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Effect of Whole-Body Vibration on Acceleration Transmission and Jumping Performance in Children

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Effect of whole-body vibration on acceleration transmission and jumping performance in children

A THESIS

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By

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Abstract

Whole-body vibration (WBV) has emerged as an exercise modality that is safe for most adults with and without clinical conditions. The aims of this research study were to investigate the effects of WBV on vertical acceleration transmission during WBV and counter-movement jump height after WBV in typically developing children ages 6-11 years old. Seventeen subjects were recruited (10M/7F) for our study. We used a side-alternating Galileo WBV and presented a total of six conditions with the combination of three vibration frequencies (20, 25, and 30 Hz) and two vibration amplitudes (1 and 2 mm). Subjects stood for one minute on the platform under each condition. We used reflective markers to register the body motion and calculate the transmission of vertical acceleration during WBV. We used a force plate to collect ground reaction force during vertical jump after WBV and calculated jump height. Results showed that vertical acceleration significantly decreased from the ankle to the head. While vertical acceleration and its transmission ratio (with respect to the platform acceleration) increased with frequency and amplitude at the ankle, body segments superior to the ankle and knee were less affected by the vibration conditions. Counter-movement jump height maintained its value after all vibration conditions. It was concluded that WBV is a safe intervention paradigm for children as little acceleration is transmitted to the head, and a single bout of WBV may not be adequate to improve jumping performance in children.

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Table of Contents

Introduction	1-2
Statement of the Question	2
Rationale	2-4
Hypotheses	4
Delimitations and Limitations	4-5
Definitions	6-7
Literature Review	7-16
Methods	16-21
Results	21-33
Discussion	34-39
Limitations and Future Studies	39
References	40-42
Appendixes	43-46

Introduction

Whole-body vibration (WBV), defined as an oscillatory motion, can be externally applied to the human body using a vibrating platform. When a person stands on a vibration platform, the waveform, amplitude, frequency, and duration can be manipulated (Bressel, Smith, & Branscomb, 2010). Frequency is defined as the repetitive oscillatory rate or speed which is measured in Hertz (Hz), while amplitude is defined as the magnitude to which the platform is oscillating and is measured in millimeters (mm) (Cardinale et al., 2005). Acceleration due to the vibration is a variable that can illustrate how much each body segment is receiving the vibration. The joints that are closer to the platform usually experience a greater acceleration, whereas the joints that are further away from the platform receive a lesser acceleration in adults (Pollock et al., 2010). Therefore, the ankles are generally accelerated the most followed by the knee, hip, trunk, and head. The acceleration to the head is the most noteworthy parameter regarding safety of WBV. It is, however, not known if children display an adult-like pattern while transmitting the acceleration from the foot to the head during WBV with different frequencies and amplitudes. The raw accelerations transmitted to the body during vibration need to be assessed in order to investigate the safety of WBV intervention for typically developing children. The central variable we want to investigate is the accelerations at the head to clarify that they are not exceedingly high.

The acute effects of WBV can give insight to the plasticity of motor adaptation and potentially augment muscular function. Counter-movement jump is often used to assess the effects of WBV frequency and amplitude on motor performance so that optimal protocols can be identified to meet the dual criteria of maximizing muscle activity while minimizing vibration transmission to the head (Pollock, Woledge, Mills, Martin, & Newham, 2010). Jump height is a common variable for estimating lower extremity muscle power and performance. However, such information is scarce in typically developing children as well as children with movement disabilities before and after WBV intervention. This information is critical for the development of future interventions, particularly for pre-adolescents with and without disabilities, with the goal of augmenting muscular activity and motor performance.

The Statement of the Question

This project will investigate the effect of WBV frequency and amplitude on acceleration transmission during WBV and counter-movement jump performance after WBV in typically developing children aged 6-11 years. We will manipulate three different frequencies and two different amplitudes for a total of six conditions in this study.

The Rationale

Scientific research with respect to WBV has increased in the last decade. WBV with low amplitude and high frequency has been shown to improve not only the strength and balance of adult populations, but simultaneously reduce bone fragility (Torvinen, Sievanen, Jarvinen, Pasanen, Kontulainen, & Kannus, 2012). The utilization of WBV in pre-adolescents is not as thoroughly researched as adult populations. Concerns arise when regarding the safety of the vibration to a child who has lower body mass and an underdeveloped neuromuscular system. Some vibration characteristics can produce exceedingly high accelerations of the platform (Kiiski et al., 2008) that may be viewed as dangerous, particularly if used with fragile populations (Bressel et al., 2010). As muscular function of children may be underdeveloped compared to adults, children may not able to attenuate the vibrations as well as adults. This knowledge is critical for the design and implementation of WBV intervention for children with and without disabilities.

Despite the substantial amount of WBV-related research, functional and neuromuscular adaptations to WBV are not fully understood, particularly in children (Ritzmann, Gollhofer, & Kramer, 2013). There are few articles that address fundamental questions such as optimal frequency, amplitude, or body position on the WBV platform (Abercromby et al. 2007; Berschin and Sommer 2004; Hazell et al. 2007, 2010). As many factors can influence the outcome of WBV such as vibration frequency and amplitude as well as body position (Figure 1, adapted from Ritzmann et al. (2013) study), it is critical to understand the effects of these individually as well as combined factors.

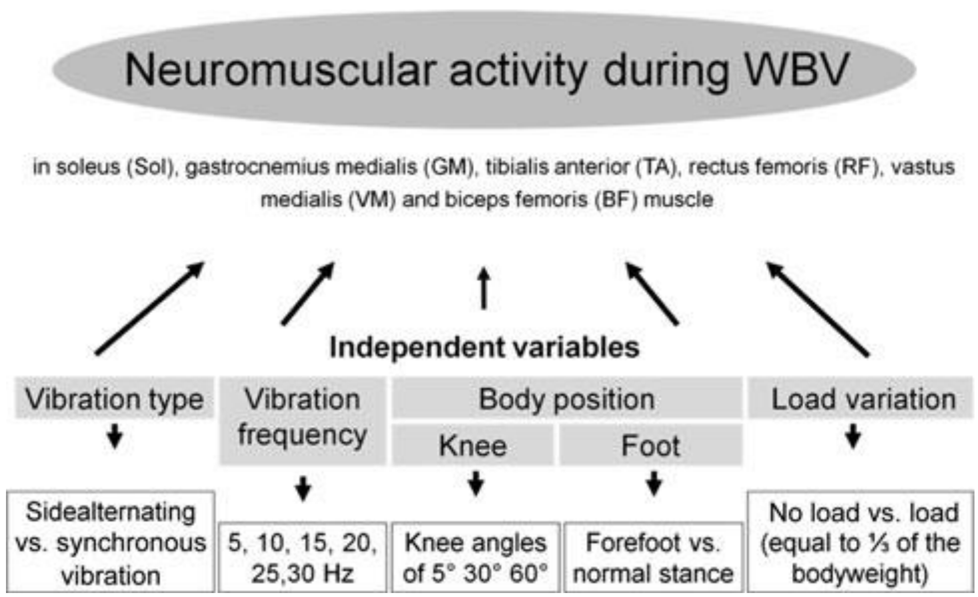

Figure 1: The vibration type, vibration frequency, body position, and load variation are all factors to consider when designing a WBV training protocol (Ritzmann et al., 2013).

Results from a previous study (Pollock et al., 2010) suggest that both vibration amplitude and frequency can increase muscle activation in adults during vibration. To our knowledge, no study has been carried out to understand if vibration frequency and amplitude will have similar effects on muscle activation during WBV and jumping performance after WBV in children.

This study aims to understand the effect of different WBV intensities (frequency and amplitude) on (1) the transmission of vertical acceleration from the feet to the head during WBV, and (2) counter-movement jump performance after WBV in typically developing children aged 6-11 years.

The Hypotheses

1. Vibration intensity will increase the vertical acceleration across the body segments.

   1a: As frequency increases vertical acceleration will increase across all segments;

   1b: As amplitude increases vertical acceleration will increase across all segments.

2. Children will display a pattern of reducing acceleration transmission from inferior to superior body parts across vibration intensities.

3. Children will increase counter-movement jump height after WBV.

   2a: As WBV frequency increases, counter-movement jump height will increase;

   2b: As WBV amplitude increases, counter-movement jump height will increase.

Delimitations and Limitations

<u>Delimitations</u>

This study evaluated typically developing pre-adolescents between the ages of 6-11 years old. The subjects were not diagnosed with any mental or physical condition that would delay motor development, such as Down syndrome, Autism spectrum disorder, intellectual disabilities, cerebral palsy, etc. Potential participants were excluded for any of the following reasons:

- Inability to perform a counter-movement jump.
- Pre-existing injuries or conditions that would prevent them from performing multiple jumps or standing trials of 60 sec.
- They do not have the mental capacity to follow directions for the WBV and counter-movement jump.
- Uncorrected abnormal vision or hearing.
- Cardiac, metabolic, or respiratory conditions that could be made worse with physical activity.
- History of seizures.
- Current medications that would affect movement, mental capacity, or concentration.
- Hyper-sensitivity to vibration.

Limitations

The subjects performed a very specific movement, standing with their knees slightly flexed on a WBV platform and following the vibration, a counter-movement jump with hands on the hips. The vibration sensitivity could limit the ability to generalize the knowledge over the whole pre-adolescent population. For example, if one subject is more sensitive to the vibration and unable to adequately attenuate the stimulus, then he/she may end up flexing the knees excessively. This excessive knee flexion could manipulate the amount of muscle activation and acceleration transmission to the head. Protocol accounted for this potential manipulation by giving verbal cues on knee flexion angle during a familiarization period and the continuation of verbal cues during each trial.

Definitions

- **Acute effect:** Short term, or immediate effect, from the WBV.
- **Amplitude:** The magnitude in which the platform is oscillating and is measured in millimeters (mm).
- **Attenuate:** To reduce the force, effect, or value of a stimulus, in this case the vibration.
- **Atypically developing population:** These subjects have been diagnosed with a mental, physical, and/or developmental condition.
- **Augment:** To improve or enhance.
- **Biomechanical:** Relating to the mechanical laws concerning the movement or structure of living organisms.
- **Body position:** The orientation of the body during the vibration, such as knee flexion angle, upright trunk, hands on the hips, etc.
- **Bone fragility:** The biomechanical tendency for a bone to resist an external load placed on the system.
- **Bone mineral density:** A measure of bone density, reflecting the strength of bones as represented by calcium content.
- **Clinical significance:** The practical importance of a treatment effect; whether it has a genuine, palpable, noticeable effect on daily life.
- **Counter-movement jump:** Where the jumper starts from an upright standing position, makes a preliminary downward movement by flexing at the knees and hips, then immediately extends the knees and hips to jump vertically up off the ground.
- **Frequency:** The repetitive oscillatory rate or speed which is measured in Hertz (Hz).

- **Motor coordination**: The combination of body movements created with the kinematic (such as spatial direction) and kinetic (force) parameters that result in intended actions.
- **Muscle activation:** An individual's ability to produce efficient muscle contraction.
- **Musculoskeletal system:** Refers to the bone, ligaments, tendons, and muscles of a particular system or limb.
- **Neuromuscular response:** Physiological response relating to nerves and muscles.
- **Neuromuscular facilitation:** The enhancement of the response of a motor neuron to a stimulus following stimulation, in this case the vibration.
- **Oscillation:** Regular variation in magnitude or position around a central point, in this case, the center of the vibrating platform.
- **Pre-adolescent:** The period of human development just preceding adolescence; in this study, 6-11 years of age.
- **Typically developing population:** These subjects do not have any diagnosed mental, physical, or developmental conditions.
- **Vibration:** Oscillatory motion, in this case, that is artificially applied to the human body using a vibrating platform.
- **Vibration transmission:** How force is transmitted to the supporting structure, in this case, how the acceleration of the vibration is transferred from the platform to the human subject.

Literature Review

<u>Whole Body Vibration</u>

Vibration is a mechanical stimulus characterized by an oscillatory motion (Cardinale et al., 2005). The two differing platform modalities are either synchronous or side-alternating. The synchronous modality involves the platform moving as uniform piece in a vertical direction like a spring. The side-alternating modality is a platform moving in a side-to-side direction around a central axis similar to a see-saw. The side-alternating platform is generally more comfortable for the participant due to the nature of the transmission of the vibration. WBV has been recently proposed as an exercise intervention because of its potential for increasing force generating capacity in the lower limbs. Its recent popularity is due to the combined effects on the neuromuscular and neuroendocrine systems (Torvinen et al., 2002).

