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Transmission of whole body vibration in children while standing

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ABSTRACT

Background: Whole body vibration has recently been used as a therapeutic intervention for the treatment of children with disabling conditions. Researchers of these studies observed encouraging results; however, children may not be capable of attenuating high vibration accelerations to the head because of low mass. The purpose of this study was to determine if children transmit vibration differently than adults while standing on a vibration platform.

Methods: The experimental protocol required 11 children and 10 adults to stand on a commercially available vibration platform at progressively greater frequencies (28, 33, and 42 Hz). Transmissibility of vibration to various skeletal landmarks was assessed with a high speed motion analysis system.

Findings: Transmissibility in children was 42% and 62% greater than adults for the ankle and hip, respectively ($P = 0.03$; effect size = 0.84–1.29). The values at the head were not different between groups ($P = 0.92$) and remained 86% and 50% lower than values at the ankle and knee, respectively (effect size = 4.75–19.1).

Interpretation: Transmissibility of whole body vibration while standing is not markedly different between children and adults. In fact, the only differences are the transmissibility to the ankle and hip which are greater in children when the vibration platform is set at 33 Hz. More importantly, transmissibility to the head is not different between groups. These results do not suggest vibration therapy is safe as the biological response of children to acute or chronic acceleration impacts during whole body vibration is unknown.

1. Introduction

Vibration, defined as an oscillatory motion, can be artificially applied to the human body using a vibrating platform. When a person stands on a vibration platform, the waveform (e.g., sinusoidal and stochastic), amplitude, frequency, and duration can be manipulated. These variables may produce benefits in muscle performance and bone mineral density (see Dolny and Reyes, 2008 for a topic review). However, some vibration characteristics can produce exceedingly high accelerations of the platform (e.g., 19 G; Kiiski et al., 2008) that may be viewed as dangerous, particularly if used with fragile populations such as children who have low mass and underdeveloped neuromusculoskeletal systems.

Despite the potential for high accelerations at certain settings, whole body vibration has been used as a therapeutic intervention for the treatment of children with disabling conditions (Semler et al., 2007, 2008; Ward et al., 2004). For example, Semler et al. (2008), exposed eight children (age = 9.3 (SD 2.8) years) diagnosed with osteogenesis imperfecta to 6 months of daily whole body vibration (duration = 9 min/day, amplitude = 1–2 mm, frequency = 15–25 Hz, and acceleration ≈ 2.5 G). After the intervention, they observed a 177% increase in weight bearing load tolerance in all participants. Ward et al. (2004) exposed 20 children (age = 9.1 (SD 4.3) years) diagnosed with cerebral palsy or muscular dystrophy to 6 months of whole body vibration (duration = 10 min/day, amplitude < 100 μm, frequency = 90 Hz; and acceleration = 0.4 G) and observed 6.3% and 5.5% increases in bone mineral density at the knee and lumbar vertebra, respectively. These clinical studies provide encouraging results for the use of whole body vibration therapy in children; however, the use of whole body vibration therapy in children raises an important question regarding its safety as it is not clear how the child's body attenuates or transmits vibration while standing.

No studies, that the authors are aware of, have determined if children transmit vibration differently than adults while standing on a vibration platform. Comparisons have been made during sitting, but the transmissibility is clearly different between the two postures (Paddan and Griffin, 1998). Assessments while seated indicate that young children absorb about 0.0156 N s^2/m of total power (normalized to acceleration) (Giacomin, 2005), which is about 88% less than adults tested at equivalent accelerations (0.1289 N s^2/m; Mansfield and Griffin, 1998). When absorbed

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power is normalized to body mass, the differences become smaller (≈14%; Giacomin, 2004) but significant correlations remain between sitting vibration attenuation, body weight, and age (Fairley and Griffin, 1989).

