive WBV. Pulsatility index also increased significantly following 10 minutes of WBV and increased more in the 6mm trial (pre= 1.639 ± 0.1299 , post= 1.729 ± 0.1324) than in the 3mm trial (pre= 1.660 ± 0.1219 , post= 1.671 ± 0.1428). No main effects or interactions were observed for resistive index or end diastolic blood flow velocity ($P > 0.05$). **Conclusion.** Ten minutes of passive WBV increases blood flow velocity. High amplitude (6 mm) produced a more pronounced increase in blood flow than the low amplitude (3 mm). Given the relationship between blood flow velocity and WBV, these results suggest that amplitude plays a role in increasing blood flow and that high amplitude (6 mm) may be more effective than low amplitude (3 mm) in improving circulation to the lower leg. **Key Words.** WHOLE BODY VIBRATION, BLOOD FLOW, ULTRASOUND, AMPLITUDE

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Chapter I Introduction

Whole body vibration (WBV) is a technique that distributes vertical vibration to the entire body. A person will either stand passively on a vibration platform or perform exercises on the platform while receiving the vibration. WBV is being marketed as an alternative and a supplement to exercise training.

Both acute and training effects of WBV have been studied. Though most of these investigations focus on the beneficial effects of vibration on indices of athletic performance such as increased muscular strength (37, 62), improved jump height (21, 62), increased power (37), and improved balance (62), and flexibility (16, 21, 58), there is burgeoning interest in non-performance areas like metabolism (52), body composition (53), and oxygen uptake (50-52). There has also been an increased interest in WBV and its effect on chronic disease and aging. Patients with multiple sclerosis, cerebral palsy, stroke, cystic fibrosis, Parkinson's disease, and diabetes have been examined. The primary focus of these studies has been on functional components related to these states such as strength (3, 38, 49, 54, 61, 66), motor function (3, 7, 33, 56, 59, 65), and balance (3, 7, 29, 38, 65). Other areas of interest within these populations include bone mineral density (32, 66) and glycemic control (6).

Cardiovascular changes have also been observed following acute bouts of WBV. These changes include increases in skin blood flow (39, 41, 43), increased arterial blood flow (39),

decreased resistance to blood flow (39), and decreased arterial stiffness (47). The changes seen in blood flow suggest that WBV may be a beneficial adjunct to exercise for populations with impaired circulation such as those with peripheral artery disease (PAD) and diabetes; specifically, the individuals who are limited during exercise because of claudication pain.

A significant limitation of the body of WBV literature is the lack of consensus regarding an appropriate frequency and amplitude that will produce physiological changes. Studies have used frequencies as low as 10Hz to as high as 60Hz and amplitudes as low as 1mm to as high as 10mm. Studies of athletic performance clearly indicate varying frequencies and amplitudes produce dissimilar physiological responses (8, 15, 16, 25, 26, 35, 41, 42, 51, 62). However similar studies of the effects of amplitude and frequency on indices of blood flow are much less prevalent. Maloney-Hinds et al. is the only group to explore how 2 different WBV frequencies (30 Hz vs. 50 Hz) affect blood flow (43). They reported that the higher frequency induced a greater increase in skin blood flow than the lower frequency. There are no published studies that describe the blood flow response to different WBV amplitudes.

Purpose

The primary purpose of this study was to determine how 2 different amplitudes of WBV affected blood flow through the popliteal artery. This study tested the following hypotheses: that WBV will increase arterial blood flow; and that a high amplitude (6 mm), will cause a greater increase in blood flow than a low amplitude (3 mm).

Delimitations

This research was delimited to 30 low risk, recreationally active, males and females. All of the subjects were exposed to 30 Hz of frequency and 3 mm and 6 mm of amplitude of

vibration using the Next Generation Power Plate (North America, LLC, Culver City, California, USA). The age range was 19-34 years. This study assessed indices of blood flow (mean velocity, peak velocity, end diastolic velocity, pulsatility index, and resistive index) through the popliteal artery pre-WBV and post-WBV using Doppler sonography. The same technician made all measurements for this experiment.

Limitations

Limitations of this study included conducting of tests at different times of the day, thus not controlling for diurnal variations in blood flow. It is unknown if these diurnal fluctuations would influence the blood flow response to WBV. This study also did not control for hormones that affect blood flow. Women were not tested at a particular phase of the menstrual cycle. During the menstrual cycle there are vascular changes which will affect blood flow (5). Another limitation to this study is that the diameter of the popliteal artery was not directly measured, so blood flow could not be measured directly. This study was also limited to a small sample size, which limits the statistical power of the results.

Definitions

- 1. Whole Body Vibration** – a technique in which low or high frequency vibration is delivered to a participant that is standing or exercising on a vibration platform.
- 2. Frequency** – the number of complete oscillations per second of energy.
- 3. Amplitude** – the maximum displacement of a vibrating particle or body from its position to rest.
- 4. Power Doppler Sonography** – a Doppler ultrasound technique utilizing the Doppler Effect to measure blood flow velocity.

5. **Mean Velocity** – the mean blood flow velocity through a vessel.
6. **Peak Velocity** – the maximal blood flow velocity through a vessel.
7. **End Diastolic Velocity** – the maximal blood flow velocity at the end of diastole.
8. **Pulsatility Index** – a measure of the variability of blood velocity in a vessel, equal to the difference between the peak systolic and minimum diastolic velocities divided by the mean velocity during the cardiac cycle.
9. **Resistive Index** – indicator of resistance to perfusion.
10. **Blood Flow** – measure of volume of blood moving through a vessel over a unit of time.

Chapter II Literature Review

Whole body vibration (WBV) is a technique used as a supplement to traditional exercise programs. WBV is a method in which low or high frequency vibration is delivered to an individual that is standing or exercising on a vibration platform. Various measures of physical performance, physiological factors, and metabolic factors are improved following WBV both acutely and with training across various populations.

Effects of Vibration on Athletic Performance

Acute Effects

The acute effect of WBV on athletic performance has been shown in a number of studies. Improvements have been reported in muscular strength and power (10, 21, 22, 27, 37, 55, 62) as well as jump height (8, 16, 19, 21, 62), flexibility (16, 21, 58), and muscle activity (9, 35, 62) following an acute bout of WBV. These improvements have been shown in sedentary individuals as well as in elite athletes. In contrast to these findings, there are reports that WBV does not improve athletic performance (8, 18, 22) and may even hinder it (16, 25).

Bosco et al. (10) examined the effect of a single session of WBV on 6 national level female volleyball players. WBV was administered in 10 bouts which lasted for 60 seconds. Subjects rested for 60 seconds between bouts. Frequency was set at 26 Hz and amplitude at 10 mm. The subjects performed 1-legged maximal presses. The vertical displacement of the

loads were measured electronically and the best of 3 trials was used for analysis. After the presses the subjects were exposed to WBV. One leg received vibration while the other leg was used as a control. Following WBV the subjects were tested again and the tests revealed significant increases in power. The researchers speculate that a neuromuscular adaptation occurred during vibration causing the observed increases (10). Cochrane et al. (21) showed that after 5 minutes of vibration with 26 Hz of frequency and 6 mm of amplitude, vertical jump height increased 8.1% and sit and reach scores increased 8.2% compared to a control and cycling intervention group. Eighteen female field hockey players were examined. Vertical jump height, grip strength and sit and reach flexibility were tested pre-vibration and post-vibration. Subjects were instructed to execute 6 positions. Positions 1-4 (standing, isometric squat, kneeling with arms placed on platform, and dynamic squatting) were held for 1 minute while positions 5 and 6 (lunge with left leg on platform and lunge with right leg on platform) were held for 30 seconds. No significant changes were observed for grip strength. It is hypothesized that enhanced power is due to stimulation of the muscle spindles which enhances the stretch-reflex pathway resulting in additional motor unit recruitment (21). Another study by Cochrane et al. (18) investigated the use of vibration in the arms of 12 climbers (5 women and 7 men), showed no improvements in grip strength, medicine ball throws, or specific climbing maneuvers. The same protocol was used from the previous study but with upper-body exercises. The exercises consisted of a chest press, triceps extension, shoulder press, a front raise static hold, and a bicep curl. Because this study was looking at sport-specific movements, which require more coordination and greater recruitment of motor units, the authors speculated that this is why there were no changes in performance (18). A study done by Cormie et al. (22) showed that while jump height increased in 9 moderately trained men, following 30 seconds of WBV, there

was no increase in power. Frequency and amplitude were set at 30 Hz and 2.5 mm, respectively. Subjects were instructed to squat at a knee angle of 100° throughout the vibration bout. No change was observed in muscle activity measured using electromyography (EMG). The authors speculate that some other physiological factor other than neuromuscular adaptations is influencing the improvements in jump height. They suggest that hormone release may be inducing the changes (22). Another study that utilized a frequency of 30 Hz in a group of 12 untrained students showed a 7% reduction in maximal isometric force in the knee extensors after 5, 60-second bouts of vibration. Amplitude was set at 8 mm. Knee extensor force was measured using a transducer placed on the shin. The maximal voluntary contraction force was established as the highest value obtained during 6 knee extensions. It is speculated that co-contraction of the hamstrings, resulting from WBV, may have affected the MVC values (25). Issurin and Tenenbaum (37) showed that in a group of 28 elite male athletes performing biceps curls, maximal and mean power increased 10.4% and 10.2%, respectively. A device was designed to impose vibration on the athletes as they performed biceps curls. Frequency was set at 44 Hz and amplitude at 3 mm. Probes were placed on the curl machine which measured velocity of the movement. Mean power was calculated as a product of velocity and force. Subjects performed 2 series of biceps curls, 1 series without vibration and 1 series with vibration. One series consisted of 3 sets of 3 repetitions which utilized 65-70% of 1 repetition maximum. The authors speculate extremely stretched muscles before each repetition may explain the increases in power they observed during vibration (37).

There is conflicting evidence with many of the studies investigating performance. This may be due to utilization of different WBV protocols, utilization of different populations, or sample size. Bosco et al. (10) examined the effect of WBV on power in females, while Cormie et

al. (22) looked at males. It is possible that the differences observed in power are due to gender differences or that 1 protocol lasted 10 minutes while the other only last 30 seconds. Another limitation to these studies are how their outcomes are measured. One study may be assessing power by looking at knee extensions (25) while another uses a leg press (10). Differences in protocol could also limit outcomes. Studies using passive vibration may not produce the same affects as those that perform exercises while receiving WBV. It appears that frequencies of WBV ranging from 20-30 Hz may be enough to improve jump height. A longer duration may be sufficient to increase other performance factors such as strength and power. It seems that these improvements are more likely to occur in trained individuals than in untrained individuals (25). It is clear WBV has some affect on performance, but the most efficient protocol has not yet been determined.