Previous research efforts have shown promising results in special populations such as the elderly, post-stroke, cerebral palsy, and Down syndrome. Bissonnette, Weir, Leigh, & Kenno (2010) conducted a study in which all 19 of their elderly participants exhibited augmented strength, balance, and flexibility after a 4-week WBV intervention. Participants underwent 15-minute WBV training sessions three times a week at intensities ranging between 25-50 Hz and amplitudes of 2-4 mm. Another study conducted by Eid (2015) investigated the effects of a WBV intervention with the amplitude of 2 mm and the frequencies of 25 and 30 Hz for durations lasting between 30 and 60 sec in children with Down syndrome. All the subjects showed improved balance using the Biodex Stability System which allows for objective balance assessment. These studies suggest that WBV is a safe and effective way to train these populations.

The results of scientific studies investigating the effects WBV training on strength and power are inconsistent, probably because of a wide variety in WBV exercise protocols (Eckhart, Wollny, Muller, Bartsch, & Friedmann-Bette, 2011). The mechanical oscillations produced by the platform induce continuous eccentric-concentric muscular work and increased oxygen consumption in children with Down syndrome (Eid, 2015). These variables may produce benefits in muscle performance and bone mineral density in children with and without disabilities (Bressel et al., 2010). The overall effects of WBV intervention have been investigated in several contexts such as, exercise physiology, sports, and rehabilitation medicine and have been proven to affect the functions of the circulatory, endocrine, and skeletal systems in healthy populations (Carlucci, Mazza, & Cappozzo, 2010). Moreover, exposure to high frequency and low amplitude vibrations has suggested to be a safe and effective way to exercise the musculoskeletal system increasing power, strength, and flexibility in the lower limbs in a short time (Carlucci et al., 2010). In the literature addressing the acute response to WBV, only a few studies have used surface electromyography to measure the level of neuromuscular activity, which can be used to evaluate training parameters such as vibration frequency and body position (Di-Giminiani, Masedu, Tihanyi, Scrimaglio, & Valenti, 2010). Torvinen et al., (2002) reported that healthy adults reduced muscle activity during four-minute WBV with an amplitude of 2 mm and a frequency of 30 Hz and maintained jump height after the vibration. The benefits of WBV may not be conclusive due to conflicting findings between studies. Torvinen discovered that muscles, particularly at the hip region, had been influenced and loaded by the vibration-regimen. In contrast to reduction in the MPF values, the root mean square voltage of the EMG increased in the gluteus medius muscles during the vibration. This finding, in turn, suggests that it may have been necessary to recruit more motor units in the gluteal muscles to compensate the evolving fatigue in these muscles during the vibration, while in the lower limb muscles such a response was not seen. Instead of signs of evolving muscle fatigue, the performance tests (i. e., the extension strength of the lower extremities and the jump height), which reflect the force production characteristics of the lower limb muscles, actually indicated slightly improved muscular performance immediately after the vibration-loading (Torvinen et al., 2002).

Whole Body Vibration: Frequency and Amplitude

Frequency is defined as the repetitive oscillatory rate or speed which is measured in Hertz (Hz), while amplitude is defined as the magnitude to which the platform oscillates and is measured in millimeters (mm) (Cardinale et al., 2005). The literature has minimal information regarding optimal frequency and amplitude that is capable of eliciting augmented muscle activation. The investigation of the threshold needed for an amplified neuromuscular response is highly warranted. Research regarding these two factors are relatively scarce and contradictory. Recent work has suggested that low amplitude (1-2 mm), low frequency (10-30 Hz) mechanical stimulation of the human body is a safe and effective way to exercise musculoskeletal structures in adults (Cardinale et al., 2005). In contrast, little consensus has been reached regarding the optimal vibration frequency and amplitude for children.

Whole Body Vibration: Acceleration Transmission

Acceleration due to vibration is a variable that can illustrate how much each body segment receives the vibration. The transmission of vibration reduces through the body (Wakeling et al., 2002) resulting from damping (any effect that tends to reduce the amplitude of oscillation) by the passive action of hard and soft tissues, joint kinematics and muscle contractions. Amplitudes of 1–5 mm and frequencies of 15-50 Hz have resulted in accelerations of ≤14 g (g is the gravitational acceleration) (Cheung et al., 2007; Roelants et al., 2004; Rubin et al., 2004; Torvinen et al., 2002). A study completed by Pollock et al. (2010) analyzed the transmission of sinusoidal WBV to healthy young adults at the ankle, knee, hip, sternum, and head. The frequency ranged from 5 to 30 Hz and the amplitudes were 2.5 or 5.5 mm. It was discovered that adults exhibited a significantly greater acceleration due to vibration at the ankle and knee. As the joints distanced themselves from the platform, such as the hips, sternum, and head, the transmitted acceleration proceeded to get substantially lower. The vibrations felt at the sternum and head were minimal and did not invoke any uncomfortable effects such as dizziness or disorientation. Therefore, the joints that are closer to the platform experience a greater acceleration transmission, whereas the joints that are further away from the platform receive a dampened acceleration transmission in adults.

Congruent results were also reported in a similar study with preadolescent children aged 6-12 years (Bressel et al., 2010). They used frequencies of 28, 33, and 42 Hz and each frequency had different amplitude increasing from 0.97mm at 28 Hz to 1.53 mm at 42 Hz. The results of peak-to-peak marker vertical motion showed that the vibration transmitted to the ankle (2.3 mm) was significantly greater than the knee (0.7 mm), the hips (0.2 mm), sternum (0.2 mm), and the head (0.5 mm). They then calculated the transmission ratio as the acceleration of the marker divided by the acceleration of the platform. They found that the transmission ratio of children was mostly similar to that of adults. They concluded that preadolescents and adults had the same relative accelerations transmitted to the head. The transmission ratios to the head did change across the 3 frequencies but was not significant. Frequencies of 28 and 42 Hz yielded the same ratio but 33 Hz yielded the greatest transmission ratio. However, the amplitude was different among the three frequencies, further confounding the interpretation of the results. The only statistical significance between the two groups was at the ankle, where preadolescents had a higher transmission ratio. This may in part be due to lower foot mass and less soft tissues in the foot of children that would be able to attenuate these vibrations adequately. As the acceleration to the head is the major concern for younger populations, their study provided evidence that WBV can be used safely with caution for both younger and older populations.

Whole Body Vibration: Muscle Activity

The effects of frequency and amplitude are not unanimously clear, but their importance has been highlighted by Torvinen et al., (2002) who reported an increase in overall muscle strength and jump height. Pollock et al., 2010 completed a study where WBV was performed at 5, 10, 15, 20, 25 and 30 Hz at high (5.5 mm) and low (2.5 mm) amplitudes. Subjects were asked to stand on the platform with straight legs, without locking their knees, while looking directly ahead with folded arms. This resulted in 15.1° (4.8 STD) of knee flexion during vibration at all frequencies and amplitudes. They stood barefooted with an even weight distribution over the forefoot and hind foot bilaterally over clearly marked foot positions corresponding to the vibration amplitude. Subjects stood on the platform in a relaxed position with arms folded for 3 sec then placed their feet into the marked positions and vibration was applied for 7 sec. The order of frequency and amplitude was randomly determined. Approximately 30 sec elapsed between bouts (Pollock et al., 2010). Bipolar EMG signals were recorded from the soleus, gastrocnemius lateralis, anterior tibialis, rectus femoris, biceps femoris, and gluteus maximus. Relative muscle activity was greatest in lower leg muscles rather than the thigh muscles. High amplitude vibrations were always associated with greater muscle activity. Higher frequencies were also correlated with greater muscle activation except for the rectus femoris and the gluteus maximus.

Roelants et al., (2006) used a vertical stimulus to examine the effect of a 20 sec exposure of a 35 Hz, 2.5 mm vibration stimulus for 3 static positions (high squat, low squat, and one-legged squat) in elderly women. The knee angle during the high squat and one-legged squat was 125° and was 90° during the low squat. Muscle activity was measured from the rectus femoris, vastus medialis, vastus lateralis, and gastrocnemius muscles. The results of this study demonstrated that WBV led to significant increases in EMG in all muscles during all positions. During the high squat, WBV resulted in increases between 92.5% and 301% when compared with the control condition. In the low squat position, WBV increased muscle activity in the range of 49%–134% compared with control, and increases of 115%–360% during the one-legged squat. The unilateral squat position resulted in greater muscle activation compared to the low squat position. While being exposed to the whole-body vibration stimulus, the leg muscles measured were activated between 12.6% and 82.4% of their maximal activation. In contrast to many studies with adults, there is little research conducted with children regarding muscle activity during WBV.

It should be remembered that, according to the muscle tuning theory, the magnitude of the muscular response is related to the interaction between the amplitude and frequency of the vibration input and the intrinsic neuromuscular properties. The muscle tuning theory states that in order to effectively target a muscle or muscle group you must apply the vibration at, or close to, that muscle’s resonant frequency. Every muscle has its own intrinsic properties that make it structurally unique. Therefore, each muscle or muscle group must be targeted to match its resonant frequency in order to be maximally stimulated. It is possible that many studies have failed to show any positive effect of vibration because the applied vibrations did not stimulate the target muscles at their resonant frequencies (Cardinale et al., 2005). The absence of vibrating at a muscle’s natural frequency can be considered unwarranted because it will not be efficiently stimulated, which will result in inefficient training. The likelihood of achieving therapeutic effects will be diminished significantly. The responses of the lower extremities to continuous vibrations or sequences of single, impact-like input were similar. This suggests that the body has a strategy to minimize its vibrations regardless of the mode of the input force. These studies support the muscle tuning paradigm, but these concepts need to be tested further. For instance, the effect of the amplitude of the input vibrations on the tuning response has not yet been determined (Cardinale et al., 2005). At high vibration amplitudes, the maximum damping from the tissues will not be as effective at dissipating the vibration energy. We do not yet know the most effective range of vibration amplitudes that can be applied safely while eliciting a significant tuning response, particularly in children (Cardinale et al., 2005).

Whole Body Vibration: Counter-Movement Jump

Counter-movement jump is a common task for estimating lower body muscle power and performance. The literature is scarce regarding children undergoing WBV and assessing counter-movement jump height post-vibration. A recent study (Maeda, Urabe, Sasadai, Miyamoto, Murakami, & Kato, 2016) investigated the effects of WBV in healthy adults aged 18-24 years. The study focused on holding a squat position on the platform for 30 sec. The selected frequency for this study was 30 Hz with amplitudes of 4 mm for 3 times a week for 8 weeks. One of the outcome measures included counter-movement jump height before and after the vibration intervention. The jump height did increase by 5 cm after vibration but was not statistically significant. The researchers found changes in performance resulting from WBV are considered to depend mainly on the vibration modality and the duration of the intervention. In addition, it is thought that the muscle-strength benefits of training with WBV are facilitated by enhanced neural control after WBV (Maeda et al., 2016). This neural control refers to the neuromuscular facilitation allowing more muscle recruitment to occur which in turn will increase the muscle power. The aforementioned study claimed that future studies need to further investigate the effect of WBV training on muscle strength and performance.

Another study (Pojskic, Pagaduan, Uzicanin, Babajic, Muratovic, & Tomljanovic, 2015) investigated the effects of WBV training and muscle performance on college football players with an average age of 20 years. One of the parameters of the muscle performance included the analysis of counter-movement jump height. The procedure included standing in a half-squatted position on a WBV platform for 60 sec for 5 sets with an added load of 30% of the subjects' body weight. The frequency was 50 Hz while the amplitude was 4 mm. Following the WBV training the subjects performed 2 counter-movement jumps with 30 sec of rest between jumps after each 60 sec trial. The results showed significant increases in counter-movement jump height. Higher vibration amplitudes (>4mm) and higher vibration frequencies (>40Hz) were associated with greater counter-movement jump performance. These studies suggest the potential for WBV being an effective modality for improving muscle performance, specifically, counter-movement jump height. The authors did not measure vertical acceleration in this study they only assessed muscular performance.