It would be valuable to know if any differences in vibration transmission exist between children and adults since knowledge of the transmissibility will help determine if whole body vibration therapy is particularly hazardous in children. One conjecture is that reduced tissue mass of children may increase vibration transmissibility to the head and lead to pathological responses such as vestibular and ocular disorientation (Griffin, 1996). To date, no injuries have been reported in the three clinical studies that exposed children to whole body vibration (Semler et al., 2007, 2008; Ward et al., 2004). One conjecture for why children may not be at greater risk of injuries is that children have a more compliant bone structure (Ding et al., 1997) and may use muscle tuning strategies (Wakeling and Nigg, 2001) or changes in joint angle to attenuate vibration (Harazin and Grzesik, 1998; Rubin et al., 2003). It is possible that despite children having less tissue mass to dampen the vibration, children will use other mechanical strategies to attenuate vibration by the time it reaches the upper body and head. These contentions are yet to be answered and will require a basic understanding of how children transmit vibration while standing.

The purpose of this present study was to determine if children transmit vibration differently than adults while standing on a vibration platform. It was hypothesized that the transmission of vibration to some skeletal locations would be different in children than adults.

2. Methods

2.1. Participants

Eleven healthy children and 10 healthy adults were asked to volunteer for this investigation. Subjects were recruited from the local community and were included in the study if they were free from musculoskeletal injuries and had not previously trained with whole body vibration. Before taking part in the study, participants or their legal guardians read and signed an informed consent form approved by the institution's ethics committee. The physical characteristics of the participants are displayed in Table 1.

2.2. Procedures and instrumentation

The experimental protocol required each participant to stand on a commercially available vibration platform (i.Tonic International B.V., Huizen, Netherlands) with progressively greater frequencies (28, 33, and 42 Hz). Participants stood on the platform for approximately 10 s at each frequency with no shoes, no socks, and knees bent (Fig. 1). We did not require a specific knee angle; instead we let the participants choose a preferred knee angle at each frequency. Our verbal directions were: (1) "Stand so that your feet are shoulder width apart and so that your whole foot touches the plate surface," (2) "Slightly bend your knees and keep your arms to your side." The knee and trunk angle chosen by each participant for each frequency of testing was quantified from video images using equipment described below. An analysis of sagittal plane knee and trunk angles indicated they were not different between groups ($P = 0.12–0.32$; Table 2).

Table 1
Physical characteristics (mean, SD, and ranges) of participants ($n = 21$).

Characteristic	Children	Adults
Age (year)	9.27 (2.54; 6–12)	25.9 (5.53; 18–39)
Gender	4 Male, 7 female	5 Male, 5 female
Height (m)	1.30 (0.26; 0.76–1.60)	1.77 (0.08; 1.63–1.91)
Body mass (kg)	32.7 (8.47; 19.1–42.2)	72.9 (9.95; 59.0–90.7)

Fig. 1. Vibration platform set-up and typical posture chosen by participants. Reflective markers highlight location of skeletal landmarks.

During pilot testing, we measured the actual motion characteristics of the i.Tonic vibration platform, which is designed to apply vertical vibration. The frequencies we observed were systematically greater from the three available nominal dial readings (i.e., 25 Hz, 30 Hz, and M) and corresponded to 28 Hz, 33 Hz, and 42 Hz in loaded and unloaded conditions. The vertical oscillation of the platform was constant between groups and was relatively sinusoidal in pattern. Peak to peak amplitudes in the low setting were different between frequencies. For example, at 28 Hz vertical motion = 0.97 (SD 0.12) mm, at 33 Hz vertical motion = 1.17 (SD 0.10) mm, and at 42 Hz vertical motion = 1.53 (SD 0.12) mm. Small oscillations of the platform in the non-vertical directions were observed (anterior ≈ 0.37 (SD 0.15) mm and lateral ≈ 0.18 (SD 0.06) mm) and may be related to flexible air cushion mounts that separate the platform from the frame.