WBV has also been shown to affect metabolic aspects of performance. Da Silva et al. (23) examined the effect of WBV on energy expenditure. Seventeen recreationally healthy males performed a 10 repetition maximum of squats without vibration and squats while being vibrated at a frequency of 30 Hz and amplitude of 4 mm. This study found that energy expenditure with vibration was 17% higher than without vibration. Energy expenditure was also significantly higher during recovery following vibration than without vibration. The authors speculate that vibration causes contractions and that these contractions stimulate neuroendocrine release which is increasing metabolic load resulting in higher energy expenditure (23). Bosco et al. (11) showed that plasma concentrations of growth hormone and testosterone were significantly higher while cortisol levels decreased in 15 men following 10 sets of 60 second bouts of vibration with a frequency of 26 Hz and an amplitude of 4 mm (11).

These findings suggest that metabolic effects of performance can be enhanced following vibration.

Training Adaptations

Another area of interest regarding WBV is its training induced effects. Training that utilizes WBV has shown increases in balance (63, 64), range of motion (58), strength (4, 28, 42), and power (4, 28).

Following 4 weeks of vibration training which utilized a frequency of 30 Hz and an amplitude of 2 mm, Sands et al. (58) showed that range of motion in the right and left legs increased 4.3 % and 4.2%, respectively, in a group of 10 young male gymnasts. Subjects were randomly placed into an experimental group and a control group. Following the gymnasts' usual work outs they were instructed to hold 4 different stretches for 1 minute. The experimental group performed stretching on a vibration device. The control group performed stretching on the same device, but did not receive any vibration (58). Delecluse et al. (27) observed the effect of WBV on strength and sprint performance in 20 young sprint trained athletes (men=13, women=7). Subjects performed static and dynamic exercises while being vibrated with a frequency of 35 – 40 Hz and amplitudes ranging from 1.7 – 2.5 mm. Upon completion of the 5 week training program there were no changes in knee-extensor or knee-flexor strength, no change in knee-extension velocity, and no change in sprint speed. The results of this study suggest that WBV does not improve speed – strength performance in sprint – trained athletes. A possible explanation for this is that muscle strength, motorneuron excitability, and fiber recruitment are already so well developed that WBV does not change them (27). In contrast, Delecluse et al. (28) also observed the effects of 12 weeks of WBV in 67 untrained females. Training consisted of performing various exercises while being vibrated. Intensity of training

was increased by increasing duration, repetitions of exercises, amplitude (2.5 – 5 mm), frequency (35 – 40 Hz), or the number of exercises performed. WBV occurred 3 times per week. In addition to the WBV group there was a resistance training group which trained 3 days per week. Training began at 20 repetitions and progressed by decreasing repetitions and increasing the weight. Increases in dynamic and isometric strength were comparable for both groups with the WBV group improving 16.6% and 9.0%, respectively, and the resistance training group improving 14.4% and 7.0%, respectively. These results suggest that improvements in strength in WBV are similar to those seen in resistance training. The authors suggest that the same neuromuscular adaptations occurring in the initial weeks of resistance training are what is causing improvements following WBV (28). Mahieu et al. (42) examined 33 competitive downhill skiers performing various leg exercises while being vibrated 3 times a week for 6 weeks. Intensity was increased by increasing amplitude from 2 mm – 4 mm and by increasing frequency from 24 Hz – 28 Hz. Isokinetic muscle strength was measured using dynamometers. For explosive strength subjects performed a high box test. Performance was measured as how many lateral jumps onto and off of the box the subject could do in 90 seconds. Following the training program isokinetic ankle and knee muscle strength and explosive strength significantly increased. It is speculated that the increases observed are due to WBV, specifically, training fast-twitch fibers. (42). Jump height was shown to increase in a group of 22 well trained ballerinas by 6.3% after exposure to WBV compared to jump height without vibration. Leg press power and velocity were also shown to increase significantly. WBV treatment included 3 sessions per week (30 Hz, 5 x 40 seconds) for 8 weeks. Amplitude was set at 5 mm. Subjects were instructed to stand in a squat position with feet and knees externally rotated. Annino et

al. (4) suggests that the improvements caused by multiple factors including antagonist muscle inhibition, co-contraction of synergistic muscles and increased motor unit synchronization (4).

There have not been many studies that explore WBV training for longer than 12 weeks. Torvinen et al. (63, 64) employed 4 minutes of vibration 3 times a week to 56 young, healthy, non-athletic men and women. They were tested after 2, 4, and 8 months of training. Frequency increased every minute from 25 Hz to 45 Hz. Subjects followed an exercise program while being vibrated which consisted of light squatting, standing in an erect position, standing in a relaxed position with knees slightly flexed, light jumping, alternating the body weight from 1 leg to another, and standing on the heels. Two months into the program the subjects exhibited an increase in lower limb extension strength of 3.7%. Four months into the training the strength benefits had diminished, but an 8.5% net increase was reported in jump height, and after 8 months a 7.8% net increase in jump height was reported. The authors speculate that the initial increase in strength and prolonged increase in jump height is due to neuromuscular adaptations, but because the subjects were young and healthy there was no need for further adaptation (63, 64).

It appears that training with WBV produces beneficial effects in performance. A limitation to some of these studies is that they increase both frequency and amplitude to progress their subjects as well as increasing their number of repetitions or shortening their rest periods. This makes it difficult to determine which factor, WBV or the accompanying exercises, is producing the changes. It is hard to compare the training studies because they all last for varying amounts of time some only last 4 weeks (58) while some last 12 weeks (28). Another limitation is that there are no gender comparisons. A strong point for these studies is that most, although not all used a large sample size.

Proposed WBV Mechanisms for Improved Athletic Performance

There is no clear reason for the increases seen in strength and power due to a lack of research in this area. There have been a number of mechanisms proposed including the tonic vibration reflex (16), muscle hypertrophy (28), increased hormone secretion (10, 11), and stimulation of proprioceptive pathways (28). Tonic vibration reflex is when vibration causes a reflex muscle contraction by exciting the muscle spindles similar to the patellar tendon reflex. It is still unknown if low frequency vibration (30 Hz) is enough of a stimulus to activate the tonic vibration reflex. It is possible that a WBV training protocol can stimulate hypertrophy. Fast- and slow-twitch muscle fibers in rats have shown enlargement following vibration (46). Although vibration induced hypertrophy has yet to be shown in humans it cannot be ruled out as a possibility in improving performance. Vibration has been shown to increase the release of testosterone and growth hormone (11) and a positive relationship between testosterone concentrations and sprinting and power performances have been shown (12). WBV has been shown to stimulate proprioceptive pathways. It is possible that training that utilizes vibration may improve the efficiency of the proprioceptive feedback loop. Proprioceptive pathways are used during isometric contractions to produce force (30). A more efficient proprioceptive feedback loop, caused by vibration, could lead to increases in force production. A better understanding of which mechanism or mechanisms influence improvements would advance the utilization of WBV as a training tool.

Effects of Vibration in Clinical Populations

WBV has been used in clinical populations to enhance strength (3, 38, 49, 53, 54, 61, 66), motor function (3, 7), balance (3, 7, 29, 38, 56, 66), gait (7, 29, 38, 56), bone mineral density

(66), and glycemic control (6). Patients with multiple sclerosis, cerebral palsy, stroke, cystic fibrosis, Parkinson's disease, and diabetes have been examined. WBV has been investigated in elderly populations as well.

Schuhfried et al. (59) investigated the effect of 5 series of 1 minute WBV bouts for 2 weeks on patients with multiple sclerosis. Twelve patients (3 men and 9 women) were randomly assigned to a WBV group and a placebo group. Frequency of WBV started at 1 Hz and increased until the patient could not tolerate further increases. Frequencies ranged from 2-4.4 Hz with an average frequency of 3 Hz. Amplitude was set at 3 mm. Transcutaneous electrical nerve stimulation was applied to the forearm of the patients in the placebo group to simulate vibration. Patients completed a sensory organization test which measures postural control by placing them on a platform and then subjects were instructed to stand upright and still for 3 20-second repetitions. From the data obtained a balance score was recorded. A higher score shows more postural stability. Patients also performed a Timed Get Up and Go Test. This test was used to measure mobility by timing how long it took a patient to get up from a chair, walk 3 meters turn around, and return to their seat. Faster times show better mobility. Timed Get Up and Go Test times were quicker in the group that performed WBV (8.1 ± 1.8 seconds) compared to the placebo group (9.2 ± 4.1 seconds), although not significantly. Postural stability scores increased more in the WBV group (76.8 ± 7) than in the placebo group (71.0 ± 15.2). These findings suggest that low frequency vibration was shown to improve postural stability and mobility in patients with multiple sclerosis (59). Parkinson's patients underwent 5 series of WBV. One series consisted of 1 minute of vibration followed by 1 minute of rest. Frequency was set at 6 Hz and amplitude was 3 mm. Motor symptoms were assessed using the Unified Parkinson's Disease Rating Scale (UPDRS). Scores showed tremor frequency, rigidity,

bradykinesia, gait and posture, and cranial symptoms. Results showed a 25% improvement in tremors and a 24% improvement in rigidity, gait and posture items show 15% improvement, and bradykinesia scores were reduced by 12%. The authors speculate that multiple physiological systems are being affected by vibration. They suggest that peripheral neural adaptations are improving gait and posture stability and that vibration results in greater supplementary motor area activation (33). Ebersbach et al. (29) investigated the effects of 30 sessions (2, 15-minute sessions a day for 1 week) of WBV on 13 patients with Parkinson's disease compared to 14 physical therapy Parkinson's patients. Patients were exposed to a frequency of 25 Hz and amplitudes of 7 – 14 mm. The physical therapy patients received 40 minutes of group exercises (muscle-stretching, relaxation, body perception), speech therapy, and occupational therapy 3 times per day 5 days per week. Measurements included balance using the Tinetti Balance Scale, gait velocity using the time it takes to walk 10 meters, and mobility using the Timed Get Up and Go Test. An increase in balance, gait velocity, and Timed Get Up and Go Test was observed for both groups. Following the intervention patients were instructed to perform maintenance exercises. There was no significant decline after 4 weeks of follow up in the WBV population (29).