Theoretically WBV should result in augmented jump height due to increase in muscle activation, but this has not been tested thoroughly yet, particularly in children. The augmented muscle activation is thought to persist for a brief period of time following the vibration. The effects of WBV do reside shortly after, though this period of time is not clearly defined. This gap in the literature could be due to the different modalities of WBV platforms and additional weight support during training. Our study will be investigating the effect of WBV with different frequencies and amplitudes on acceleration transmission and jump height in healthy preadolescent populations.

Methods

Recruitment and Data Collection

We recruited 17 subjects consisting of 10 males and 7 females between the ages of 6-11 years old. Of the 17 participants, every subject completed every condition. All 17 subjects were used for data analysis. Table 1 contains the anthropometric measures of the subjects. The data collection was held in the biomechanics lab at Georgia State University. The parents were asked to bring compression shorts and/or a swimsuit for their child. If they were unable or do not bring one, a pair of compression shorts was provided.

Upon arrival, the child was given plenty of time to acclimate to the lab environment by walking around, sitting in a chair, or playing with stuffed animals. A verbal overview of the process was given to the parents and the child. Parents signed an Informed Consent form for their child (Appendix A). An assent script was read to the child aged 6-10 years for his/her verbal assent and a written assent form was signed by the child aged 11 years and above (Appendix B). All aforementioned documents were approved by the Georgia State University Internal Review Board.

A modified marker set was used, and subjects were marked prior to the application of reflective markers with a washable eyebrow pencil. The following locations were marked on both sides of the body: ankle, heel, knee, anterior superior iliac spine, posterior superior iliac spine, sternum, and temple. This modified marker set allowed us to measure acceleration at

Table 1: Anthropometric measures of the subjects analyzed.

Subject ID	Age	Gender	Height (cm)	Mass (kg)	Leg Length (cm)	Dominant Leg
WBV01	9	Male	147	33.5	81.25	R
WBV02	6	Female	124	21.4	67	R
WBV03	10	Female	150	40.8	83.5	R
WBV04	11	Male	160.5	51.7	84.75	R
WBV05	8	Female	136	35.7	71.5	R
WBV06	6	Female	116	21.8	57.75	R
WBV07	10	Male	134	28.7	75.75	R
WBV08	6	Male	126	26.2	64	R
WBV09	9	Male	140	43.5	75	R
WBV10	12	Male	162	42	89	R
WBV11	6	Female	131	27.5	71	R
WBV12	9	Male	133	30.4	69	R
WBV13	10	Male	151	32.8	85.5	R
WBV14	8	Female	136	28.5	72.5	R
WBV15	11	Male	150	42	83.2	R
WBV16	8	Male	133	31.3	73.2	R
WBV17	8	Female	130.5	27	70	R
Mean	8.65	10M/7F	138.82	33.33	74.94	
STD	1.9		12.79	8.48	8.52	

each level of the body. Anthropometric measurements were then taken using the marks including ankle width, knee width, and leg length. Once the measurements were taken, reflective markers were attached at the marks and reinforced with tape.

The subjects were then asked to stand on one of the force plates and hold a T-pose for calibration. The T-pose required the subject to stand and hold the arms out 90° to the body. Five sec of data was captured while holding the T-pose. The data was recorded using Vicon Nexus and 8 cameras at a sampling frequency of 100 Hz. Kinetic data such as ground reaction force was collected using an AMTI force plate which was recorded at 1000 Hz. We recorded EMG in order to obtain muscle activation during and after the WBV application. The muscles measured were the gastrocnemius, tibialis anterior, quadriceps muscle group, and the hamstrings muscle group from the dominant leg, the one used to kick a ball. We recorded the baseline EMG activity from these muscles when the subject stood on the WBV platform with the appropriate 30° knee angle but the WBV was not turned on. The EMG data were not analyzed and reported for this thesis.

Each subject performed three counter-movement jumps before WBV exposure. A counter-movement jump simply involved the subjects bending their knees to roughly a 90° angle and then ascending upward as quickly and forcefully as they were able. The degree of knee bend was practiced at 90°, although the emphasis was for the subject to perform a comfortable counter-movement jump and not discard jumps where the subjects failed to meet the 90° knee bend.

The subject was instructed to stand with knees slightly bent to 30°. We visually assessed the knee joint angle and familiarized our subjects to that specific knee angle and reminded them throughout the vibration procedure to try and maintain the 30° knee bend. This 30° flexion angle was feasible since this was a minor knee bend and was a comfortable standing position on the platform. They stood with their hands on their hips and maintained their balance and posture to the best of their ability. A successful trial was completed when the subject stood on the platform without falling off for the entire 60 sec duration, and then performed the counter-movement jump on the force plate. The subjects went through a series of 6 trials involving random combinations of 3 frequencies and 2 amplitudes. The frequencies were 20, 25, & 30 Hz while the amplitudes were 1 mm and 2 mm. Each combination of frequency and amplitude was only experienced once. They were continuously reminded of the proper knee angle while standing on the vibrating platform. Following the 60 sec vibration the subjects immediately performed 3 counter-movement jumps on the force plate with 30 sec of rest between each jump. They then rested for five minutes before the next trial. No subjects requested that they needed more time to rest before moving on to the next trial.

This concluded the data collection. The child was given time to change out of the swimsuit or compression shorts. The parents and child were thanked for their time and contribution to the study.

Data Recording and Analysis

The kinematic data were recorded using Vicon Nexus (Oxford, UK) and 8 cameras with a sampling rate of 100 Hz. The acceleration of the vibration to the joints and head was analyzed through the same protocol used in the 2010 study by Pollock et al. Three-dimensional position data from each reflective marker was exported from the Vicon Nexus software. These position data were filtered with a low-pass Butterworth filter with a cut-off frequency of 100 Hz (Bressel et al., 2010). The data was detrended to remove postural sway from the position data.

Vertical Acceleration

Acceleration of the platform was calculated experimentally by placing a marker on the platform at the desired frequency and amplitude in order to normalize each condition. A marker was placed on the 1mm amplitude mark and was recorded at each frequency (20, 25, and 30Hz). The marker was then placed on the 2mm amplitude mark and was recorded at each frequency (20, 25, and 30Hz). It should be noted that we calculated average of the rectified acceleration not the peak acceleration. We collected our acceleration data in the middle 30sec of our 60sec trials so we did not record the platform starting the vibration or ending the vibration. The values at the beginning and end our 60sec trials were not valid for our analysis so we did not include that. Observations conclude that acceleration increases relatively linearly in perspective of the frequency and amplitude progression. Acceleration increased with increasing frequency and also with increasing amplitude. We used an experimental protocol in order to obtain more accurate acceleration data. We attached a reflective marker to the platform and progressed through all 6 of the conditions in order to obtain all the marker data necessary to calculate the experimental acceleration. We took the raw acceleration data from the subjects at each level and normalized them by dividing by the experimental acceleration of the platform.

Transmission Ratio

Transmission ratio was calculated by taking the value of acceleration obtained from the marker data, stated above, and dividing it by the average rectified platform acceleration data ratio. This value gave us the transmission ratio transmitted to each segment relative to the acceleration from the platform.

Counter-Movement Jump Height

Jump height was assessed through kinetic data from the force plates. We factored out mass to calculate vertical acceleration of the center of mass. We then integrated it in order to get initial velocity at takeoff.

$$Vf^2 = Vi^2 + 2ad$$

Vf^2 is the final velocity, which is 0 since this is the landing. Vi^2 is the initial velocity calculated through our Matlab program by removing mass and obtaining the center of mass acceleration. a refers to the acceleration due to gravity which is $-9.81\ ms^2$. d is the displacement which in this case is the jump height calculated.

Statistical Analysis

To investigate how WBV frequency and amplitude affect vertical acceleration and its transmission, we conducted two-way (3 frequency x 2 amplitude) ANOVA with repeated measures on both factors (frequency and amplitude) on vertical acceleration of the markers and transmission ratio for each segment. To investigate differences in transmission ratio among five segments, we conducted three-way (5 segment x 3 frequency x 2 amplitude) ANOVA with repeated measures on frequency and amplitude on transmission ratio. For a possible three-way interaction, we conducted five 2-way (3 frequency x 2 amplitude) ANOVAs with repeated measures on both factors on the transmission ratio for each segment. In the case of significant differences, post-hoc pair-wise comparisons with Bonferroni adjustments were completed. Significant differences were concluded at an alpha level of 0.05.

Results

Acceleration

Acceleration values ranged depending on the frequency and amplitude from 0.05 g at the sternum and 6.8 g at the ankle. The ankle ranged from 1.3 g at the lowest condition to 6.8 g at the highest condition (Fig. 2). The knee displayed a range from 0.8 g to 1.7 g where the highest reported acceleration occurred at 20 Hz, 2 mm (Fig. 3). The range at the hip marker was 0.4 g to 0.6 g (Fig. 4). Though the difference is minimal it is worth noting the highest acceleration occurred at 25 Hz, 2mm. The sternum marker ranged from 0.15 g to 0.22 g (Fig. 5) and the temple displayed a range from 0.12 g to 0.16 g (Fig. 6).

Acceleration increased with frequency and amplitude at the ankle, which is similar to the increase in the acceleration of the platform over conditions (Fig. 2). Statistical analysis revealed that ankle acceleration demonstrated a frequency by amplitude interaction ($F(2,1)=6.124$, $p=0.006$). Post-hoc analysis indicated that acceleration increased from 20Hz to 25Hz to 30Hz, and that at the 25Hz and 30 Hz conditions there was greater acceleration at the 2mm amplitude compared to the 1mm amplitude.

Acceleration at the knee was greatest with higher amplitudes and was greatest at 20Hz (Fig. 3). Acceleration increased with frequency but tended to decrease with amplitude. Knee acceleration displayed a frequency by amplitude interaction ($F(2,1)=4.560$, $p=0.019$). Post-hoc analysis indicated that acceleration at the 1mm amplitude increased from 20Hz to 25Hz but decreased from 25Hz to 30Hz. The 2mm amplitude decreased acceleration from 20Hz to 25Hz but increased between 25Hz and 30Hz. These differences were in fact significant after Bonferroni adjustments. The two amplitudes were relatively similar for each frequency at 25Hz and 30Hz but the difference was much greater between the two amplitudes at 20Hz.

The hip displayed a pattern that was relatively similar across all conditions and greatest at 25Hz (Fig.4). The sternum and temple showed minimal change across all conditions and the values for acceleration were low ~0.17 g (Fig. 5 & 6). This average was calculated from all six conditions at both the sternum and temple. Statistical analysis revealed that there was neither a main effect nor an interaction for the hip, sternum, and temple.

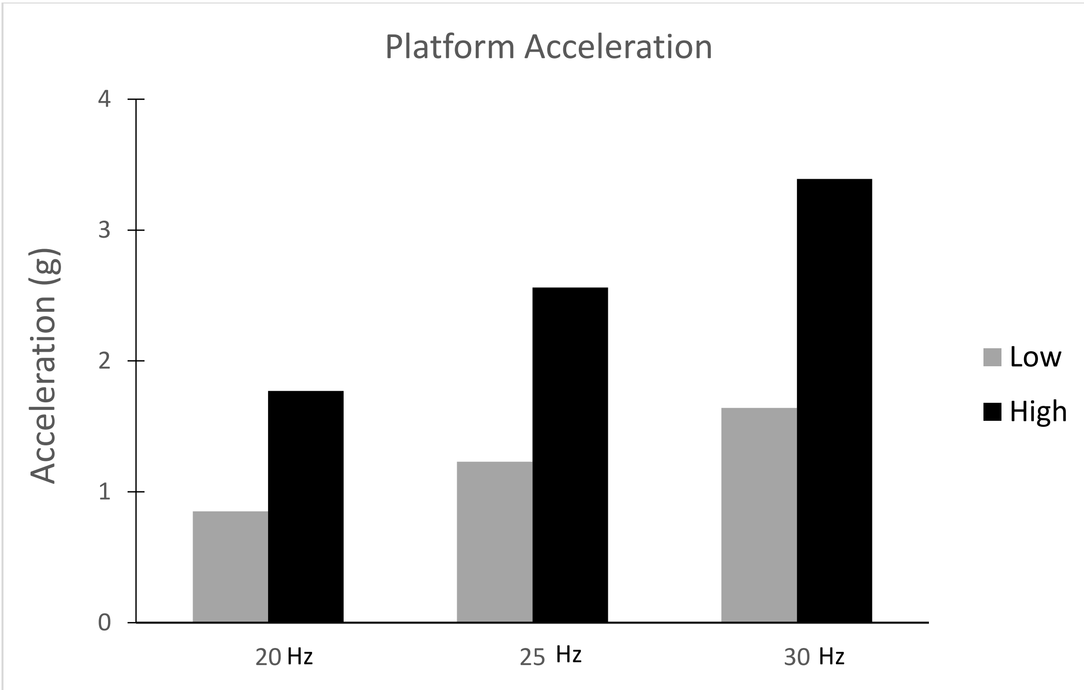

Figure 1: Vertical acceleration of the platform.