In the present study, transmissibility of vibration for each subject at each frequency was assessed with a high speed motion analysis system (Vicon MX system, Vicon Motion Systems, Centennial, CO, USA). Seven T-20 cameras sampling at 500 Hz tracked low mass retro-reflective markers (mass = 2.2 g) placed on the vibration platform and on the skin over the following bony landmarks: Lateral malleolus (ankle), tibial tuberosity (knee), anterior superior iliac spine (hip), sternum, and anteromedial frontal bone (head; Fig. 1). Markers were placed bilaterally; results are reported as average of right and left side characteristics.

The Vicon motion analysis system was calibrated according to manufacturer guidelines and its accuracy for tracking markers was assessed using a 'spot checking' technique described by Della Croce and Cappozzo (2000). The errors from the spot checking

Table 2
Sagittal plane knee and trunk angles (mean, SD, and ranges) for children and adults.

Joint	Children	Adults
Knee angle (°)	25.0 (4.28; 17.5–32.0)	27.7 (3.13; 23.8–32.7)
Trunk angle (°)	19.5 (2.52; 14.7–25.5)	21.0 (5.61; 15.3–35.0)

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assessment in our lab were $z = 0.0001$ m, $y = 0.0003$ m, and $x = 0.0001$ m and are considered negligible (Della Croce and Cappozzo, 2000). To further validate our data, we mounted an accelerometer (Kistler Instrument Corp. Type 8702B25, Switzerland) to our vibration platform and computed the root-mean-square (RMS) accelerations for one participant. We then compared the RMS accelerometer data to our estimates from motion analyses for the same participant and observed minor differences between measurement techniques (accelerometer RMS = 2.20 G; motion analysis RMS = 2.21 G).

Three-dimensional position data from each reflective marker were computed from direct linear transformations using Vicon Nexus software and then exported to a Microsoft Excel spreadsheet for post analyses. Vertical oscillations for 20 cycles of data for each marker were recorded then filtered with a low-pass Butterworth filter (cutoff frequency = 100 Hz). It was obvious from the time-series curves that postural sway would influence amplitude measures so a de-trending algorithm was applied to remove sway from the high frequency vibration data. Accelerations were then computed from the filtered and de-trended position data using finite difference equations and expressed with a RMS. Transmissibility (*T*) for each body marker was calculated as:

$$T(f) = a_{marker}(f)/a_{plate}(f)$$

where a_{marker} is RMS acceleration of the marker, a_{plate} is the RMS acceleration of the vibration platform, and f is the frequency of vibration (Mansfield, 2005). Accordingly, greater transmission ratio values would indicate less vibration attenuation. This method of quantifying transmissibility was the most logical given the purpose of the study and the relatively sinusoidal waveform of the platform (Fig. 2; Paddan and Griffin, 1998).

Subjective comments regarding which setting a child "liked the most" or "preferred" (i.e., 28, 33, or 42 Hz) were collected immediately after the vibration protocol. The intention was to gain some appreciation regarding how children perceive vibration frequencies and to qualitatively assess if conditions of high transmissibility were linked to undesirable sensations.

2.3. Statistical analysis

Subjective comments regarding which frequency setting children liked the most (i.e., 28, 33, or 42 Hz) were summarized in a frequency histogram. Marker position data over time for each group (i.e., children and adults) were graphed to qualitatively evaluate the data. Accelerations of the vibration plate for each frequency were descriptively reported to appreciate the input for each transmission ratio.

We chose to analyze differences between conditions with non-parametric tests given the high variability expected with transmissibility (Paddan and Griffin, 1998). Transmissibility between groups (children and adults) was assessed with the Mann–Whitney test, and differences between markers (ankle, knee, hip, sternum, and head) and frequencies (28, 33, and 42 Hz) were assessed with Friedman's ANOVA. When appropriate, post-hoc comparisons were made with Wilcoxon signed rank tests with an alpha set at 0.05 for all comparisons. Effect sizes (ES) were also quantified to appreciate the meaningfulness of any statistical differences. The ES were calculated with the following formula: ES = (high value − low value)/(standard deviation of high value).