In 8 stroke patients randomly assigned to a WBV group produced transient favorable effects on force and muscle activation compared to a control group. All patients were first-time stroke victims whose strokes were less than 6 weeks before beginning the intervention. Patients were exposed to 1 session of WBV after their usual physical therapy. The session consisted of 5 bouts lasting for 1 minute with 2 minutes of rest in between. Frequency was set at 20 Hz and amplitude was set at 5 mm. Isometric and eccentric knee extension force increased by 36.6% and 22.2%, respectively, in the WBV group and by 8.4% and 5.3%,

respectively in the control group. Muscle activity increased by 13.1% for the vastus lateralis in the WBV group while the control group experienced no change (61). In comparison, Van Nes et al. (65) investigated using 6 weeks of WBV in stroke patients. They employed 4, 45-second bouts of WBV, 5 days per week for 6 weeks. Fifty-three patients were subjected to vibration with a frequency of 30 Hz and amplitude of 3 mm. There were no significant differences between the WBV group and the exercise therapy group for any of the variables measured (Berg Balance Scale, Trunk Control Test, Rivermead Mobility Index, Barthel Index, Functional Ambulation Categories, Motricity Index, and somatosensory threshold). The results of these 2 studies suggest that daily WBV training improvements were no more beneficial in improving balance and activities of daily living than an exercise therapy program (65).

In 14 patients with cerebral palsy (4 men and 3 women), 6 minutes of WBV set between 25-40 Hz of frequency, 3 times a week for 8 weeks resulted in decreased spasticity in the knee extensors and an increase in gross motor function. Only 4 of the 8 measures of isokinetic strength significantly increased in the WBV group, while the resistance training group saw an increase in all 8 measures. There was no improvement in Six-Minute Walk Test or the Timed Get Up and Go Test in either group (3). Following 6 months of WBV training 5 days a week, Roth et al. (56) observed increases of 4.7%, 6.6%, and 6.7% in muscle power, velocity, and muscle force, respectively. Eleven cystic fibrosis patients performed body exercises (leg bends, trunk bends, extension, and rotation of the trunk) while being vibrated for 6 minutes. Five days a week patients received vibration with a frequency 12 Hz to improve range of motion and on 3 days they also received 26 Hz to improve power and force (56). Baum et al. (6) explored using WBV in people with diabetes for 12 weeks. Forty subjects (24 men and 16 women) were divided into 3 groups, a flexibility training group, a resistance training group, and a WBV group. For the

first 9 weeks subjects received vibration with a frequency of 30 Hz and then 35 Hz for the last 3 weeks. Amplitude remained constant at 2 mm. Subjects performed 8 exercises while receiving vibration. The resistance training group performed 8 exercises (leg extension, leg flexion, leg press, calf raises, lat pull downs, chest press, butterfly, and rowing). The flexibility group performed 8 stretches which involved both upper and lower body. The program illustrated no change in endurance capacity, but increased maximal isometric torque of the quadriceps muscles. Fasting glucose concentrations decreased in all groups although not significantly. HbA1C values increased in the flexibility and resistance trained groups while there was small decrease in the vibration group. The results of this study suggest that WBV may be an effective device to enhance glycemic control in subjects with diabetes (6).

These studies, with the exception of a few (6, 33, 65), are limited by their small sample size. Another limitation is that many of these patients are on medications for their symptoms. If these medications help to improve their balance or mobility then these medications may alter the results. The protocol used for testing some of the populations varied and in some cases subjects determined their own frequency and amplitude (29, 59). Many of the outcomes obtained in these populations are measured using questionnaires which are objective and may limit the findings.

There is a burgeoning interest in adaptations in the elderly after performing WBV. All of the literature in this area is on training adaptations; there is only 1 acute study with this population and it is a comparison between the differences in adaptations between young individuals and older individuals. Twelve young healthy males and females and 12 older healthy males and females performed trials of squats with loads of 0%, 20%, and 40% of body mass with WBV and without WBV. Each WBV condition lasted for 4 minutes with 30 second rest intervals.

Vibration frequency was set at 30 Hz and amplitude at 1 mm. VO_2 and HR increased significantly in both groups with a higher increase seen per load in the younger group. The elicited improvement in VO_2 although significant may be inefficient enough to stimulate improvements in the cardiovascular system (20).

The training studies are as short as 6 weeks to as long as 8 months. In a 6 week study involving 42 elderly volunteers living in a nursing home physical therapy supplemented with low frequency WBV (10 – 26 Hz) was more effective in improving elements of fall risk and quality of life than was physical therapy only. Subjects were trained 3 times per week. Training consisted of 4 series of WBV. All series last for 1 minute. Series 1 and 3 used a frequency of 10 Hz and an amplitude of 3 mm, while the second and fourth series used a frequency of 26 Hz and 7 mm of amplitude (13). Bautmans et al. (7) also investigated nursing home residents for 6 weeks. Twenty-four males and females were randomly placed into a WBV group and a control. The WBV group performed static exercises during WBV with a frequency of 30 Hz and amplitude of 2 mm 3 times per week. The control group performed the same exercises as the WBV group on the vibration platform, but was not exposed to vibration. Improvements in mobility and body balance were significantly greater in the group performing WBV than the control group. The authors speculate that the adaptations to allow the subjects to maintain equilibrium on the vibration platform are causing their improvements (7). Sixty-seven subjects (4 men and 63 postmenopausal women) participated in 8 weeks of routine exercise supplemented with WBV. Subjects were randomly placed into a WBV group (n=40) and a control group (n=27). Subjects received vibration at a frequency between 12-20 Hz for 4 minutes once a week. Amplitude was not given. Walking speed, step length, and 1 – legged standing time were significantly higher following vibration than performing exercise alone (38). Rees et al. (49) explored using WBV in

combination with lower limb exercises compared to the exercises without WBV in a group of 30 subjects (16 men and 14 women) aged 66-85 years of age. The frequency was constant at 26 Hz while the amplitude increased 1 mm every 2 weeks from 5 – 8 mm. Training lasted 8 weeks. Subjects were randomly placed into either a WBV group or an exercise group. The exercise group performed static squats, dynamic squats, and calf raises 3 times per week. Strength and power were assessed using a Cybex dynamometer. While there was no significant difference between groups in knee flexor or extensor strength, there was a significant increase in ankle plantar flexion strength and power following vibration. It is speculated that WBV stimulates reflex muscle contractions and that the muscle group closer to the platform will attenuate the vibration more, resulting in the improvements in ankle strength and power (49).

Twenty – four weeks of WBV utilizing frequencies of 35 – 40 Hz and amplitudes of 2.5 – 5.0 mm, while performing body weight exercises for a maximum of 30 minutes was examined in a group of postmenopausal women not taking hormone replacement therapy. Subjects were randomly separated into a WBV group (n=30) and a resistance training group (n=30). Resistance training lasted for 1 hour and was progressed over the 24 week period by lowering repetitions and increasing the resistance. Results revealed increases of isometric and dynamic knee extensor strength in the WBV group of 15% and 16.1%, respectively, and increases in the resistance training group of 18.4% and 13.9%, respectively. Jump height and speed of movement of the knee extensors also increased in the WBV group by 19.4% and 7.4%, respectively, and in the resistance training group by 12.9% and 6.3%, respectively. The authors hypothesize that neuromuscular adaptations are what cause the improvements in both groups (54). Verschueren et al. (66) investigated the effects of 24 weeks of WBV at frequencies of 35 – 40 Hz. Seventy postmenopausal women volunteered for the study. Subjects were randomly put

into 3 groups, a WBV group, a resistance training group, and a control group. Subjects performed static and dynamic exercises while being vibrated 3 times a week for a maximum of 30 minutes per session. The resistance training group followed the same program as Roelants et al. (54). The control group was instructed not to alter their current physical activity in any way. Strength was measured using motor-driven dynamometers and bone mineral density was measured using the DEXA. Isometric and dynamic strength of the knee extensors increased 15% and 16.5%, respectively. While there was no increase in total body or lumbar spine bone mineral density, there was a 1.5% increase in total hip bone mineral density. It is speculated that reflexive muscle contractions in response to WBV are enough to mechanically load the bone and induce increases in hip bone mineral density (66). Gusi et al. (32) explored the benefit of eight months of low frequency (12.5 Hz) WBV in a group of 28 untrained post – menopausal women. Subjects were randomly placed in a WBV group and a walking group. The subjects in the WBV group performed 6 sessions of 1 minute vibration bouts with 1 minute rest in between 3 times per week. The walking group walked for 55 minutes a day 3 times per week. Bone mineral density of the femoral neck increased 4.3% and balance increased 29% compared to a walking group, while there was no change in lumbar spine bone mineral density (32).

The studies lasting 24 weeks were better controlled than the shorter duration studies. All 3 investigated the same population and had large sample sizes, with the exception of the Gusi et al. (32) study. The Gusi et al. (32) and Roelants et al. (53) both control for training status by only using untrained women, while the Verschueren et al. (66) study did not control for physical activity status. All 3 studies look at postmenopausal women which are not on hormone replacement therapy. It is unknown how WBV would affect bone density in younger populations or populations on hormone replacement therapies. Limitations to the shorter

duration studies are that some have uneven numbers in their groups (i.e. 4 men and 63 postmenopausal women), large age ranges (i.e. 63 – 98 years), and varying vibration protocols. One investigation used 2 different frequencies and amplitudes during alternating minutes (13). It appears that shorter WBV training may be beneficial in improving balance and mobility and that longer training is needed to affect bone mineral density.

WBV can be an effective tool in improving strength, power, and bone mineral density. It can also be used as an effective instrument in increasing balance, mobility, and gait in clinical populations that exhibit neuromuscular problems. Another area of interest is the use of WBV to improve glycemic control in diabetic populations.

Effects of Vibration on the Cardiovascular System

Beneficial cardiovascular changes have been observed following acute bouts of WBV. These changes include increases in skin blood flow at different areas in the body (39, 41, 43), increased arterial blood flow (39), decreased resistive index (39), and decreased arterial stiffness (47). Different frequencies and amplitudes have been utilized to elucidate these changes.

Kerschman-Schindl et al. (39) examined the effect of WBV on alterations in blood volume. Twenty subjects, 8 women and 12 men, recreationally active, were recruited to participate in the study. Subjects were exposed to WBV with a frequency of 26 Hz and amplitude of 3 mm for 9 minutes. Three sets using 3 different positions were used. In the first position subjects stood with their legs straight and feet parallel, in the second position subjects slightly bent their knees, and the third position was the same as position 2 except with legs rotated externally 30°. Color and power Doppler ultrasonography were used to measure blood volume. No change in vessel diameter of the popliteal artery was observed. Color Doppler ultrasonography was used to measure the number of visualized vessels. The number of visualized vessels increased in

response to vibration which represents an increase in skin blood flow. Arterial blood flow was measured using power Doppler ultrasonography. While there was no statistically significant change in maximal systolic or diastolic flow of the popliteal artery, the mean speed of blood flow increased significantly. In addition to the increase in flow there was a significant decrease in resistive index, a measure of vascular resistance. One limitation to this study is that it has a small sample size. Subjects also shifted position every 3 minutes. The current study is the only one that has investigated blood flow through the popliteal artery. One of the strengths of this study is that it measured vessel diameter. The authors hypothesize that vibration causes rhythmic muscle contractions which cause the vessels downstream from the popliteal artery to vasodilate which would increase blood flow through the artery (39).