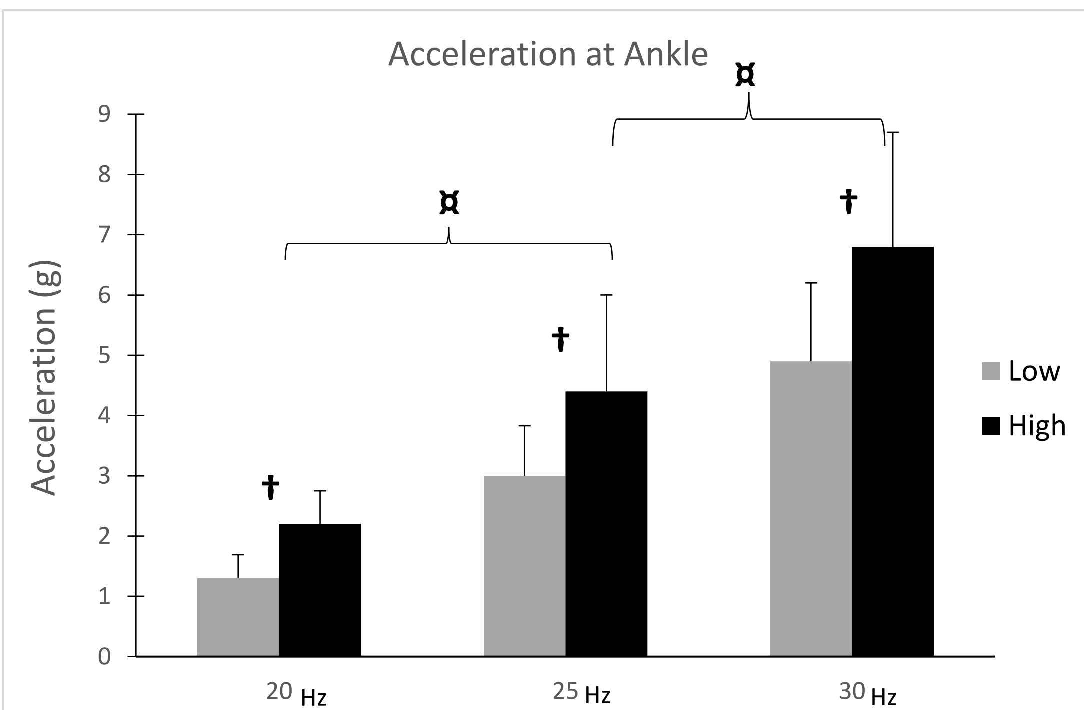

Figure 2: Acceleration at the ankle. (¤ denotes a frequency effect and † denotes an amplitude effect)

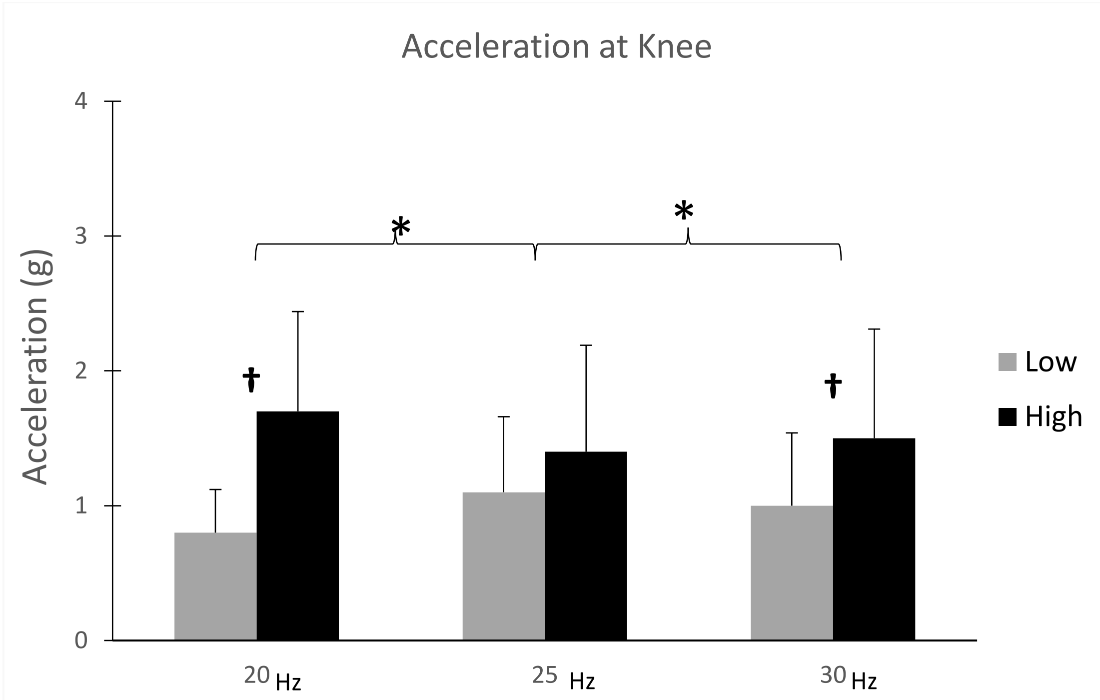

Figure 3: Acceleration at the knee. (¤ denotes frequency effect and † denotes an amplitude effect)

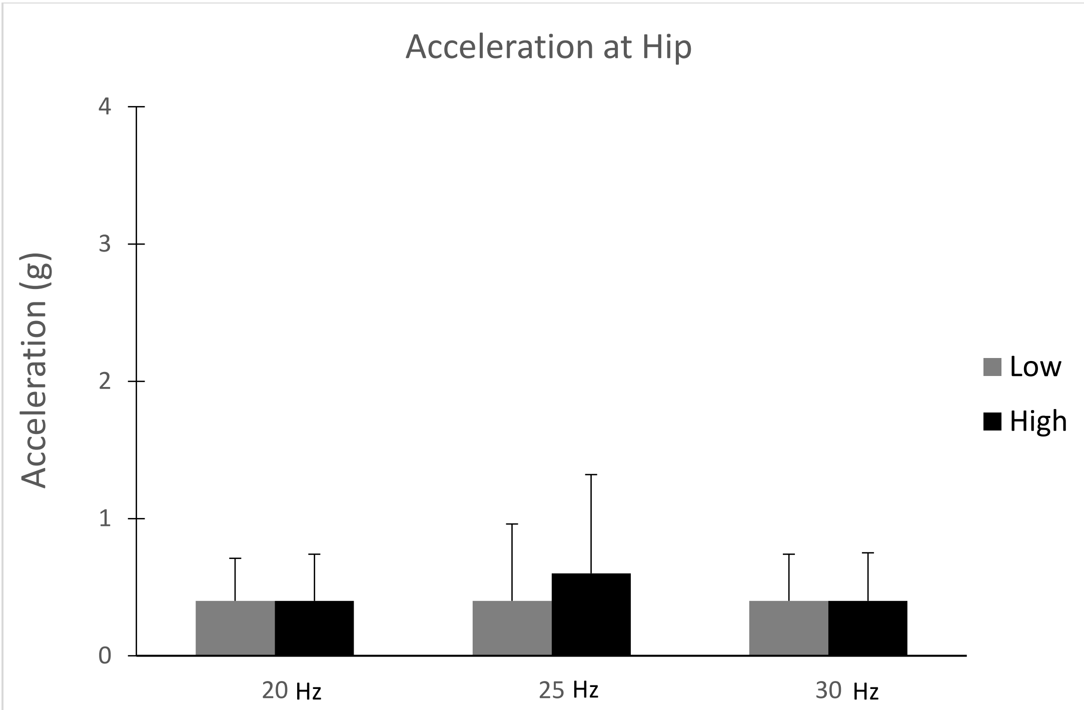

Figure 4: Acceleration at the hip.

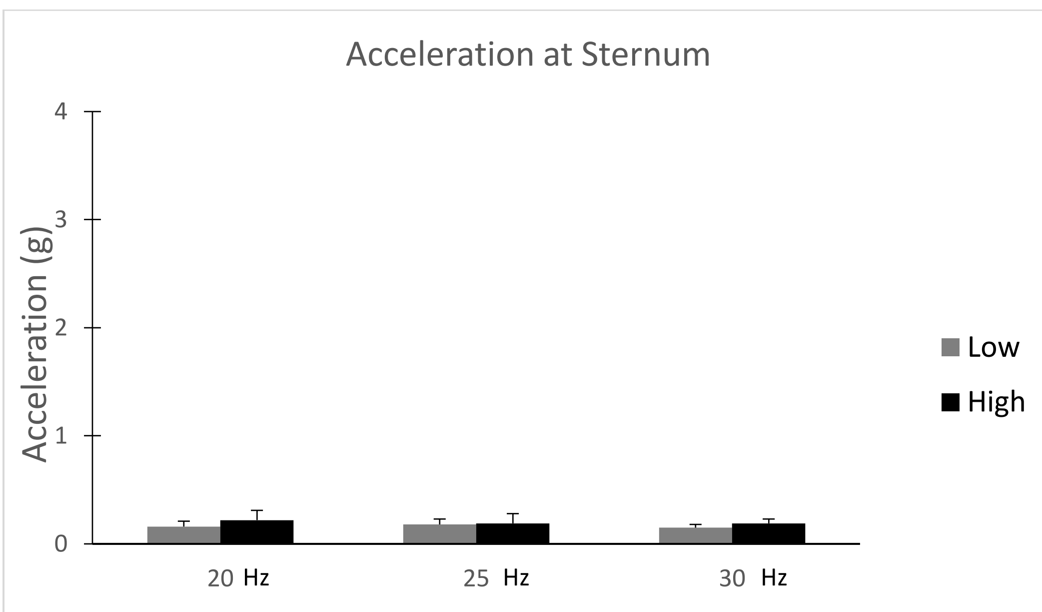

Figure 5: Acceleration at the sternum.

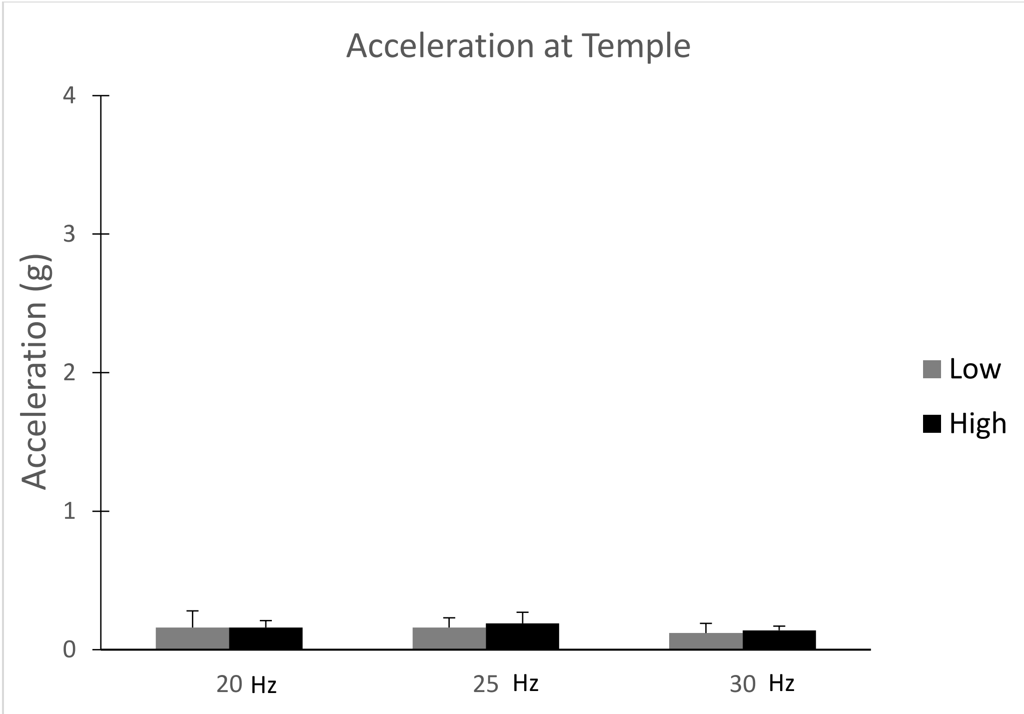

Figure 6: Acceleration at the temple.