3. Results

None of the vibration settings were more preferred than another. That is, children preferred the 28, 33, and 42 Hz settings equally. Regarding the marker position data, waveforms were relatively sinusoidal and amplitudes ranged between 0.2 and 2.3 mm (Fig. 2). Vibration plate, ankle, knee, hip, sternum, and head accelerations (RMS) generally increased with frequency and displayed magnitudes that ranged between 0.25 (sternum) and 7.3 G (ankle; Fig. 3).

Between group comparisons indicated that transmission ratios for children at 30 Hz were 42% and 62% greater than adults for the ankle and hip, respectively ($P = 0.03$; ES = 0.84–1.29; Fig. 4). No other between group differences were observed ($P = 0.07$–0.92; Fig. 4). The Friedman's ANOVA revealed that, regardless of group, frequency and marker location were factors influencing transmissibility ($\chi^2 = 8.0$–60.0; $P = 0.001$–0.04). Accordingly, post-hoc analyses were computed on the collapsed group data and showed that transmissibility was greater in the ankle and knee at 33 Hz ($P = 0.003$–0.004; ES = 0.73–0.82) and lower in the hip, sternum, and head at 42 Hz ($P = 0.001$–0.01; ES = 0.50–1.30).

All five marker location values were significantly different from one another ($P = 0.001$–0.004; ES = 4.75–19.1). That is, transmissibility to the ankle was just over 2.0 (or 200%) but decreased by

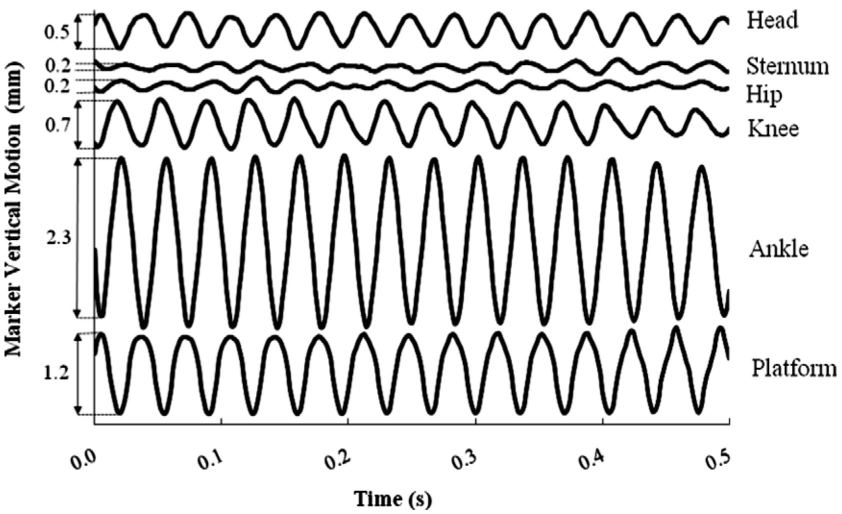

Fig. 2. Representative marker position data for the vibration platform, ankle, knee, hip, sternum, and head during 25 Hz vibration. Data for each waveform are unfiltered and display reasonably well maintained sinusoidal waveforms. It should be noted that the resolution for the combined waveforms masks some of the additional signal components that may otherwise be visible in a single waveform figure.