In 2007, Lohman et al. (41) investigated the effect of WBV on lower limb skin blood flow. There were 45 healthy adult subjects (23 men and 22 women), aged 18 – 45 years old, who were randomly split into 3 groups. The 3 groups consisted of a vibration exercise group (VE), an exercise only group, and a vibration only group. WBV was delivered with a frequency of 30 Hz and amplitudes of 5 – 6 mm. After a baseline measure was taken, subjects performed either active isometric therapeutic exercise with or without vibration or they received local vibration only. Each exercise lasted 60 seconds. The vibration only group received local vibration of the right calf for 3, 60-second bouts. For local vibration subjects were supine on the floor with their calves placed on the vibration plate. Skin blood flow was measured using laser Doppler ultrasonography. A laser scans the body and then using Doppler imaging creates a picture of blood flow to the skin. Following the vibration the vibration only group's skin blood flow increased twice as much as the VE group and the exercise only group. Skin blood flow decreased rapidly 10 – minutes post vibration, but the vibration only group's blood flow

remained higher than both comparison groups. A limitation to this study is that it has a large age range. There was no information regarding physical activity habits. There was also no gender comparison to explore possible gender differences. This study did control for ambient temperature. It also investigated both passive vibration as well as active vibration in addition to exercise only. This study observed that exercise with or without vibration actually slightly decreases skin blood flow, while vibration alone increases it. This suggests that the need for blood flow in the exercising limb, with or without vibration, surpasses the cutaneous vascular changes responding to vibration. The authors suggest that because the increased need for blood in the exercising muscle was of short duration, blood may have been shunted away from the skin, thus, decreasing skin blood flow. Furthermore, they speculate that mechanical vibration stimulated the endothelial to increase nitric oxide production, resulting in vasodilation of resistant blood vessels (41).

Maloney-Hinds et al. (43) compared the effect of 30 Hz and 50 Hz passive vibration on the skin blood flow of the forearm. Twenty – five healthy subjects (14 men and 11 women) were recruited to participate in this study which involved 2 experiments. In the first experiment, 18 subjects (11 men and 7 women) were placed into either the 30 Hz group or the 50 Hz group. Subjects sat in front of the vibration platform and placed their forearm on it with hand placed palm down. Skin blood flow was measured using laser Doppler ultrasonography. Skin blood flow was measured during vibration every minute for 10 minutes and then during recovery every minute for 15 minutes. A second experiment was performed to determine if the results of the first experiment were due to subject variability. This experiment had 7 subjects (3 men and 4 women) receive both 30 Hz and 50 Hz on 2 different days. The same protocol for the first experiment was utilized for the second experiment. The first experiment showed no

significant differences between skin blood flow before, during, or after vibration for either group. However, there was a significant increase in the rate at which skin blood flow increased. The 50 Hz group observed faster increases in skin blood flow than the 30 Hz group for every minute. At the fourth minute both groups exhibited a significant increase in skin blood flow with the fifth minute having the highest increases in skin blood flow. Skin blood flow measurements remained elevated through the ninth minute of vibration. While the 30 Hz group dropped below baseline during 15 minutes of recovery the 50 Hz group did not return to baseline within 15 minutes. The results of the second experiment were similar to the first with the highest skin blood flows being reached around 5 minutes of vibration. Similar to the first experiment the 50 Hz group did not reach baseline within the 15 minutes of recovery, but the 30 Hz group reached baseline within 5 minutes of recovery. A limitation to this investigation is the small sample size used for both experiments. Unlike the current study, this study used laser Doppler ultrasound. This allows the researchers to directly measure microcirculatory flow instead of using indices of flow. Physical activity status was not accounted for. This study shows that either frequency produces increases in skin blood flow with the higher frequency producing greater increases (43).

In 2008, Otsuki et al. (47) observed that arterial stiffness, a risk factor for cardiovascular disease, acutely decreases following whole body vibration (47). Ten healthy young men, with an average age of 26.6 years, were recruited for the study. Arterial stiffness was measured using brachial – ankle pulse wave velocity (baPWV). BaPWV sends pulsed waves from the heart to the brachial recording site and from the heart to the post-tibial recording site. The difference between these 2 distances is divided by the difference between the times it took for the pulsed wave to reach the 2 sites. Subjects performed 2 trials, a WBV trial and control trial which

consisted of subjects performing a static squat without WBV. During WBV the subjects performed a static squat while receiving vibration at a frequency of 26 Hz and amplitudes of 2 – 4 mm. The trial consisted of 10, 60-second bouts of vibration with 60 seconds of rest between bouts. There were no differences in the control trial before or after. At 20 and 40 minutes after WBV, a decrease in baPWV was observed. The major limitation to this study is its small sample size. Another limitation is that a specific amplitude was not utilized. It is possible that 2 mm and 4 mm may produce different affects. The implications of this finding are that if a decrease in arterial stiffness can be elicited then cardiovascular risk can be decreased. Although a single WBV session may produce minor effects, it is possible the cardiovascular system could benefit from a long-term WBV treatment. Further assessment is necessary to observe what kinds of effects this may have in different populations. Although the mechanisms behind the decrease in arterial stiffness are still uncertain it is possible that the mechanical influences of WBV on artery may be related to endothelial function and to the acute decreases in arterial stiffness. Nervous system changes, vasodilators, vasoconstrictors, and body temperature might also be factors that play a role in changes in arterial stiffness (47).

Proposed Mechanisms for Increasing Blood Flow

It has been well established that aerobic exercise increases blood flow both to the skin and to the muscle (2, 17, 34, 36, 57). There are numerous reasons blood flow increases during aerobic exercise such as maintaining a balance between the metabolic demands of the tissue (36) and the delivery of nutrients (36). The predominant mechanism for the increase in blood flow is arteriolar vasodilation resulting in a decreased vascular resistance (36). Compounds that may cause the increase in blood flow include: adenosine, nitric oxide (NO), potassium ions (K^+), hydrogen ions (H^+), and ATP/ADP.

Although it has been proposed that acetylcholine (Ach) may be linked to the early blood flow response (57), the initial increase in blood flow (1 – 3 seconds following contraction) may be due to mechanical factors of the muscle. When the muscle contracts it blocks flow. Immediately after the contraction is released there is a concomitant drop in intramuscular pressure causing a drop in resistance to flow which causes an immediate marked elevation in the blood velocity (57). This increase in blood velocity leads to a 60% increase of blood flow above resting values. The early increase in blood flow without the affiliated vasodilation may be explained by an elevated pressure gradient between the mean arterial pressure and the venous end of the capillary (57).

After the initial increase in blood flow vasodilation must occur because arterial blood pressure is not elevated and muscle pressure remains unchanged. One of the most commonly proposed exercise-dependent vasodilators is NO. It has been hypothesized that when blood flow increases it causes an increase in shear stress acting on the endothelial wall. The increased stress being placed on the endothelial wall stimulates the release of NO to stimulate vasodilation of the vessel. Gilligan et al. (31) observed that when NO synthesis is inhibited, exercise-induced vasodilation is reduced (31). Other vasodilators are prostaglandins which may be synthesized by increases in intracellular Ca^{2+} levels in endothelial cells and by mechanical factors such as shear stress (40). Stiegler et al. (60) showed that arterial infusion of prostaglandins leads to a marked increase in blood flow in the human forearm (60). Endothelial-derived hyperpolarizing factor (EDHF) is another mechanism that is thought to cause vasodilation during exercise. When nitric oxide synthase (NOS) and cyclooxygenase (COX) are inhibited, blood flow in the forearm is shown to increase via bradykinin, which has been speculated to be increased because of EDHF (34).

Adenosine is responsible for 20 – 40% of the constant state of exercise hyperemia at submaximal and maximal workloads (44). The AMP released from muscle fibers is what produces the adenosine. The adenosine causes dilation by acting on A_{2A} receptors on the extraluminal surface of the arterial smooth muscle (44). ATP also contributes to vasodilation by acting on P2Y receptors, which stimulates the release of vasodilators such as NO, prostaglandins, and EDHF (17). Other factors that may play a role in vasodilation are hydrogen ions, potassium ions, and oxygen. Although changes in pH have been shown to produce relaxation in smooth muscle, there does not appear to be a direct relationship between H^+ and exercise hyperemia. It is more likely that changes in pH modify other vasodilatory mechanisms (17). Once a muscle contracts K^+ diffuses into the interstitial fluid around the vasculature. A large increase in K^+ levels has been shown to cause vasodilation (24). It is still unclear how K^+ causes vasodilation, but recent literature demonstrates that the primary component of the vasodilation is activation of Kir channels (17). An active muscle requires oxygen to function and when oxygen in the muscle is compromised blood flow to that muscle increases. Current evidence suggests that although a lack of oxygen affects the muscle vasculature oxygen delivery is not the main regulator of blood flow to active muscle (17). No one vasodilatory factor has been found that primarily regulates blood flow. It is likely a combination of all the factors working together to increase blood flow.

The effects of WBV are similar to those observed during exercise. It is possible that the same mechanisms that promote increases in blood flow during exercise are the ones causing increases in blood flow during WBV. It has been speculated that when the body is exposed to vibration it evokes rhythmic muscle contractions (23, 39). These muscle contractions induce changes in peripheral circulation. Widening of the capillaries in the gastrocnemius and

quadriceps facilitates the passage of more molecules, excretion of waste products, and delivery of oxygen (39). The increase in mean velocity of the popliteal artery may be due to widening of the small vessels in the muscle which will reduce peripheral resistance, which may also decrease the resistive index. Another reason mean velocity increases may be that vibration reduces the viscosity of blood thereby increasing the speed of blood flow (39). Another factor that may play a role in increased blood flow might be an increased production of nitric oxide (NO). The underlying mechanism for the significant increase in blood flow following vibration may be due to pulsatile endothelial stress resulting in increased circulating NO concentration as a result of increased endothelial NO synthase activity (41). Most likely it is not a single mechanism but a combination of mechanisms causing improvements in blood flow in response to WBV.