Transmission ratio

Three-way (5 segment x 3 frequency x 2 amplitude) ANOVA revealed that there was a three-way interaction on transmission ratio (F(8,1)=4.590, p<0.001, Fig. 7-12). All conditions showed significant differences between the ankle and the knee except for the 20Hz 2mm condition. The ankle displayed greater transmission ratios than all other segments at each condition.

Transmission ratios at the ankle increased with frequency but decreased with amplitude (Fig 13). Transmission ratios at the ankle displayed a frequency by amplitude interaction (F(2,1)=8.618, p=0.001). Post-hoc analysis showed that transmission ratio increased with frequency to a less degree for the low amplitude condition than for the high-amplitude condition.

The knee decreased transmission ratios with increasing frequency and amplitude (Fig.14). Transmission ratios at the knee displayed a frequency main effect ($F(2,1)=4.205$, $p=0.024$) but post-hoc analysis showed that transmission ratio at 20 Hz was different from that at 25 and 30 Hz.

Transmission at the hip, sternum, and temple were all relatively similar. The overall ratio decreased with both frequency and amplitude. Transmission at the hip displayed an amplitude main effect ($F(2,1)=9.042$, $p= 0.008$) with no interaction. Transmission at the sternum displayed a frequency main effect ($F(2,1)=4.746$, $p= 0.016$) and an amplitude main effect ($F(2,1)=20.714$, $p= 0.000$) but no interaction between the frequency and amplitude. The transmission was significantly different between 25Hz and 30Hz. Transmission at the temple indicated an amplitude main effect ($F(2,1)=9.764$, $p= 0.007$) where the difference was greatest at 25Hz, but post-hoc analysis did not reveal an interaction between frequency and amplitude.

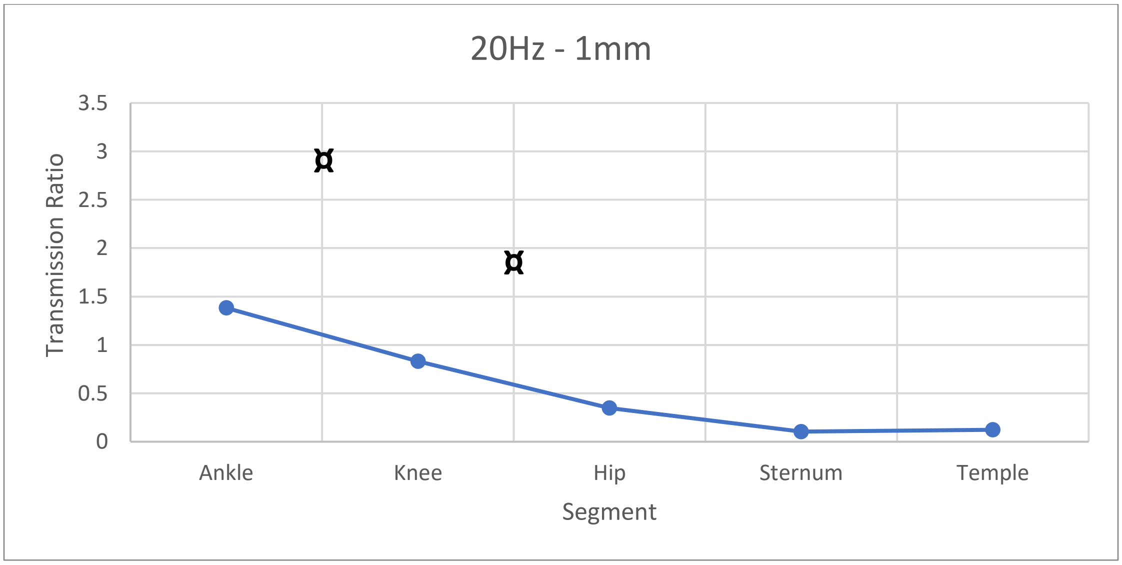

Figure 7: Transmission at each segment for the condition 20Hz and 1mm (¤ denotes a frequency effect).

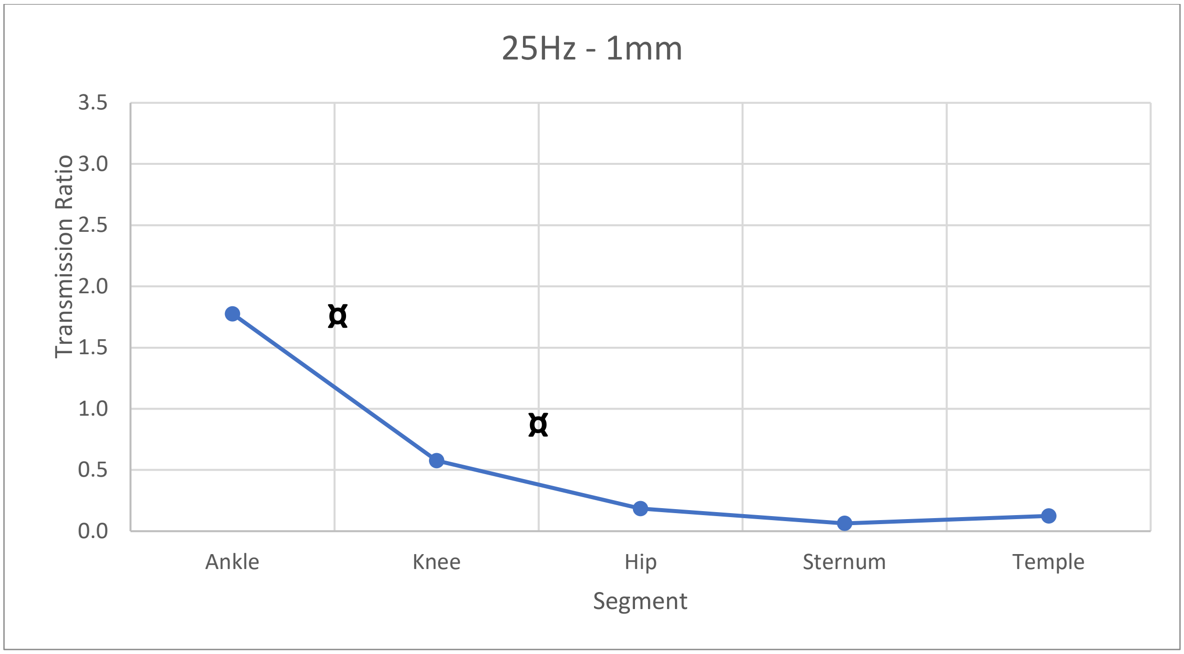

Figure 8: Transmission at each segment for the condition 25Hz and 1mm. (¤ denotes a frequency effect).

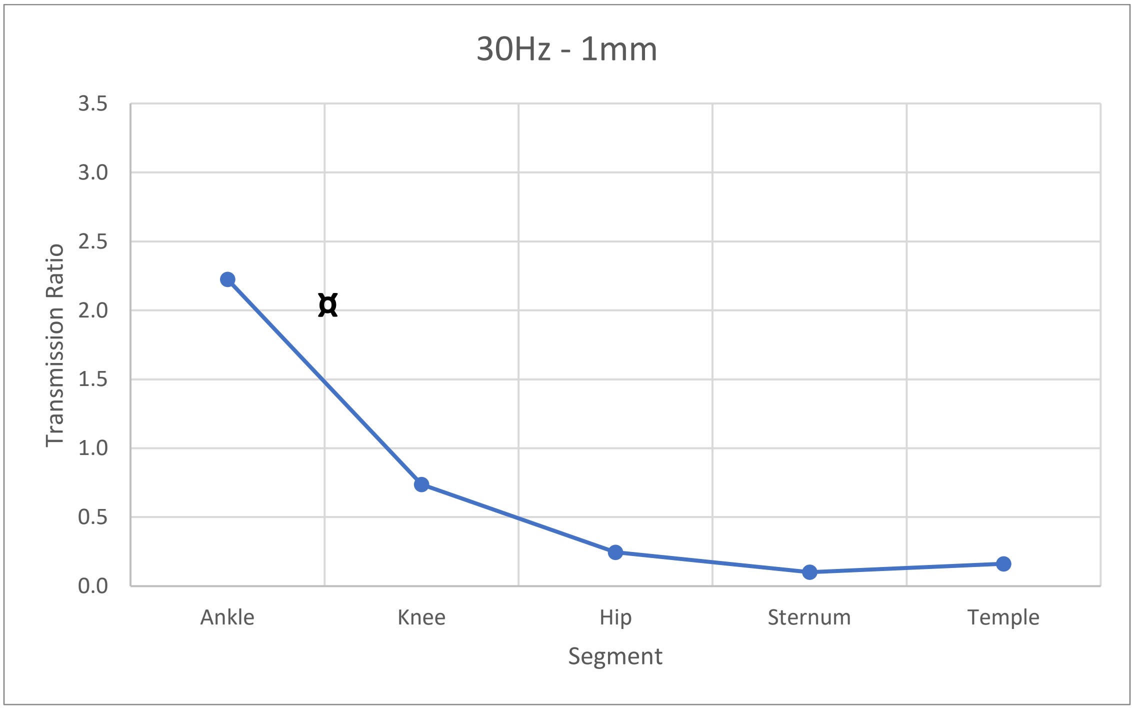

Figure 9: Transmission at each segment for the condition 30Hz and 1mm.

(¤ denotes a frequency effect (F(4,1)=148.404, p<0.001).

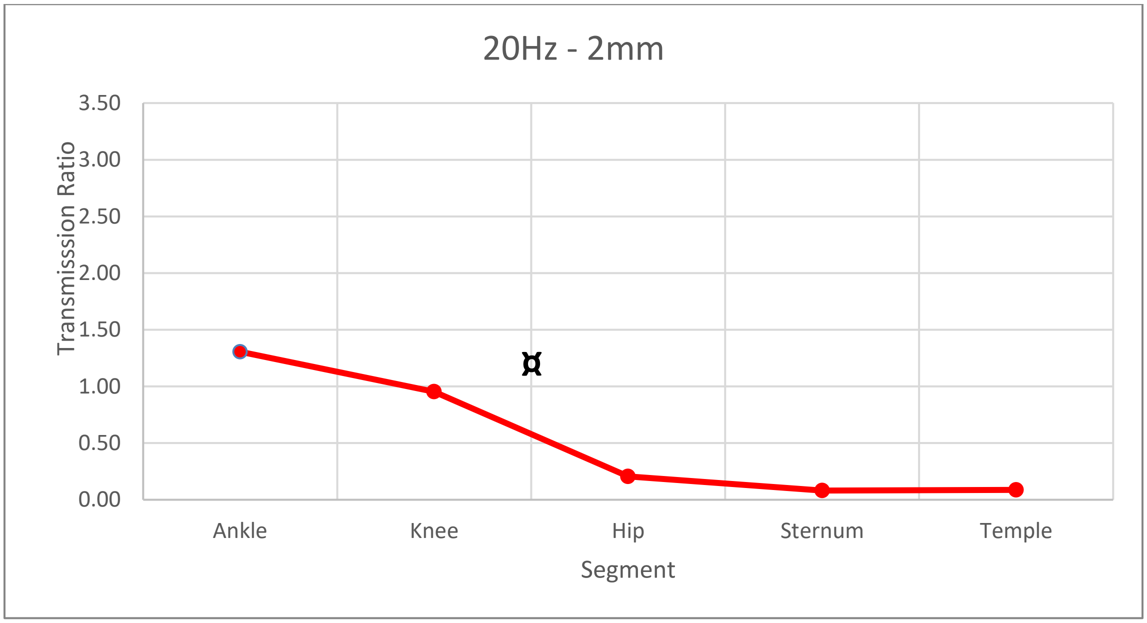

Figure 10: Transmission at each segment for the condition 20Hz and 2mm (¤ denotes a frequency effect).