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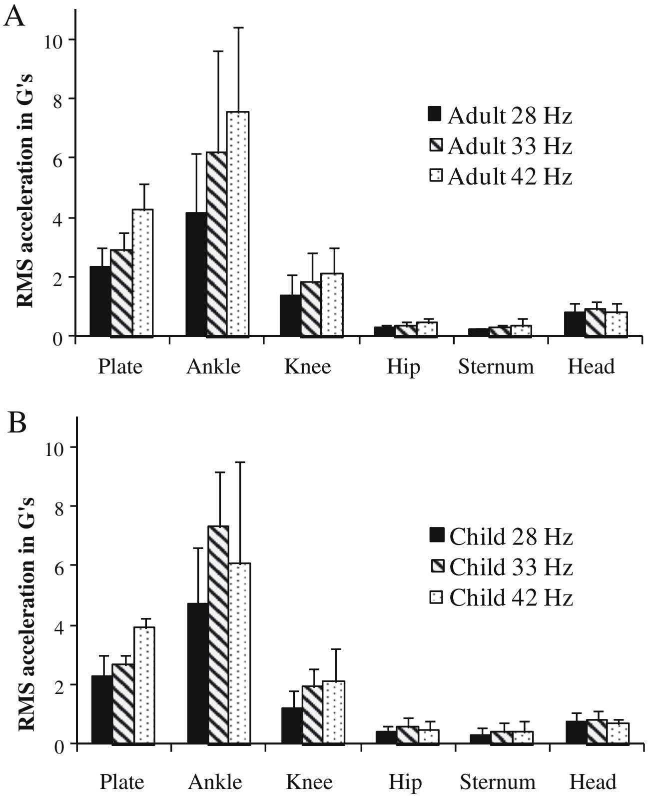

Fig. 3. Vibration platform, ankle, knee, hip, sternum, and head accelerations (RMS; G's) for adults (A) and children (B) at each frequency tested (28, 33, and 42 Hz). Accelerations generally increased with frequency of vibration with the ankle displaying the greatest values in both groups.

95% from the ankle to the sternum and increased slightly from the sternum to head (Fig. 4). The values at the head, however, remained 86% and 50% lower than values at the ankle and knee, respectively.

4. Discussion

The purpose of this study was to determine if children transmit vibration differently than adults while standing on a vibration platform. The results revealed that transmissibility was not markedly different between groups. In fact, the only statistical differences were the transmissibility to the ankle and hip which were greater in children when the vibration platform was set at 33 Hz. More importantly, it was observed that transmissibility to the head was not different between groups.

The transmission values in this study were consistent with those reported previously (3.0–0.01; Harazin and Grzesik, 1998; Kiiski et al., 2008) and displayed some variation according to vibration frequency and marker location (Fig. 4). Both groups displayed ankle transmission ratios that were greater than 2.0 but quickly dropped below 0.56 at the knee, hip, sternum, and head. The elevated transmission values of the ankle may be related to the decoupling of the foot with the vibration platform, which accelerated the less massive segment. Additionally, the majority of the body's natural shock absorbers (foot, meniscus, intervertebral disc, muscle, and bone; Voloshin and Wosk, 1982) are superior to the ankle, which reduces its capacity to attenuate vibration. It may also be expected that the natural shock absorbers would take time to strain, so that as vibration propagates from the ankle to head, transmissibility would decrease and a phase lag would occur as evidenced in Fig. 2.