Utilization of Various Frequencies and Amplitudes

One of the primary issues with utilizing WBV as a training tool is that there is no consensus regarding an appropriate frequency and amplitude. Multiple combinations of frequencies and amplitudes produce dissimilar physiological effects. Torvinen et al. (62) showed a 2.5% increase in jump height, 3.2% increase in isometric extension strength of the lower extremities, and a 15.7% improvement in body balance following 4 minutes of WBV in young, healthy subjects (8 men and 8 women). Amplitude was kept constant at 10mm. The vibration was delivered over 4, 1-minute bouts with frequency (15, 20, 25, and 30 Hz) changing every minute. Results for each frequency were not obtained (62). De Silva et al. (26) investigated the differences between 20, 30, and 40 Hz in 31 recreationally active males. Amplitude was set at 4 mm. Vibration was delivered over 6, 60-second bouts. The results showed increases in squat jump and counter movement jump height with the 30 Hz having a more pronounced increase than 20 Hz, while 40 Hz showed a decrease. One rep maximal values increased with 20 Hz, but

decreased with 30 and 40 Hz. Significant increases were seen in power with 20 and 30 Hz, while there was only a slight increase with 40 Hz. The authors hypothesize that the increases are due to improved neuromuscular function because of increased activity in the superior motor center resulting in increased motor unit recruitment (26). A study inspecting muscle activity of 3 muscle groups explored using 10 random WBV conditions utilizing 5 frequencies (25, 30, 40, and 45 Hz) and 2 amplitudes (2 mm or 4 mm) for 45 seconds. Ten recreationally active males performed an isometric squat, a dynamic squat, and a static and dynamic biceps curl for all 10 WBV conditions. Muscle activity was measured during each exercise. It was reported that following WBV, muscle activity increases ranged from 2.9% - 6.7% in the vastus lateralis during the isometric squat and 3.7% - 8.7% during the dynamic squat compared to no vibration. Muscle activity in the biceps brachii and triceps brachii following a dynamic biceps curl resulted in increases ranging from 0.6% - 0.8% and 0.2% - 1%, compared to no vibration, respectively. During the static biceps curl the biceps brachii had no change while the triceps brachii showed an increase ranging from 0.3% - 0.7% increase. The results of this study showed that the higher amplitude and frequencies produced more increases in muscle activity than the lower amplitude and frequencies (35). A study by Cardinale et al. (16) compared the effect of 2 different frequencies on jump height. Fifteen subjects (13 men and 2 women) performed 5 bouts of WBV lasting 60 seconds each with either 20 Hz or 40 Hz. The subjects exposed to a frequency of 20 Hz saw a 4% improvement in jump height while the subjects exposed to 40 Hz showed a decrement in jump height. It is hypothesized that the decrement observed in jump height is due to a fatiguing effect that occurred in response to the higher frequency (16). In contrast to the results observed in the Cardinale et al. study, Bazett-Jones et al. (8), examined the effect of 45 seconds of squatting at 30, 35, 40, and 50 Hz in 58 untrained subjects (40 men and 18 women).

Each trial was done on separate days and both males and females were investigated. There were no improvements in jump height for males at any frequency. Jump height in females was unchanged at 30 and 35 Hz, but increased by 9.0% at 40 Hz and 8.3% at 50 Hz of WBV frequency when compared to no vibration. It is speculated that viscoelastic properties, or stiffness, may affect how the body responds to WBV. The authors suggest that because women are proposed to be less stiff, greater neuromuscular adaptations may have occurred causing improved jump height (8). It appears that higher frequencies (40 -50 Hz) may produce decrements in performance. Although this is not always the case, it has been speculated that a fatiguing effect occurs at frequencies higher than 40 Hz (16, 50). Training status may also play a role in how the body responds to higher vibration frequencies. It has been shown that untrained subjects experience decrements in performance (25) while trained subjects show improvements (10). It is likely a combination of these factors that causes a decrease in performance.

Rittweger et al. (51) compared different frequencies and amplitudes on VO_2 in 10 young, healthy male subjects. During the frequency test amplitude was constant at 5 mm while frequencies increased 18, 26, and 34 Hz. During the amplitude test frequency was constant at 26 Hz while amplitude increased 2.5, 5, and 7.5 mm. Subjects stood for 4 minutes while they received vibration. This study reported that the higher the frequency and amplitude the higher the VO_2 . It is hypothesized that both frequency and amplitude of WBV causes a certain amount of muscle work and that increases in VO_2 are a result of the increased work of the muscle (51).

Only 1 study has explored using different frequencies during WBV. The Maloney-Hinds et al. (43) paper utilized 30 and 50 Hz of frequency while keeping amplitude at 5-6 mm. The results of this study show that both frequencies produce increases in skin blood flow and that

the higher frequency induces a greater increase in skin blood flow. To date, there are no published studies examining the effect of different amplitudes of WBV on blood flow.

Chapter III Methodology

Recently, studies of skin and arterial blood flow suggest WBV causes increases in blood flow. However, only 1 study has assessed the impact of vibration frequency on blood flow, and there are no published investigations of amplitude's effect on blood flow. The primary purpose of this study was to assess the effect of low and high amplitudes during WBV on lower limb arterial blood flow.

Subjects

The Ball State University Institutional Review Board approved the methodology for this study. Thirty subjects (N=15 men, N=15 women) aged 19 – 34 years participated in the study. Subjects were recruited through word of mouth and mass emails from Ball State University and the surrounding community. The subjects were all asked to provide signed informed consent prior to participation in the study. Exclusion criteria included current tobacco use, having a low physical activity classification, taking medication that would affect blood flow, or the presence of a diagnosed neuromuscular (i.e. multiple sclerosis), orthopedic (i.e. arthritis), or circulatory disease (i.e. PAD) that would affect the variables under examination.

Procedures

Subjects reported to the laboratory for testing after having refrained from consuming caffeine for at least 12 hours, alcohol for at least 24 hours, any food or drink other than water for at least 4 hours, and exercise for at least 12 hours. After completing the informed consent process, subjects filled out a health history questionnaire and a short-form International Physical Activity Questionnaire (IPAQ) to describe physical activity level. Each subject's height and weight were then obtained.

Two amplitudes (3mm and 6mm) were tested in random order separated by a recovery period. After lying prone for 15 minutes the popliteal artery was located and marked behind the right knee using a non-toxic marker to assure proper alignment of the ultrasound probe and a baseline measurement was obtained. The subjects then moved to the vibration platform and were asked to stand still for 3 minutes to allow positional blood flow velocity changes through the popliteal artery to stabilize. After 3 minutes a standing baseline measurement of blood flow velocity was obtained. Subjects stood on the WBV platform for 10 continuous minutes. Immediately after the 10 – minute vibration period, a third measurement of blood flow velocity was taken in the standing position. Subjects then resumed a prone position for a minimum of 10 minutes, or until mean blood flow velocity returned to within 8% of baseline. The experiment was then repeated using the alternate vibration amplitude.

Vibration

WBV was administered to a subject via a vibration platform (Next Generation, Power Plate North America, LLC, Culver City, California, USA). The frequency was set at 30 Hz for all

tests, and amplitude was set to either 3mm or 6mm. The subjects were shoeless, with knees slightly bent, feet parallel and shoulder width apart while they stood for 10 continuous minutes.

Data Collection

Height and Weight Procedures

Measures of height and weight were obtained with shoes off. Height was measured using a stadiometer (Detecto, Web City, MO, USA). Subjects stood with feet together and backs straight against the stadiometer. Subjects took a deep breath and held it until the measurement was obtained. Body weight was measured by a weight scale (Detecto, Web City, MO, USA). All subjects wore a t-shirt and shorts.

Physical Activity Assessment

Physical activity for the week prior to the trial was assessed using the IPAQ, a questionnaire developed for the purpose of surveying a population's physical activity status (1). The IPAQ quantifies MET*minutes/week for 3 specific types of activities: walking, moderate intensity activities, and vigorous intensity activities. The summation of all the activities was used to compute a total score that is reported in MET-minutes/week, which is then used to identify the subjects' physical activity classification as high, moderate, or low.

Physical Activity Classification	Requirements
Low	<ul style="list-style-type: none"> • No activity reported or • Some activity reported but not enough to meet moderate or high classification
Moderate	<ul style="list-style-type: none"> • ≥ 3 or more days of vigorous activity lasting ≥ 20 minutes per day or • ≥ 5 or more days moderate activity/walking for 30 minutes per day or • ≥ 5 or more days of walking/moderate/vigorous activity or a minimum of 600 MET-minutes/week
High	<ul style="list-style-type: none"> • Vigorous-intensity activity on ≥ 3 days and accumulating 1500 MET-minutes/week or • ≥ 7 days of walking/moderate/vigorous activity or accumulating at least 3000 MET-minutes/week

Doppler Ultra Sonography Procedures

Blood flow was measured using power Doppler ultrasound (Megas ES, Biosound Esaote, Inc., Indianapolis, IN, USA). The ultrasound transducer (Biosound LA 522, Biosound Esaote, Inc., Indianapolis, IN, USA) was placed flat against the skin on the right leg along the axis of the popliteal artery forming a 90° angle. Sound wave peaks were displayed on the ultrasound monitor. Every peak represents 1 cardiac cycle. To measure indices of blood flow, the sound waves were traced. The waves that were the most visibly accurate were chosen and the measurements were repeated in triplicate and the average was recorded. The blood flow measures included mean velocity (V_{mn}) which represents the average velocity of blood flowing through the artery over 1 cardiac cycle, peak velocity (V_p) which is the maximum velocity of blood moving through the artery, and end diastolic velocity (EDV) the maximum amount of blood moving through the artery at the end of diastole. Two other measurements that are ratios of the blood flow velocity were also obtained. Pulsatility index (PI) is the variability of

blood flow velocity in the artery [$PI = (V_p - EDV) / V_{mn}$] and resistive index (RI) is used as an indicator of vascular resistance [$RI = (V_p - EDV) / V_p$].