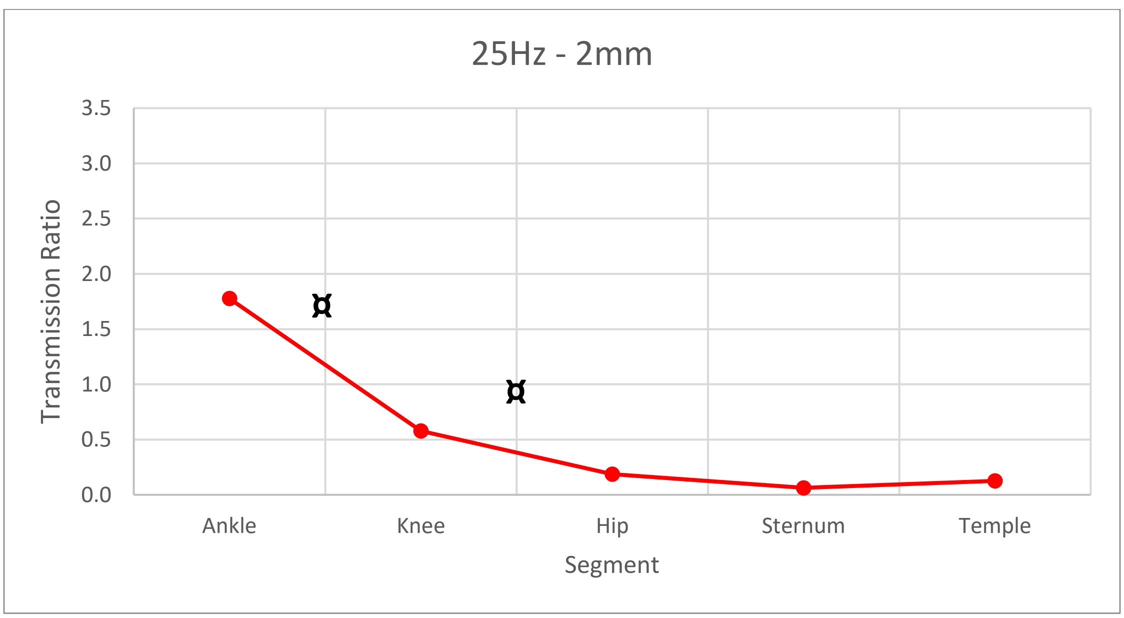

Figure 11: Transmission at each segment for the condition 25Hz and 2mm (¤ denotes a frequency effect).

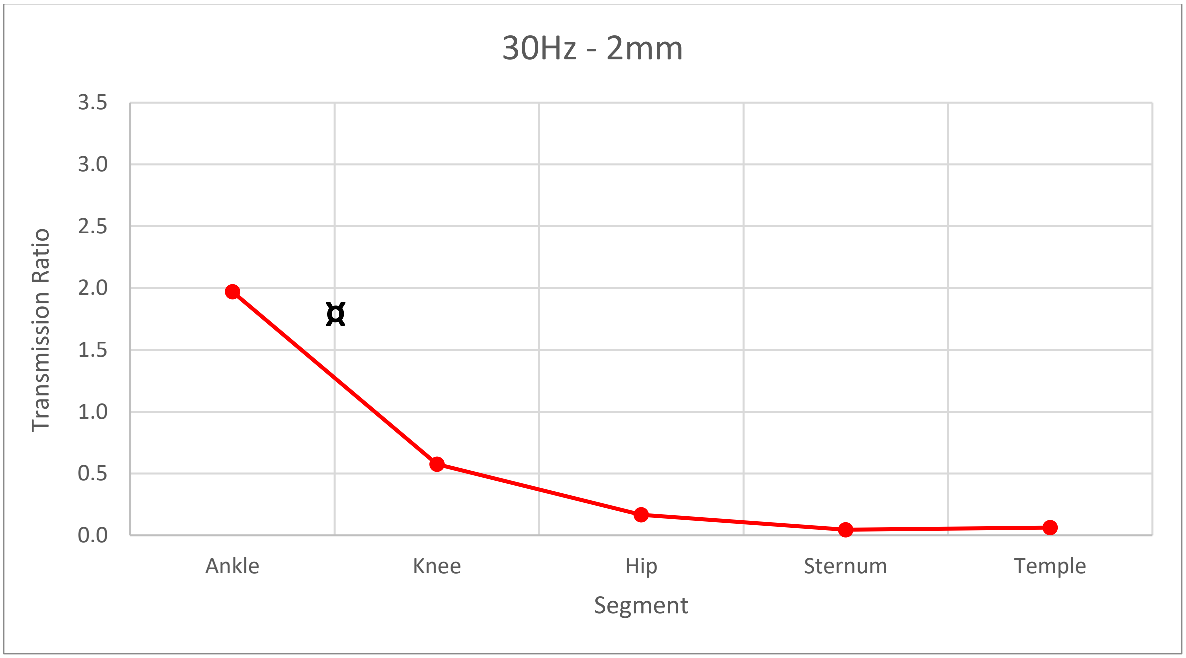

Figure 12: Transmission at each segment for the condition 30Hz and 2mm (¤ denotes a frequency effect).

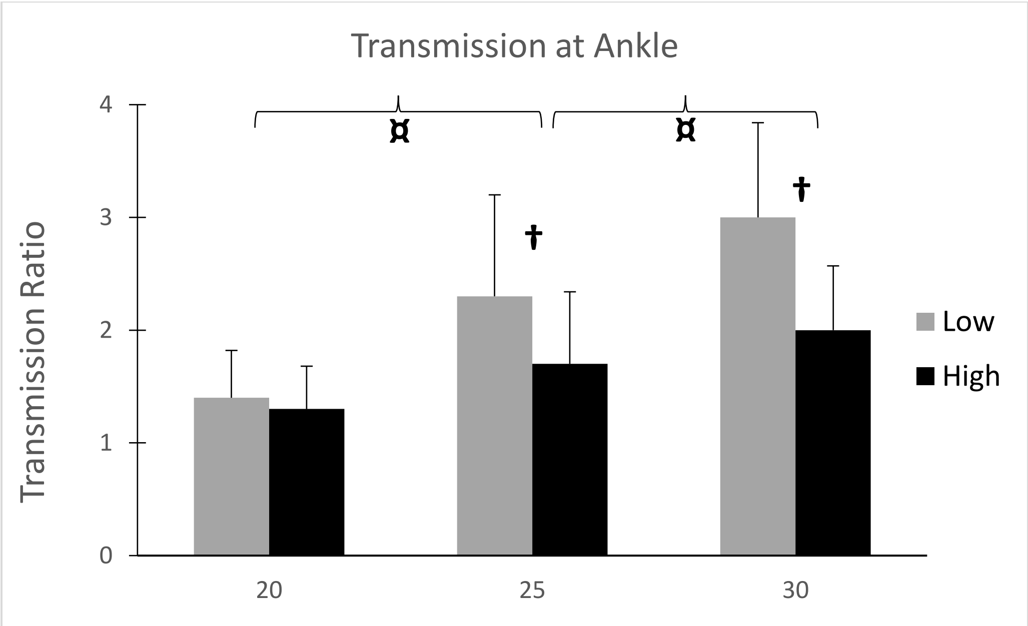

Figure 13: Acceleration transmission at the ankle (¤ denotes a frequency effect and † denotes an amplitude effect)

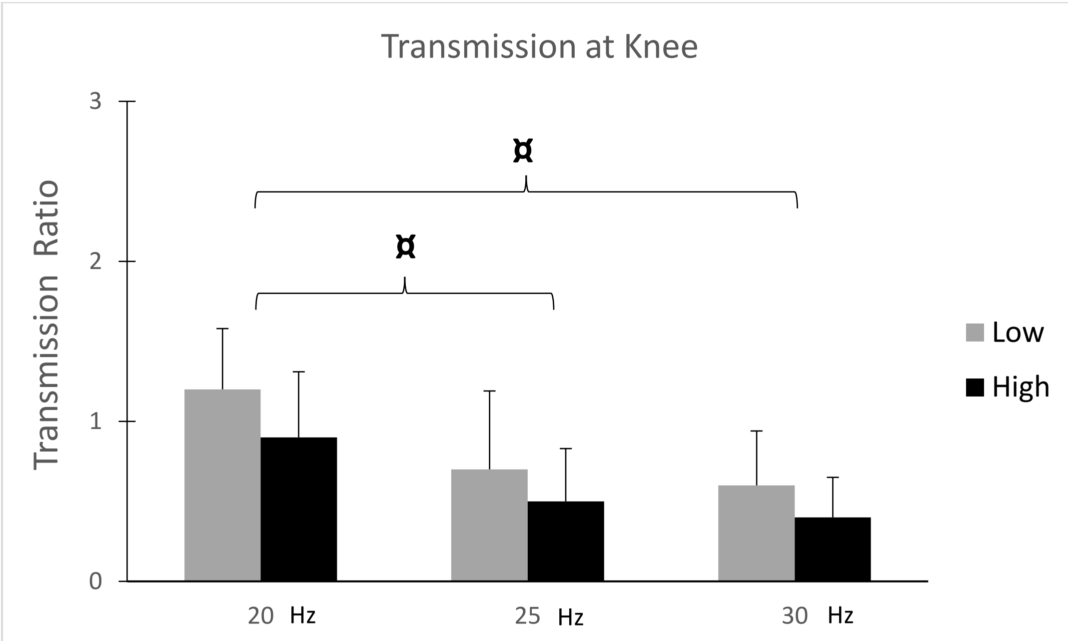

Figure 14: Transmission at the knee (¤ denotes a frequency main effect)

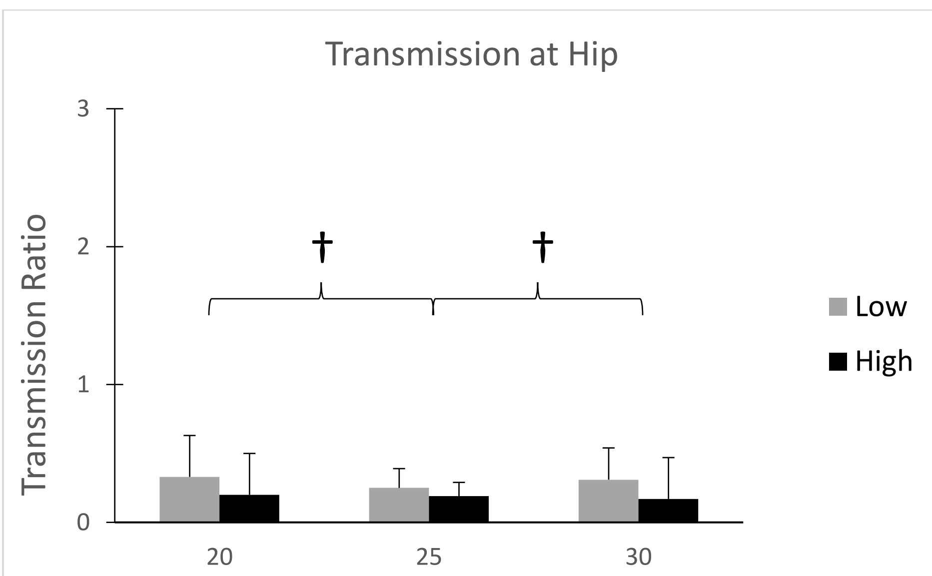

Figure 15: Transmission at the hip († denotes amplitude main effect)