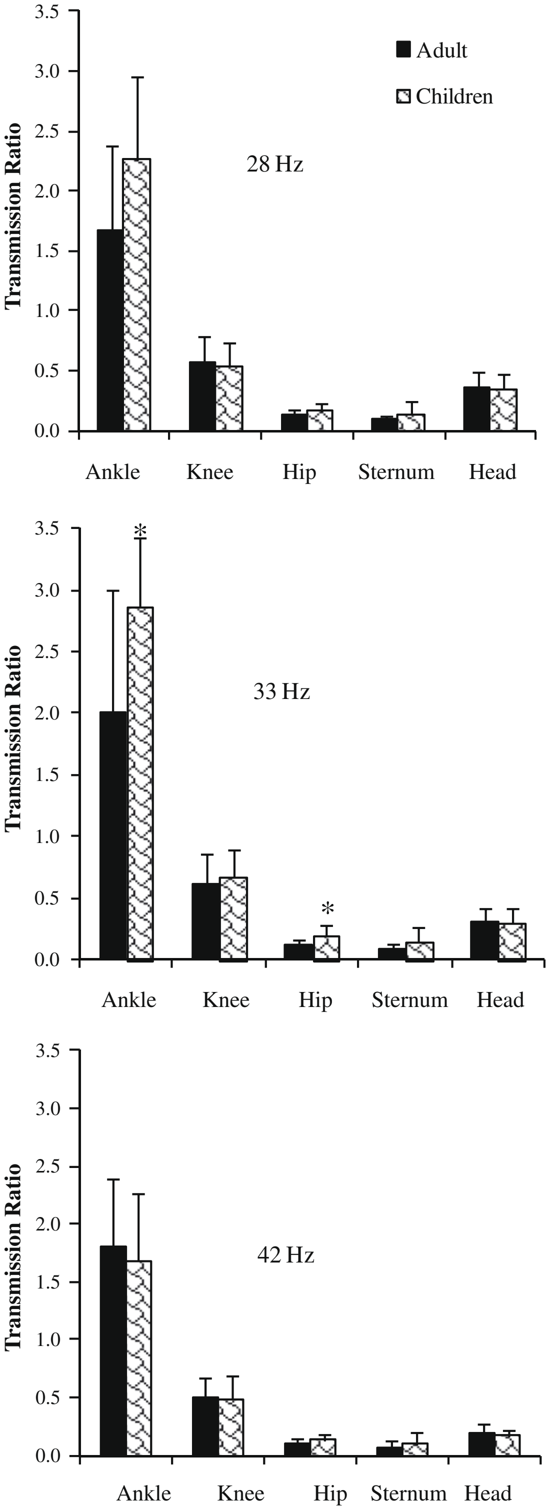

Fig. 4. Mean (SD) vertical transmissibility of low amplitude (0.97–1.53 mm) platform vibrations at 28, 33, and 42 Hz. Transmissibility to the ankle, knee, hip, sternum, and head were similar between children and adults vibrating at 28 Hz and 42 Hz. Transmissibility was greater in the ankle and hip in children with vibration at 33 Hz. Asterisk (∗) indicates values were significantly different from adults ($P = 0.03$).

Unique to our study was that we observed greater transmission values at the ankle and hip in children than adults but only at the 33 Hz setting. These values also tended to be greater at the 28 Hz setting ($P = 0.07$) but not the 42 Hz setting ($P = 0.92$; Fig. 4). It is possible that the children were more easily put out of phase at the higher frequency which prevented resonance or amplification of the acceleration at 42 Hz. The identification of resonance is important for determining vibration safety (Griffin, 1996; Rubin et al., 2003). Resonance is the tendency of a system to oscillate at its maximum amplitude, and is associated with specific frequencies so that even small amplitude input vibrations can produce large or dangerous output amplitudes.

Previous researchers have observed distinct resonance at various skeletal landmarks during standing whole body vibration but they were below 20 Hz (Griffin, 1996; Rubin et al., 2003). The lowest frequency tested in the present study was 28 Hz and the maximum difference between frequencies was 14 Hz. Accordingly, distinct resonances were not observed but amplification of acceleration was present in the ankle and knee at 33 Hz and a decay of transmission to the hip, sternum, and head was observed at 42 Hz (Fig. 4).

The clinical implications of this study are that vibration accelerations transmitted to the head are similar between adults and children. This observation does not suggest that whole body vibration therapy is safe for children but that high accelerations produced at the plate (Fig. 3) are not directly transmitted to the head. In fact, less than 28% of the plate acceleration in children and adults was transferred to the head in the present study. This finding is particularly remarkable considering children had 55% less tissue mass to dampen the vibration accelerations. The observation may also be concerning since children use an immature neuromusculoskeletal system to absorb the mechanical energy. The biomechanical strategy used by children to attenuate the vibration was not tested in this study but may have relied more on muscle tuning strategies (Wakeling and Nigg, 2001) and less on joint position strategies (Rubin et al., 2003) as the latter were not different between groups (Table 2).