Statistical Analysis

A repeated measures analyses of variance (ANOVA) was used to determine potential gender differences in blood flow indices by using time (pre- and post-treatment) and amplitude (3 mm, 6 mm) as within subjects factors and gender as the between subjects factor. Since gender did not influence any variable's response to vibration at either amplitude, men and women were grouped together and a second repeated measures ANOVA was used to analyze differences in blood flow indices (V_{mn} , V_p , EDV, PI, and RI) using time (pre- and post-treatment) and WBV amplitude (3mm, 6mm) as within subjects factors. Statistical significance was accepted at $P < 0.05$

Chapter IV
Research Manuscript

Journal Manuscript

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Manuscript Title: The effect of high and low amplitudes during whole body vibration on lower leg arterial blood flow

Abstract

Whole body vibration (WBV) is a technique that has been shown to induce positive blood flow changes, however little is known about the effect of different vibration amplitudes on arterial blood flow. **Purpose.** The purpose of this study was to determine the effect of 2 different amplitudes during an acute bout of WBV on blood flow through the popliteal artery. **Methods.** Thirty healthy, recreationally active subjects (15 women, 15 men) aged 19-34 years performed two, 10 - minute bouts of vibration at a frequency of 30 Hz and high amplitude (6 mm) or low amplitude (3 mm) in random order after a period of prone rest. Doppler ultrasound was used to assess changes in blood flow. Mean blood flow velocity, peak velocity, end-diastolic velocity, pulsatility index, and resistive index measures were taken immediately before vibration and immediately after. **Results.** Mean blood flow velocity increased after 10 minutes of WBV. Mean velocity increased more in the 6mm trial (pre= 21.6 ± 4.74 cm/s, post= 25.3 ± 6.11 cm/s) than in the 3mm trial (pre= 22.3 ± 4.33 cm/s, post= 23.5 ± 5.94 cm/s). Peak blood flow velocity increased following 10 minutes of WBV and increased more in the 6mm trial (pre= 37.1 ± 9.78 cm/s, post= 43.7 ± 10.95 cm/s) than in the 3mm trial (pre= 37.8 ± 8.92 cm/s, post= 39.4 ± 10.5 cm/s) following 10 minutes of passive WBV. Pulsatility index also increased significantly following 10 minutes of WBV and increased more in the 6mm trial (pre= 1.639 ± 0.1299 , post= 1.729 ± 0.1324) than in the 3mm trial (pre= 1.660 ± 0.1219 , post= 1.671 ± 0.1428). No main effects or interactions were observed for resistive index or end diastolic blood flow velocity ($P > 0.05$). **Conclusion.** Ten minutes of passive WBV increases blood flow velocity. High amplitude (6 mm) produced a more pronounced increase in blood flow than the low amplitude (3 mm). Given the relationship between blood flow velocity and WBV, these results suggest that amplitude plays a role in increasing blood flow and that high amplitude (6 mm) may be more effective than low amplitude (3 mm) in improving circulation to the lower leg.

Key Words. WHOLE BODY VIBRATION, BLOOD FLOW, ULTRASOUND, AMPLITUDE

Introduction

Whole body vibration (WBV) is a method being marketed as an alternative and a supplement to exercise training. WBV is a modality that distributes low frequency vibration to the entire body. Participants either stand passively on a vibration platform or perform exercises on the platform while receiving the vibration.

Scientific evidence suggests that WBV may be a useful adjunct to athletic performance resulting in improvements after acute and chronic use. Reported results from studies of both healthy and clinical populations include increases in muscular strength (2, 3, 11, 13, 16, 17, 21, 22, 27, 31-33, 35, 38), jump height (13), power (8, 21), balance (2, 6, 18, 22, 36, 37), and flexibility (12, 34). In addition to changes in athletic performance, changes in metabolism (28), body composition (31) bone mineral density (19, 38), glycemic control (5), and oxygen uptake (28-30) have also been explored.

Though published data are limited, cardiovascular changes during WBV have also been observed. Three studies have reported increased skin and arterial blood flow during WBV (23-25), and one documented decreased arterial stiffness (26). These changes suggest that WBV may be a beneficial adjunct to exercise for populations with impaired circulation such as those with peripheral artery disease (PAD) and diabetes; specifically, the individuals who are limited during exercise because of claudication pain.

A significant limitation of the body of WBV literature is the lack of consensus regarding an appropriate frequency and amplitude that will produce physiological changes. Studies have used frequencies as low as 10Hz to as high as 60Hz and amplitudes ranging from 1mm to 10mm. The utilization of different vibrations frequencies produces dissimilar results in athletic performance (7, 10, 15, 20, 25, 29, 36) and blood flow. There are only a limited number of

studies investigating the affect of different amplitudes of WBV on athletic performance (9, 29) and no published studies of the impact vibration amplitude has on blood flow.

The primary purpose of this study was to determine the effect of different amplitudes during WBV on lower leg arterial blood flow. This study tested the hypotheses that WBV will increase arterial blood flow and that higher WBV amplitude will increase arterial blood flow more than lower amplitude.

Methods

The Ball State University Institutional Review Board approved the methodology for this study. A pre-post test design was implemented to examine the relationship between changes in blood flow through the popliteal artery before WBV utilizing specific amplitude and after 10 minutes of continuous WBV.

Subjects

Subjects were recruited from Ball State University and the surrounding community. Subjects were excluded if they currently used tobacco or medications that would affect blood flow, had a diagnosed neuromuscular, orthopedic, or circulatory disorder, or fell into a low physically active classification. A total of 30 subjects (15 men and 15 women), aged 19-34 years participated.

Procedures

Subjects reported to the laboratory for testing after having refrained from consuming caffeine for at least 12 hours, alcohol for at least 24 hours, any food or drink other than water for at least 4 hours, and exercise for at least 12 hours. After completing the informed consent process, subjects filled out a health history questionnaire and a short-form International

Physical Activity Questionnaire (IPAQ) to describe physical activity level. Each subject's height and weight were then obtained.

Two amplitudes (3mm and 6mm) were tested in random order separated by a recovery period. After lying prone for 15 minutes the popliteal artery was located and marked behind the right knee using a non-toxic marker to assure proper alignment of the ultrasound probe and a baseline measurement was obtained. The subjects then moved to the vibration platform and were asked to stand still for 3 minutes to allow positional blood flow velocity changes through the popliteal artery to stabilize. After 3 minutes a standing baseline measurement was obtained. Subjects stood on the WBV platform for 10 continuous minutes. Immediately after the 10 – minute vibration period, a third measurement was taken in the standing position. Subjects then resumed a prone position for a minimum of 10 minutes, or until mean blood flow velocity returned to within 8% of baseline. The experiment was then repeated using the alternate vibration amplitude.

Vibration

WBV was delivered to subjects via a vibration platform (Next Generation, Power Plate North America, LLC, Culver City, California, USA). The frequency was set at 30 Hz for all tests, and amplitude was set to either 3mm or 6mm. The subjects stood shoeless, with knees slightly bent, feet parallel and shoulder width apart while they were vibrated for 10 continuous minutes.

Height and Weight Procedures

Measures of height and weight were obtained with shoes off. Height was measured using a stadiometer (Detecto, Web City, MO, USA). Subjects stood with feet together and backs

straight against the stadiometer. Subjects took a deep breath and held it until the measurement was obtained. Body weight was measured by a weight scale (Detecto, Web City, MO, USA). All subjects wore a t-shirt and shorts.

Physical Activity Assessment

Physical activity for the week prior to the trial was assessed using the IPAQ, a questionnaire developed for the purpose of surveying a population's physical activity status (1). The IPAQ quantifies MET*minutes/week for 3 specific types of activities: walking, moderate intensity activities, and vigorous intensity activities. The summation of all the activities was used to compute a total score that is reported in MET-minutes/week, which is then used to identify the subjects' physical activity classification as high, moderate, or low.

Doppler Ultra Sonography Procedures

Blood flow was measured using power doppler ultrasound (Megas ES, Biosound Esaote, Inc., Indianapolis, IN, USA). The ultrasound transducer (Biosound LA 522, Biosound Esaote, Inc., Indianapolis, IN, USA) was placed flat against the skin on the right leg along the axis of the popliteal artery forming a 90° angle. Sound wave peaks were displayed on the ultrasound monitor. Every peak represented 1 cardiac cycle. To measure indices of blood flow, the sound waves were traced. The waves that were the most visibly accurate were chosen and the measurements were repeated in triplicate and the average was recorded. The blood flow measures included mean velocity (V_{mn}) which represents the average velocity of blood flowing through the artery over 1 cardiac cycle, peak velocity (V_p) which is the maximum velocity of blood moving through the artery, and end diastolic velocity (EDV) the maximum amount of blood moving through the artery at the end of diastole. Two other measurements that were

ratios of the blood flow velocity were also obtained. Pulsatility index (PI) is the variability of blood velocity in the artery [$PI = (V_p - EDV) / V_{mn}$] and resistive index (RI) is used as an indicator of vascular resistance [$RI = (V_p - EDV) / V_p$].

Statistical Analysis

A repeated measures analyses of variance (ANOVA) was used to determine potential gender differences in blood flow indices by using time (pre- and post-treatment) and amplitude (3 mm, 6 mm) as within subjects factors and gender as the between subjects factor. Since gender did not influence any variable's response to vibration at either amplitude, men and women were grouped together and a second repeated measures ANOVA was used to analyze differences in blood flow indices (V_{mn} , V_p , EDV, PI, and RI) using time (pre- and post-treatment) and WBV amplitude (3mm, 6mm) as within subjects factors. Statistical significance was accepted at $P < 0.05$

Results

Fifteen men and fifteen women participated in this study. The subjects' characteristics are shown in Table 1. A gender comparison was performed to show potential gender differences in the blood flow indices. There were small but statistically significant between gender effects for EDV and RI. RI values for women were as follows: pre= 0.99 ± 0.00 and post= 0.99 ± 0.01 . In men, RI values were 0.99 ± 0.00 at baseline and 1.00 ± 0.00 after treatment. EDV was lower in men (pre= 0.28 ± 0.04 cm/s, post= 0.10 ± 0.02 cm/s) than women (pre= 0.42 ± 0.04 cm/s, post= 0.45 ± 0.21 cm/s). No other significant main effects or interactions were observed. Because gender did not influence any variable's response to vibration at either amplitude, men and women were analyzed together in 1 group.

Results for V_{mn} are depicted in figure 1. There was a significant main effect of time but no main effect of amplitude. The time x amplitude interaction was also significant. V_{mn} at 3mm increased from 22.3 ± 4.33 cm/s to 23.5 ± 5.94 cm/s after 10 minutes of vibration. The 6 mm amplitude caused an increase in V_{mn} from 21.6 ± 4.74 cm/s to 25.3 ± 6.11 cm/s following 10 minutes of vibration.

Results for V_p are shown in figure 2. There was a significant main effect of time but no main effect of amplitude. There was also a significant time x amplitude interaction. V_p increased following 10 minutes of vibration at 3 mm of amplitude from 37.8 ± 8.92 cm/s to 39.4 ± 10.5 cm/s. The 6 mm amplitude increased from 37.1 ± 9.78 cm/s to 43.7 ± 10.95 cm/s following 10 minutes of vibration.

The PI results are shown in figure 3. A main effect of time was observed for PI, but showed no main effect of amplitude. A significant interaction between time and amplitude was also observed. The PI prior to vibration at 3 mm was 1.660 ± 0.1219 and 1.671 ± 0.1428 following vibration. Following 10 minutes of vibration at 6mm of amplitude PI increased from 1.639 ± 0.1299 to 1.729 ± 0.1324 . There were no significant main effects or interactions for RI. There were no significant main effects for time or amplitude for EDV, and no time X amplitude interaction.