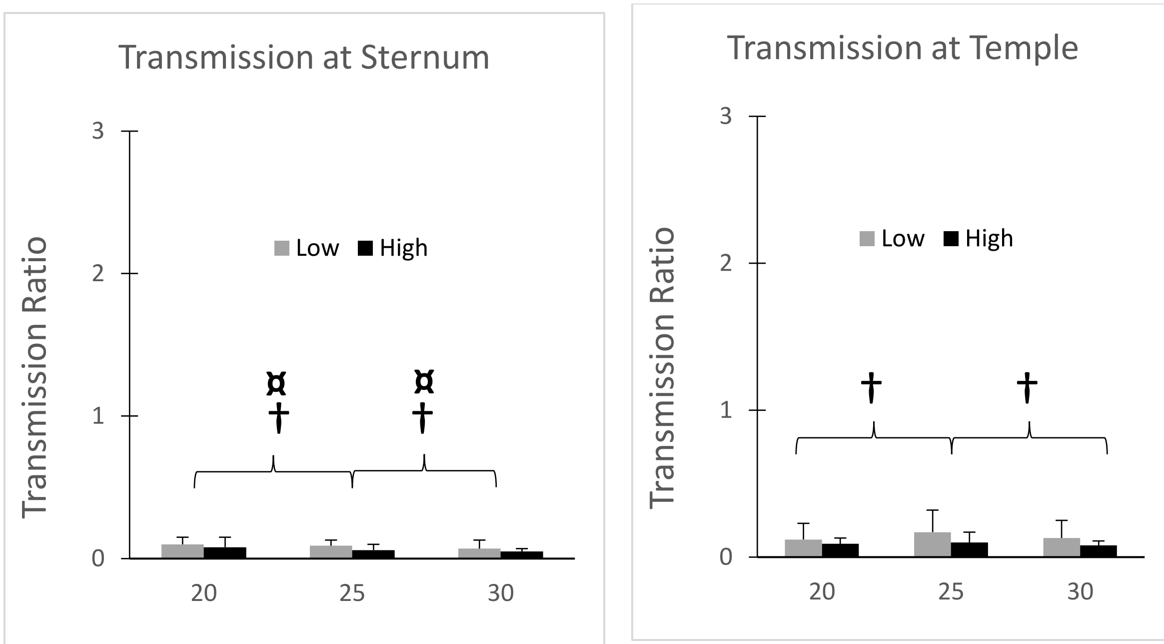

Figure 16: Transmission at the sternum and temple display similar patterns. Sternum: (¤ denotes a frequency main effect (F(2,1)=4.746,p= 0.016) and † denotes a amplitude main effect); Temple: († denotes an amplitude main effect).

<u>Counter-Movement Jump Height</u>

There was no significant difference in the counter-movement jump height following the vibration. Baseline jump heights were highest across almost all subjects suggesting that vibration did not augment neuromuscular performance. Frequencies 20 and 25 displayed similar responses regarding jump height where the low amplitude was less than the baseline and the high amplitude was less the low amplitude. 30Hz was slightly different where the lower amplitude was lower than the baseline but the high amplitude was higher than the low amplitude, but still less than the baseline nonetheless.

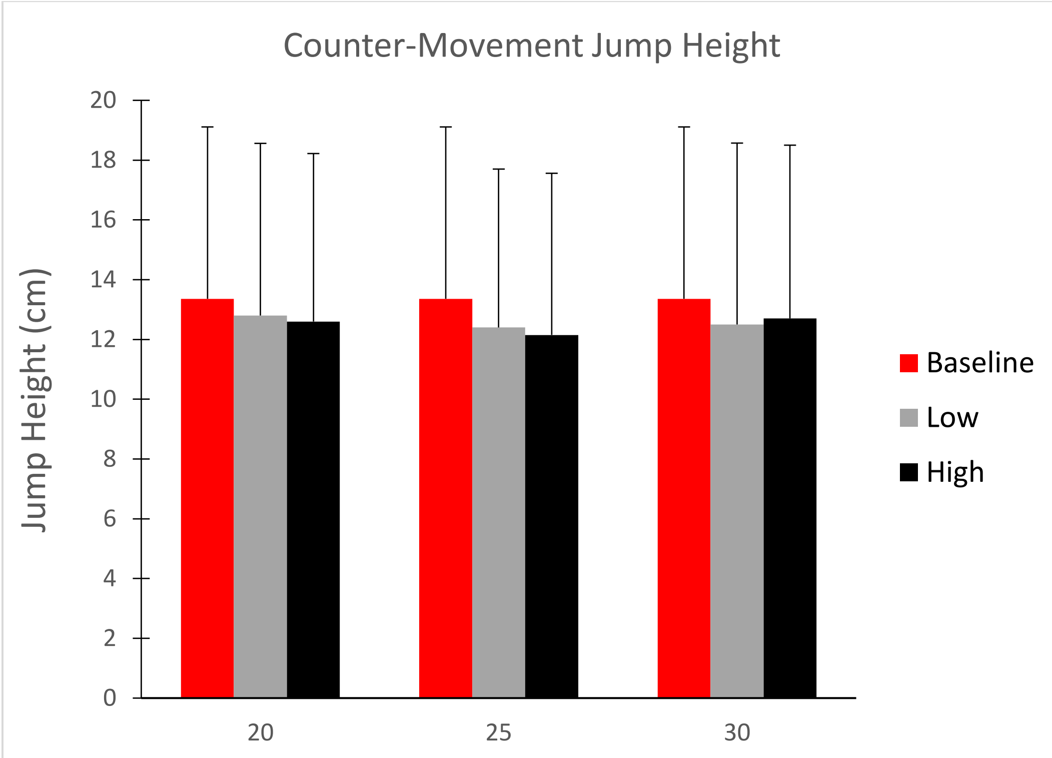

Figure 17: Counter-movement jump height at baseline and each condition.

Discussion

These findings confirm our hypotheses regarding the acceleration and transmission of the mechanical energy from the platform to reduce from the feet to the head. Data shows that there is substantial damping at the knee at 30Hz which is congruent with the study done by Pollock et al., 2010. Pooled data from three different frequencies, amplitudes and body positions reported acceleration at the head of 0.34 g (Crewther et al., 2004) in agreement with our values.

We did not investigate the effect of body posture but there was little effect of frequency or amplitude on acceleration at the head where low accelerations are reassuring as strong vibrations here can have adverse effects (Pollock et al., 2010). The reduced acceleration above the knee at frequencies >15 Hz may partly be explained by the muscle tuning theory (active damping) whereby muscle activity minimizes the potential for adverse effects (Crewther et al., 2004; Mester et al., 1999; Wakeling and Nigg, 2001; Wakeling et al., 2002). The resonant frequency of the tissues in the legs is ~10–50 Hz (Wakeling and Nigg, 2001) which is within the frequency range of WBV and so resonance may occur.

At select frequencies, specifically at the ankle, transmission from the platform exceeded 100% suggesting that resonance occurred (Rubin et al., 2003). The decrease in transmission indicates that damping occurred. The precise mechanisms for damping are unclear. Transmission of vibration through the body is regulated by many mechanisms and tissues (e.g. bone, cartilage, synovial fluid, soft tissue, joint kinematics and muscular activity (Wakeling et al., 2002) and will also be affected by the type of platform used. The alternating movement with sinusoidal platforms causes pelvic rotation resulting in further damping and less acceleration at the head (Abercromby et al., 2007). The foot appeared to do a significant portion of the damping along with the knee. At high frequencies and amplitudes the foot has a tendency to grip the platform by increasing muscle activation. This can only be speculated as we did not analyze muscle activation in the feet. The knee also appeared to do a significant amount of damping as the acceleration transmission values were low above the knee. The degree of knee flexion and muscle activation can play a pivotal role in the attenuation of these vibrations. Transmission values for sinusoidal platforms should be interpreted with caution as the lateral aspect of the foot experiences higher amplitude than the medial, making it hard to determine the exact amplitude experienced (Pollock et al., 2010). For our study we had subjects align the midline of their foot with a designated line on the platform to ensure the average vibration amplitude of the foot.

We hypothesized that high accelerations would occur at higher amplitudes and this only occurred at the ankle. The more distal segments tended to display a trend of decreasing acceleration with higher frequencies and amplitudes which can be partially explained by the damping of the muscular system as well as the muscle tuning theory explained above.

Acceleration

The ankle displayed patterns of increasing acceleration between the 2 amplitudes at each frequency. The higher amplitudes yielded a greater acceleration but the middle conditions of 25Hz 1mm and 25Hz 2mm showed the greatest accelerations suggesting either the muscle tuning theory was present or we can speculate that the children may have stood more flat footed. Similar findings became apparent in previous studies where mid-ranged conditions such as ours yielded higher accelerations (Torvinen et al., 2002). The damping of the accelerations at other conditions could be caused by increased muscle activation which inevitably attenuates the vibratory stimulus from the feet to the head.

The acceleration at the knee displays a pattern inversely related to the platform. This data causes speculation that the knee can act as a significant damper of the acceleration to the superior segments. All segments above the knee displayed minimal acceleration which indicates that knee flexion could be a potential mechanism for attenuating vibrations. The marker data showed that the knee was more reactive to the amplitude change which agrees with the study done by Pollock et al., 2010. The knee was accelerated the greatest at the high amplitude regardless of frequency. Accelerations greater than 20Hz declined relatively linearly with the higher amplitude still displaying a greater acceleration. The knee played a pivotal role in the attenuation of the vibration because the value of acceleration above the knee decreased significantly. This is suggested to be caused by the muscle mass of the quadriceps and hamstrings muscle groups according to Bressel et al., 2010. EMG data would be able to further prove this suggestion.

Acceleration at the hip was relatively similar across all conditions. The lower frequency was unaffected by amplitude with relatively low values due to attenuation of the knee and upper leg muscles. The mid-range frequency displayed greater acceleration at the higher amplitude while the acceleration at the lower amplitude was the same as the 20Hz data. The higher frequency was also unaffected by amplitude with the lowest values of all frequencies. The higher frequencies tend to cause the children to bend their knees more in order to maintain comfort which in turn causes more muscle activation of the upper leg muscles. This mechanism could be responsible for the lowest values at the high frequency conditions.

Acceleration at the sternum and temple were relatively low with minimal change across conditions. Our data showed that the accelerations transmitted to the head are safe and do not produce any adverse or uncomfortable effects. The raw acceleration data collected aimed to assess the safety of the platform as to see if the vibrations were exceedingly high. The subjects were asked at the end of every condition whether they enjoyed the stimulus or thought it was uncomfortable or anything in between. All subjects enjoyed the vibration.

Transmission

Transmission at the ankle somewhat followed the progression of the platform. Each condition yielded higher transmission ratios to the ankle as the acceleration increased, but the low amplitude condition was continuously greater than the high amplitude. The ankle is typically higher than any other segment due to the proximity of the platform. Studies such as Bressel et al., 2010, Pollock et al., 2010, Torvinen et al., 2002 shared similar results regarding acceleration at the ankle.

Similar to the acceleration, the knee displayed an inverse relationship to the platform. The low amplitude was always greater than the high amplitude and the transmission ratio decreased as the acceleration progressed. The platform progression refers to the concept of increasing both frequency and amplitude to increase acceleration. This transmission decrease in the high amplitude could be due to the soft tissues of the foot absorbing or attenuating the mechanical energy from the platform. The foot tends to grip the platform and higher amplitudes in order to maintain foot placement and with more muscle activation there will be more energy absorption. Transmission at the hip was also lower at the higher amplitudes which can be related to the chain of increasing lower and upper leg muscle activation during high amplitude accelerations.

Transmission to the sternum and the temple suggest that this is a safe modality for children. Our study did not report any adverse effects to the head which is a main concern when involving preadolescents. The vibrations transmitted to the head were minimal, especially when compared to other studies. Accelerations to the head in a similar study by Pollock et al., 2010 yielded an average of 0.34 g to the head while our average was 0.11 g. Acceleration transmission values give more insight as to the damping each segment attributes. Our study showed that the ankle and knee play a significant role in the attenuation of these vibrations.