An important question that remains is how safe is vibration therapy for children? Indeed, the present study, at most, gives clues and the ultimate answer is unknown because of a plethora of biological (e.g., mass, gender, age, and mental preparedness) and mechanical (e.g., joint position and muscle activity level) factors that affect transmission and absorption of vibration loads (Griffin, 1996). Vibration safety standards have been provided for occupational whole body vibration exposure, (Standardisation, 1997) but even these guidelines are not applicable to children (Giacomin, 2004). One challenge in applying the standards to children is that the biological response of children to standing whole body vibration is unknown.

Researchers have identified a number of biological differences between adults and children that are relevant to understanding the safety of vibration therapy in children. For instance, children are different from adults in that their bones (e.g., tibia) contain a greater concentration of collagen and have the ability to strain more before failure (Ding et al., 1997). This mechanical feature may lead to greater vibration absorption (Cardinale and Wakeling, 2005), but the growing skeletal system is also vulnerable to injury because of weak epiphyseal plates (Shanmugam and Maffulli, 2008). Research on non-accidental head injuries (e.g., shaken baby syndrome) indicates that children as old as 15 years are biomechanically more susceptible to some head injuries because of weak neck muscles and immature connective tissues in the brain (Bandak, 2005; Lancon et al., 1998). Researchers have estimated that non-accidental head injuries (e.g., retinal hemorrhage) may occur with head accelerations equal to 7–15 G (Bandak, 2005; Rangarajan and Shams, 2006). Their estimates far exceed those observed in the present study (<1 G; Fig. 3) and those reported previously (Paddan and Griffin, 1998), but the persistent application of even lesser accelerations to the head may be damaging (Griffin, 1996). These anatomical and mechanical comparisons highlight the complexity in determining if whole body vibration is safe in children. Future clinical research with children and studies that examine biological responses of children to vibration therapy may help determine what a safe or unsafe vibration therapy exposure is.

Generally speaking, the children in the present study were excited to participate and thought it was fun to stand on the vibrating platform. Most of the children reported that they liked the stimuli and felt no discomfort or vision problems. Their perceptions of which setting they liked the most were inconclusive and suggest that neither setting was more likable. Curiously, the human body has been described as sensitive at detecting noxious stimuli (Edwards and Fillingim, 2001) and seems capable of perceiving movements that are potentially dangerous (Shrier et al., 2009). Hence, it is possible that children in the present study were not able to detect any noxious or hazardous stimuli or alternatively that the vibratory stimuli were not noxious or hazardous. Indeed, their perceptions may have changed if lower frequencies, higher amplitudes, greater durations of exposure, and straight knees were applied.

A limitation of the present study was that skin-mounted markers were used to track skeletal landmark accelerations. The low mass markers used presumably have some of the same limitations as low mass skin-mounted accelerometers which are frequently used in vibration studies (Harazin and Grzesik, 1998; Kiiski et al., 2008). That is, soft tissues distort and overestimate peak accelerations (Lafortune et al., 1995). Acceleration of Steinmann pins mounted directly to bone are more accurate (Lafortune et al., 1995) but the invasiveness of this technique was not ethically responsible for the children used in the present study. We examined the marker position data for clues as to how much soft tissue distortions were present and observed well maintained sinusoidal waveforms (Fig. 2). Additionally, because skin-mounted markers were used on both groups (i.e., children and adults), it is unlikely that transmission comparisons between groups were affected.

It may be concluded that transmissibility during standing vibration is similar between children and adults at 28 Hz and 42 Hz. In fact, the only statistical differences were the transmissibility to the ankle and hip which were greater in children when the vibration platform was set at 33 Hz. More importantly, less than 28% of the vibration was transmitted to the head and this value was not different between groups.

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