Discussion

The purpose of this study was to investigate the effect of an acute bout of passive WBV utilizing 2 different amplitudes on indices of blood flow through the popliteal artery. V_{mn} , V_p , and PI were increased following vibration. This supports the hypothesis that vibration increases blood flow velocity following 10 minutes of vibration, and corroborates results of previous

studies that reported similar blood flow responses. Furthermore, the higher amplitude (6 mm) produced more pronounced increases in V_{mn} , V_p , and PI than the 3 mm amplitude.

A possible explanation for the result of this study is that WBV promoted vasodilation in the micro-vasculature of the leg downstream from the popliteal artery. Kerschman-Schindl et al. suggested that vibration causes the body to make rhythmic muscle contractions to maintain balance (23). These rhythmic muscle contractions may increase the shear stress on the vascular wall, causing the release of nitric oxide (NO), a potent vasodilator, as well as increase metabolic fuel usage, waste production, and a need for oxygen in the muscle. These by-products of muscle activation will also stimulate vasodilation in the contracting muscle. When the capillaries and micro-vasculature in the muscle body vasodilate, vascular resistance decreases. Increased blood flow through an artery whose diameter is unchanged would cause increased blood flow velocity. The findings of the current study are supported by those reported by Kerschman-Schindl et al. who observed that mean blood flow velocity increased significantly in the popliteal artery following vibration, as well as a recent report that documented increased skin blood flow following 3, 60-second bouts of passive vibration to the calf (24). Investigators of the latter study hypothesized that the increase in skin blood flow was due to vasodilation of capillaries in and around the calf muscles. Similar results were observed in a study by Maloney-Hinds et al. who observed increases in skin blood flow following 5 minutes of passive vibration (25). The findings of the present study combined with evidence in the literature indicate that blood flow through the popliteal artery was increased during WBV. These findings also support that the 6 mm amplitude augmented blood flow to a greater degree than the 3 mm amplitude.

Limitations of this study included the conducting of tests at different times of the day, thus not controlling for diurnal variations in blood flow. It is unknown if these diurnal

fluctuations would influence the blood flow response to WBV. This study also did not control for hormones that affect blood flow. Women were not tested at a particular phase of the menstrual cycle. During the menstrual cycle there are vascular changes which will affect blood flow (4). Another limitation to this study is that the diameter of the popliteal artery was not directly measured, so blood flow could not be measured directly. This study was also limited to a small sample size, which will limit the statistical power of the results.

Further research should explore different combinations of frequencies and amplitudes to see which combination would have the most beneficial effect on blood flow. Studies need to look at the differences in blood flow between passive WBV and WBV in combination with exercise. A larger subject pool of varying ethnicities, ages, and exercise habits needs to be examined to observe a wider population's changes in blood flow following WBV. Future WBV studies should investigate if WBV, passive or in combination with exercise, is beneficial in populations with compromised blood flow. The exact mechanisms through which blood flow may be enhanced through WBV needs to be elucidated. A careful evaluation of potential risks of WBV for clinical populations also needs to be examined.

In conclusion, the present study observed that blood flow velocity increased following 10 minutes of passive vibration. The 6mm amplitude induced a more pronounced increase in blood flow velocity. WBV appears to be a safe adjunct to exercise with possible clinical benefits, but the risks of long-term use are unknown. These findings provide a more concise understanding of which amplitude is more effective in increasing blood flow in the leg, and suggest that WBV may be a beneficial tool to various clinical populations such as those with cardiovascular issues and those with impaired circulation.

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Table 1. Subject Characteristics.

	n=15 Males	n=15 Females
Gender		
Age (years)	23.9±3	
Height (cm)	67.5±3.4	
Weight (kg)	152.1±31.5	
BMI (kg/m ²)	23.3±3.4	
Physical Activity (MET*Min/week)	3076±2289	

Figure Legends

Figure 1. The response of mean blood flow velocity to 2 different amplitudes (3 mm and 6 mm) before and after 10 minutes of WBV. Data are expressed as means \pm SE.

Figure 2. The response of peak blood flow velocity to 2 different amplitudes (3 mm and 6 mm) before and after 10 minutes of WBV. Data are expressed as means \pm SE.

Figure 3. The response of pulsatility index to 2 different amplitudes (3 mm and 6 mm) before and after 10 minutes of WBV. Data are expressed as means \pm SE.

Figure 1

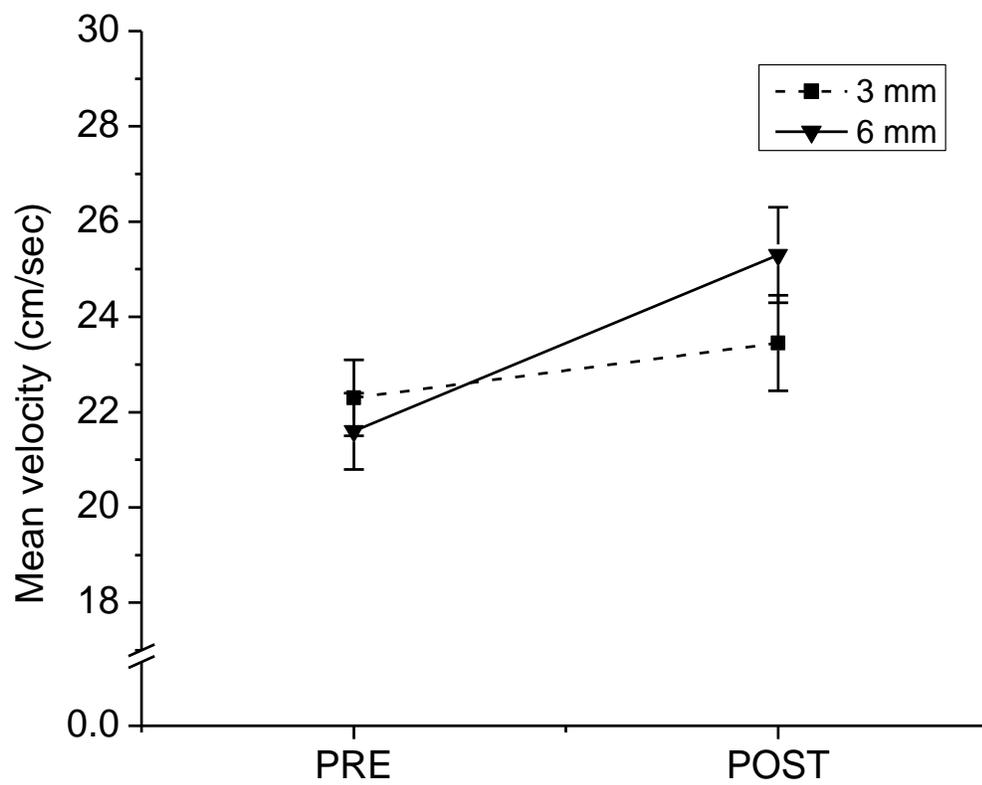


Figure 2

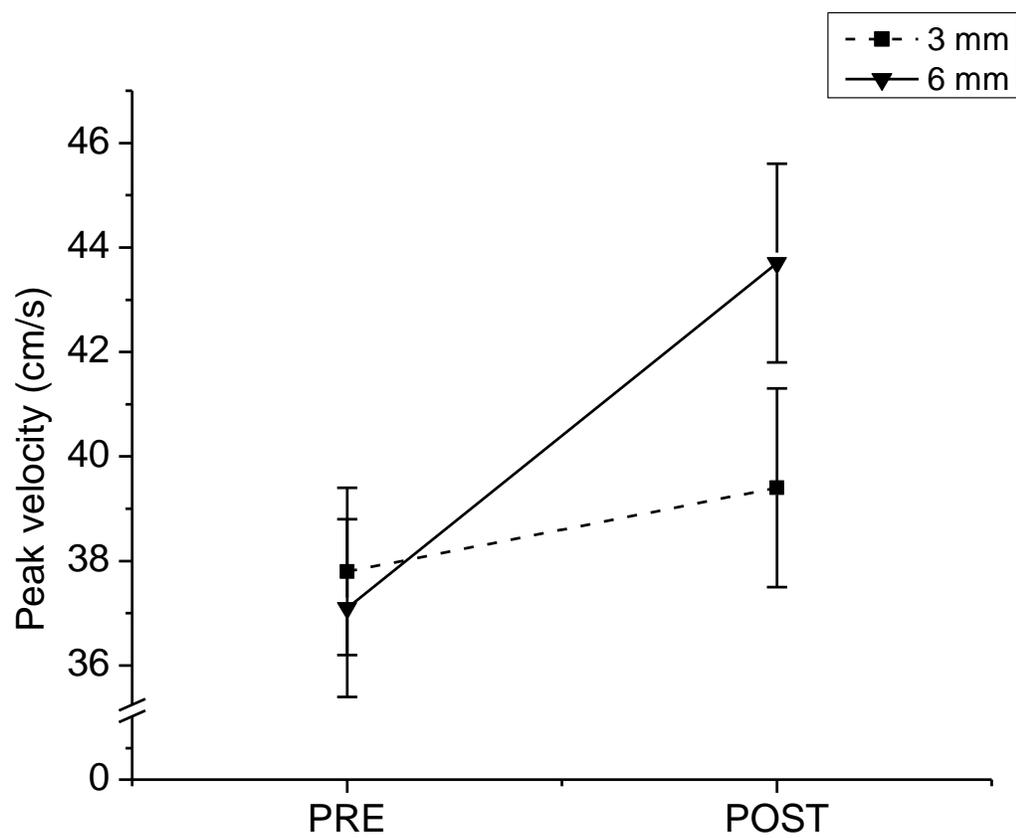
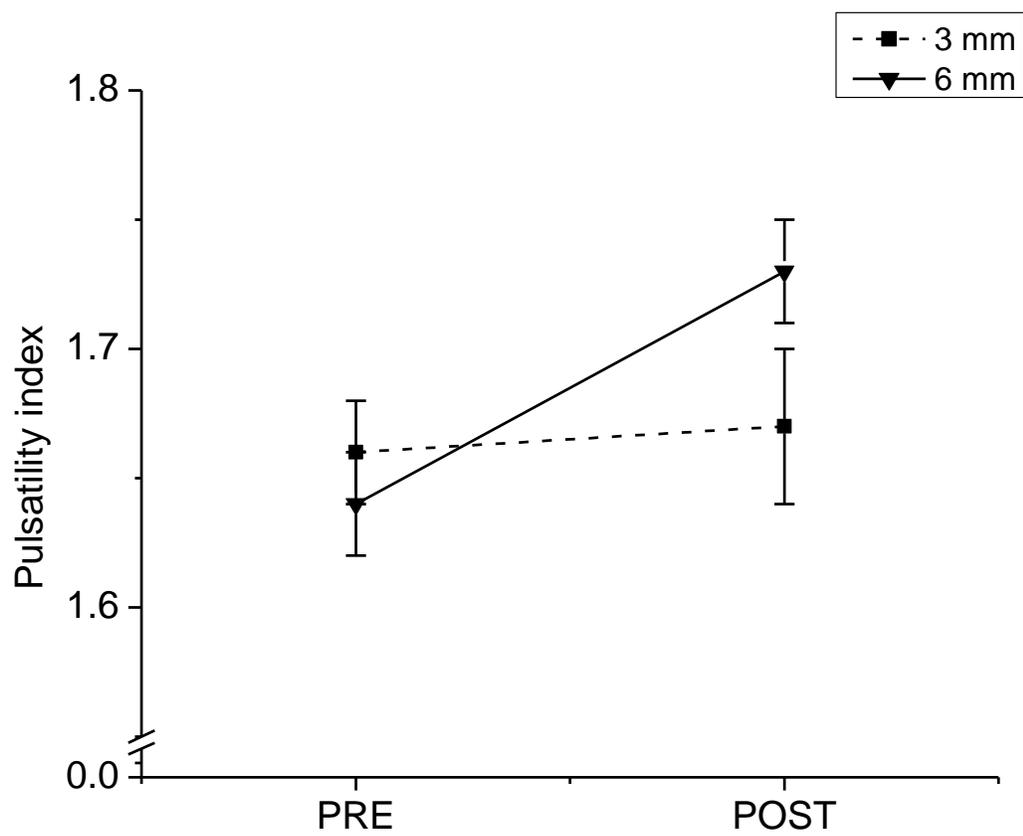