Counter-Movement Jump Height

Counter-movement jump height did not appear to be augmented by the vibratory stimulation. The baseline jumps were the highest on average of most subjects. Unlike the study done by Maeda et al., 2016 we did not see an increase in counter-movement jump performance after the vibration intervention. The intensity and duration of our studies differ quite significantly. The intervention used a frequency of 30 Hz and an amplitude of 4 mm. Sessions occurred 3 times a week for 8 weeks. They proposed the mechanism responsible for this augmented jump performance is the neuromuscular facilitation allowing more muscle activation following the vibration. It is possible that our intervention had inadequate stimulus in order to augment neuromuscular facilitation. Another study that investigated football players with WBV and counter-movement jump performance. The difference is not significant between conditions but it is worth noting the decrease in muscle performance. The short duration of the vibration (60 sec) should not have induced muscle fatigue. The jumps had a 30 sec rest period between each of the 3. Following the 3 jumps the subjects had 5 min of rest between each condition. These times allotted attempted to reduce any muscle fatigue possibility. The decrease in jump performance could be due to the vibration stimulus being inadequate in order to increase neuromuscular performance. The benefits of WBV may not be conclusive because there are many conflicting results present in the literature. This can provide some evidence as to why there was no increase in counter-movement jump performance in our study. It is possible that either the combination of the frequency and amplitude were not strong enough to elicit an augmented muscle response or the duration was not long enough.

Limitations and Future Studies

There were few limitations to this study. Our sample size was children aged 6-11 and the variability in motor development could have played an important role in their motor ability. The counter-movement jump height could be less variable with more subjects and a smaller age range. The frequency and amplitude chosen were because of previous studies done and are not generalized. We did not want to complete a study on preadolescents that had not been tested for the safety of the subjects. We also provided each subject with a 5 min wash-out period to ensure the residual effects of the vibration had worn off. It is highly unlikely that the vibration effect lingered after the 5 min but it is worth noting the potential residual effect could still be present.

Our study was part of a larger study including data that has not been processed yet. The potential future studies will be listed after the completion of the unprocessed data including joint kinetics and kinematics, EMG, and ground reaction forces.

Conflict of interest

There is no conflict of interest in this study.

References

Abercromby, A.F.J., Amonette, W.E., Layne, C.S., McFarlin, B.K., Hinman, M.R., Paloski, W.H. (2007). Variation in neuromuscular responses during acute whole-body vibration exercise. *Med. Sci. Sports Exerc*. 39, 1642–1650.

Bressel, E., Smith, G., & Branscomb, J. (2010). Transmission of whole body vibration in children while standing. *Clinical Biomechanics,25*(2), 181-186. doi:10.1016/j.clinbiomech.2009.10.016

Cardinale, M. (2005). Whole body vibration exercise: are vibrations good for you? * Commentary. *British Journal of Sports Medicine,39*(9), 585-589. doi:10.1136/bjsm.2005.016857

Carlucci, F., Mazzà, C., & Cappozzo, A. (2010). Does Whole-Body Vibration Training Have Acute Residual Effects on Postural Control Ability of Elderly Women? *Journal of Strength and Conditioning Research,24*(12), 3363-3368. doi:10.1519/jsc.0b013e3181e7fabb

Cheung, W., Mok, H., Qin, L., Sze, P., Lee, K., & Leung, K. (2007). High-Frequency Whole-Body Vibration Improves Balancing Ability in Elderly Women. *Archives of Physical Medicine and Rehabilitation,88*(7), 852-857. doi:10.1016/j.apmr.2007.03.028

Dolny, D. G., & Reyes, G. F. (2008). Whole Body Vibration Exercise. *Current Sports Medicine Reports,7*(3), 152-157. doi:10.1097/01.csmr.0000319708.18052.a1

Eckhardt, H., Wollny, R., Müller, H., Bärtsch, P., & Friedmann-Bette, B. (2011). Enhanced Myofiber Recruitment During Exhaustive Squatting Performed as Whole-Body Vibration Exercise. *Journal of Strength and Conditioning Research,25*(4), 1120-1125. doi:10.1519/jsc.0b013e3181d09e0e

Eid, M. A. (2015). Effect of Whole-Body Vibration Training on Standing Balance and Muscle Strength in Children with Down Syndrome. *American Journal of Physical Medicine & Rehabilitation,94*(8), 633-643. doi:10.1097/phm.0000000000000224

Giminiani, R. D., Masedu, F., Tihanyi, J., Scrimaglio, R., & Valenti, M. (2013). The interaction between body position and vibration frequency on acute response to whole body vibration. *Journal of Electromyography and Kinesiology*,*23*(1), 245-251. doi:10.1016/j.jelekin.2012.08.018

Hazell, T. J., Jakobi, J. M., & Kenno, K. A. (2007). The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. *Applied Physiology, Nutrition, and Metabolism,32*(6), 1156-1163. doi:10.1139/h07-116

Kiiski, J., Jarvinen, T. L., Kannus, P., & Sievanen, H. (2008). Transmission of Vertical Whole Body Vibration to the Human Body. *Journal of Bone and Mineral Research,23*(8).

Maeda, Noriaki, et al. "Effect of Whole-Body-Vibration Training on Trunk-Muscle Strength and Physical Performance in Healthy Adults: Preliminary Results of a Randomized Controlled Trial." *Journal of Sport Rehabilitation*, vol. 25, no. 4, 2016, pp. 357–363., doi:10.1123/jsr.2015-0022.

Pojskic, Haris, et al. "Acute Effects of Loaded Whole Body Vibration Training on Performance." *Asian Journal of Sports Medicine*, vol. 6, no. 1, 2015, doi:10.5812/asjsm.24054.

Pollock, R. D., Woledge, R. C., Mills, K. R., Martin, F. C., & Newham, D. J. (2010). Muscle activity and acceleration during whole body vibration: Effect of frequency and amplitude. *Clinical Biomechanics,25*(8), 840-846. doi:10.1016/j.clinbiomech.2010.05.004

Ritzmann, R., Gollhofer, A., & Kramer, A. (2012). The influence of vibration type, frequency, body position and additional load on the neuromuscular activity during whole body vibration. *European Journal of Applied Physiology,113*(1), 1-11. doi:10.1007/s00421-012-2402-0

Torvinen, S., Sievänen, H., Järvinen, T. A., Pasanen, M., Kontulainen, S., & Kannus, P. (2002). Effect of 4-min Vertical Whole Body Vibration on Muscle Performance and Body Balance: A Randomized Cross-over Study. *International Journal of Sports Medicine,23*(5), 374-379. doi:10.1055/s-2002-33148

Wakeling, J. M., & Nigg, B. M. (2001). Modification of soft tissue vibrations in the leg by muscular activity. *Journal of Applied Physiology,90*, 412-420.

Appendix A:

Georgia State University
Department of Kinesiology and Health
Parental Permission Form

Title: Effect of whole-body vibration on acceleration transmission, and jumping performance in children

Principal Investigator: Jianhua Wu, PhD
Student Principal Investigator: Michael Lelko, EP-C

I. Purpose: Your child is invited to take part in a research study. The purpose of the study is to look at how typical children adapt to a vibrating platform and how it affects their jump height. Your child is invited to take part because he or she is developing typically and is between 6 and 11 years old. You and your child will come to the Biomechanics lab at Georgia State University one time for 2 hours.

II. Procedures: If you allow your child to take part and your child wants to take part, your child will wear a bathing suit or compression shorts for data collection. We will use a scale with height rod to measure your child's height and weight. We will use a tape measure to record your child's limb length and width. We will place 12 reflective stickers on your child's body to observe their movement. Our cameras will only record the position of the reflective stickers. Your child's image will not be recorded. We will also place four small blocks in front and back of your child's leg to understand his muscle activity. Your child will first stand on a vibrating board for 1 min and then be asked to jump as high as they can. Your child will do this 3 times after each 60 sec. Researchers will stand near your child in case they lose their balance. Your child will have a 5 min break between each set of standing on the vibrating platform and jumping.

III. Risks: Data collection will include taking body measurements, wearing reflective stickers and small blocks, and treadmill walking. The risks associated with these activities are minimal. The small blocks could cause skin irritation due to the tape that keeps them on your child's skin. The potential irritation is very short term and the redness of the skin, if any, should go away within hours. Your child may lose his or her balance and fall while standing on the vibrating platform. Your child may lose their balance while jumping, but it is not very different from children's daily activity. Researchers will stand near your child in case they lose their balance. Soft mats will be placed around the treadmill in case of a fall. Your child may feel muscle soreness from jumping. This soreness will usually go away quickly. We will closely watch your child for signs of pain. We will stop the study at once if there is presence of pain.

IV. Benefits: Participation in this study will not benefit your child personally. We hope to gain information about how typically developing children adapt to the vibrating platform and its effect on jumping performance. We hope to use this information to help develop treatments for children with and without disabilities who have difficulty jumping.

V. Voluntary Participation and Withdrawal: Participation in research is voluntary. Your child does not have to be in this study. If your child decides to be in the study and changes his or her mind, he or she has the right to drop out at any time. You may also drop your child from this study at any time. Whatever you and your child decide, your child will not lose any benefits to which your child is otherwise entitled. Your child is free to slow the pace, take rest, or withdraw from this study at any time. There are no social and psychological risks associated with this study.

VI. Confidentiality: We will keep your records private to the extent allowed by law. We will save your child's personal information in a locked file cabinet in the principal investigator's office. Only the principal investigators will have access to it. We will use a subject number (such as TD01) instead of your child's name for data collected at lab visits. We will save these data on a password-protected desktop computer in the lab. Only principal investigator and his assistants will have access to these motion data. We may share the information with those who make sure the study is done correctly (GSU Institutional Review Board, the Office for Human Research Protection (OHRP). Your child's name and other facts that might point to you will not appear when we present this study or publish its results. Your child will not be identified personally.

VII. Contact Persons: Contact Michael Lelko at 678-793-4226 or mlelko1@student.gsu.edu if you have questions, concerns, or complaints about this study. You can also contact Jianhua (Jerry) Wu at 404-413-8467 or jwu11@gsu.edu. You can also call if you think your child has been harmed by the study. Call Susan Vogtner in the Georgia State University Office of Research Integrity at 404-413-3513 or svogtner1@gsu.edu if you want to talk to someone who is not part of the study team. You can talk about questions, concerns, offer input, obtain information, or suggestions about the study. You can also call Susan Vogtner if you have questions or concerns about your rights in this study.

VIII. Copy of Consent Form to Participant: We will give you a copy of this permission form to keep. If you are willing to volunteer your child to take part in this research, please sign below.

____
Printed Child's Name

Printed Parents or Guardian's Name	Signature	Date
Printed Investigator's Name	Signature	Date

Appendix B:

Georgia State University
Department of Kinesiology and Health
Verbal Assent Form

Title: Effect of whole-body vibration on acceleration transmission, and jumping performance in children

Principal Investigator: Jianhua Wu, PhD
Student Principal Investigator: Michael Lelko, EP-C

The following assent script was delivered to the subject between 6 and 10 years of age.

> I would like you to play some games with me at this lab. I will put stickers on your body. You will stand on a vibration board, and then jump on the floor. We will do a total of six times.
>
> You don't have to stand on the vibrating board or jump if you don't want to. No one will be mad at you if you don't want to stand and jump. Would you like to come play games and jump with me?

The subject provided verbal assent to participate in this study.

________________________________ ________ ______________

Subject's Name Age Date

________________________________ ________________________

Name of Investigator Signature of Investigator

Georgia State University
Department of Kinesiology and Health
Written Assent Form

Title: Effect of whole-body vibration on acceleration transmission, and jumping performance in children

Principal Investigator: Jianhua Wu, PhD
Student Principal Investigator: Michael Lelko, EP-C

This assent script will be used for children between 11 and 17 years of age.

We are asking you to take part in a study about standing on a vibration board and then jumping on the hard floor. The researchers from Georgia State University want to learn about how children respond to a vibrating board and if it makes them jump higher. You will wear stickers and small blocks. You will stand on the vibration board for 1 min and then jump on the hard floor. We will repeat this for a total of six times. It will take 90 minutes of your time.

You are taking part because you want to. You don't have to be in this study, and your parent(s)/legal guardian(s) cannot make you be in it. You can stop being in the study at any time, and if you do not want to continue then you do not have to. No one will be mad at you if you want to stop.

_______________________________________ _______
Subject's Printed Name Age

_______________________________________ ________________
Subject's Signature Date

____
Investigator's Printed Name

_______________________________________ ________________
Signature of Investigator Date