Figure 3



Chapter V Summary and Conclusions

The current study examined the effect of WBV utilizing different amplitudes upon blood flow in the lower leg of 15 men and 15 women. Subjects were passively vibrated for 10 minutes using 3 mm and 6 mm amplitude settings. Blood flow velocity was measured using Doppler ultrasound prior to and immediately following the vibration sessions.

The major findings of this study were that V_{mn} , V_p , and PI were increased following 10 minutes of passive vibration. The higher the amplitude the more pronounced the increase in blood flow velocity. There was a between gender difference for EDV and RI, but because gender did not influence time or amplitude men and women were analyzed together in 1 group. There were no significant changes for EDV or RI in response to WBV with either amplitude. Given the relationship between blood flow velocity and WBV, these results suggest that WBV may be beneficial in improving blood flow velocity to the lower leg.

A possible explanation for the result of this study is that WBV promoted vasodilation in the micro-vasculature of the leg downstream from the popliteal artery. Kerschman-Schindl et al. suggested that vibration causes the body to make rhythmic muscle contractions to maintain balance (39). These rhythmic muscle contractions may increase the shear stress on the vascular wall, causing the release of nitric oxide (NO), a potent vasodilator, as well as increase metabolic fuel usage, waste production, and a need for oxygen in the muscle. These by-products of

muscle activation will also stimulate vasodilation in the contracting muscle. When the capillaries and micro-vasculature in the muscle body vasodilate, vascular resistance decreases. Increased blood flow through an artery whose diameter is unchanged would cause increased blood flow velocity. The findings of the current study are supported by those reported by Kerschman-Schindl et al. who observed that mean blood flow velocity increased significantly in the popliteal artery following vibration, as well as a recent report that documented increased skin blood flow following 3,60-second bouts of passive vibration to the calf (41). Investigators of the latter study hypothesized that the increase in skin blood flow was due to vasodilation of capillaries in and around the calf muscles. Similar results were observed in a study by Maloney-Hinds et al. who observed increases in skin blood flow following 5 minutes of passive vibration (43). The findings of the present study combined with evidence in the literature indicate that blood flow through the popliteal artery was increased during WBV; likely due to vasodilation of capacitance vessels downstream from the main artery, and that the 6 mm amplitude augmented blood flow to a greater degree than the 3 mm amplitude.

A second explanation for the findings of this study is that WBV caused vasoconstriction of the popliteal artery. Vasoconstriction of the vessel would cause V_{mn} and V_p to increase as well as PI. Narrowing of the vessel decreases the radius of the vessel which will decrease blood flow through the vessel according to Poiseuille's equation [$Q = \pi r^4 (\Delta P) / (8 \eta L)$, where Q is flow; r is radius; ΔP is pressure difference; η is the viscosity coefficient; and L is the tube length] (45). A decrease in diameter causes an increase in vascular resistance. To maintain constant blood flow (volume per minute) with this increase in vascular resistance, the V_p and V_{mn} have to increase. PI is a ratio between blood flow velocities [$PI = (V_p - EDV) / V_{mn}$] and is sometimes related to vascular resistance (45). The increase in PI observed in the present study, thus, may also

suggest vasoconstriction. However, this study showed no change in resistive index which, in a young healthy population, directly relates to vascular resistance (14). RI is calculated as $(V_p - EDV)/V_p$. It is expected that, if the popliteal artery were constricted during vibration, an increase in RI and EDV would be observed. Though vessel dimensions were not measured in this study, the lack of change in RI or EDV in the present study suggests that the diameter of the measured artery was unchanged. This is supported by the results of a previous investigation that reported popliteal artery diameter did not change after WBV at a frequency of 26 Hz and an amplitude of 3 mm (39).

One other possible explanation for the increase in blood flow velocity is the thixotropism effect. Thixotropism is when a fluid, such as blood, changes its viscosity with an increase in shear stress. WBV may or may not influence blood viscosity (48, 67). If the viscosity of the blood is reduced then this would cause the blood flow velocity to increase (39). Further research is needed in this area to identify if this is a possible reason why blood flow increases in response to WBV.

Recommendations for Further Research

Further research should explore different combinations of frequencies and amplitudes to see which combination would have the most beneficial effect on blood flow. Studies need to look at the differences in blood flow between passive WBV and WBV in combination with exercise. A larger subject pool of varying ethnicities, ages, and exercise habits needs to be examined to observe a wider population's changes in blood flow following WBV. Future WBV studies should investigate if WBV, passive or in combination with exercise, is beneficial in populations with compromised blood flow. The exact mechanisms through which blood flow

may be enhanced through WBV needs to be elucidated. A careful evaluation of potential risks of WBV for clinical populations also needs to be examined.

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Appendix A
Informed Consent Statement

Consent Form: The Effect of high and low amplitudes during whole body vibration on lower leg blood flow.

The purpose of this study is to assess the changes in lower leg blood flow responses to whole-body vibration (WBV) using high and low amplitudes.

Blood flow and the circulatory system can be adversely affected by various pathologies, including diabetes and peripheral artery disease. Whole-body vibration has previously been shown to enhance blood flow. It is not known what vibration amplitude produces the most beneficial effects. We are studying how high and low amplitude WBV affects blood flow. Results of this study may be used to make more effective recommendations regarding the use of WBV for the purpose of improving circulation.

Recreationally active and apparently healthy (*i.e.* have not been diagnosed with a chronic illness) men and women who are 18-45 yrs of age may be eligible to participate in this study, which will be done in one 1-hr session in the Exercise Science Laboratory (room PL 211). During this session, you will complete one high amplitude trial and one low amplitude trial, conducted in random order. Each trial will consist of lying in a prone position for at least 15 minutes and then standing on a WBV platform for 10 minutes. At three times during each trial we will measure skin temperature using an infrared thermometer and arterial blood flow using ultrasound from your right leg. Your total time commitment to this study is expected to be approximately 1 hour.

Very long-term exposure to vibration such as is experienced in certain occupational settings may result in chronic pain. However, there are no known risks associated with WBV for the brief durations that are used in the present study. There are also no risks associated with the temperature or blood flow measurements in this study. Emergency medical treatment is available in the event of injury. You will assume responsibility for the costs of medical care that is provided. In the unlikely event of injury or illness of any kind as a result of participation in this research project, Ball State University, its agents and employees will assume whatever responsibility is required by law.

The results of this study may indicate that WBV stimulation produces beneficial blood flow responses that are cardioprotective. Exercise programs, particularly for patients with circulatory diseases, might benefit from the inclusion of WBV technology.

Your participation in this study is completely voluntary and you are free to withdraw at any time for any reason without penalty or prejudice from the investigators. Upon completion of the study you will be reimbursed \$30. If you have any questions, either now or in the future, feel free to ask the investigator.

Subject confidentiality will be protected to the maximum extent allowable by law. All data will be collected by study personnel. Paper files containing all data, including

personal information, will be stored in a locked filing cabinet in Dr. Nagelkirk's office. Electronic files will identify subjects only by number and will be stored on Dr. Nagelkirk's computer hard drive and backup medium (DVD or CD). The electronic files, hard drive and backup media will each be password protected. Paper files will be shredded after being retained for three years following study completion. Electronic files will be stored as indicated until Dr. Nagelkirk determines they are no longer needed, after which all copies will be deleted or destroyed. A number that is assigned to each participant will be used in all study-related communications as well as any publications or presentations of the results.

For one's rights as a research subject, contact the Coordinator of Research Compliance, Office of Academic Research and Sponsored Programs, Ball State University, Muncie, IN 47306, (765) 285-5070, irb@bsu.edu.

I, _____, agree to participate in this research project entitled, "The Effect of High and Low Amplitudes During Whole Body Vibration on Lower Leg Blood Flow." I have had the study explained to me and my questions have been answered to my satisfaction. I have read the description of this project and give my consent to participate. I understand that I will receive a copy of this informed consent form to keep for future reference.

Participant's Signature

Date

Investigator's Signature

Principal Investigator:

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Appendix B
Health History Questionnaire

Health History Questionnaire

Name: _____

Sex: Male Female

DOB: ____/____/____

Height: _____ Weight: _____

Please answer put an X next to your answer.

1. ____yes ____no Have you ever been diagnosed with a neuromuscular, orthopedic, or circulatory disorder?
 2. ____yes ____no Do you currently use tobacco?
-

Please List all Medications (including any over the counter medications)

Appendix C

International Physical Activity Questionnaire

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

_____ **days per week**

No vigorous physical activities → **Skip to question 3**

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

_____ **hours per day**
 _____ **minutes per day**

Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

No moderate physical activities → **Skip to question 5**

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**
_____ **minutes per day**

Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

No walking → **Skip to question 7**

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**
_____ **minutes per day**

Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**
_____ **minutes per day**

Don't know/Not sure

This is the end of the questionnaire, thank you for participating.