Dose-Response:
An International Journal
January-March 2019:1-7
© The Author(s) 2019
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1559325819827467
journals.sagepub.com/home/dos
SAGE

Transmission of Acceleration From a Synchronous Vibration Exercise Platform to the Head During Dynamic Squats

Robert C. Caryn[1] and James P. Dickey[1]

Abstract

Many research studies have evaluated the effects of whole-body vibration exercise on muscular strength, standing balance, and bone density, but relatively few reports have evaluated safety issues for vibration exercises. Knee flexion reduces acceleration transmission to the head during static exercise. However, few studies have evaluated dynamic exercises. The purpose of this investigation was to evaluate the transmission of acceleration to the head during dynamic squats. Twelve participants performed dynamic squats (0°-40° of knee flexion) on a synchronous vertical whole-body vibration platform. Platform frequencies from 20 to 50 Hz were tested at a peak-to-peak nominal displacement setting of 1 mm. Transmissibilities from the platform to head varied depending on platform frequency and knee flexion angle. We observed amplification during 20 and 25 Hz platform vibration when knee flexion was <20°. Vibration from exercise platforms can be amplified as it is transmitted through the body to the head during dynamic squats. Similarly, this vibration energy contributes to observed injuries such as retinal detachment. It is recommended that knee flexion angles of at least 20° and vibration frequencies above 30 Hz are used when performing dynamic squat exercises with whole-body vibration.

Keywords

whole-body vibration exercise, exercise training, knee flexion, vibration, frequency, transmissibility

Introduction

Whole-body vibration exercise (WBVE) has become a popular modality and is found in homes, public gyms, and in the offices of various health-care professionals. WBVE can lead to improvements in strength,[1] improved bone mineral density in animal models,[2] articular cartilage in human subjects,[3] and decreased risk of falls in the elderly.[4,5] While these studies report benefits of WBVE, others have reported mixed results depending on the performance indicator.[6-8]

Several studies have investigated the safety of WBVE and the response of the body to mechanical vibration.[9-12] Occupational research has identified that prolonged exposure to whole-body vibration has deleterious effects on the musculoskeletal system.[13,14] In particular, resonance, where the vibration is amplified, may increase the risk of injury from mechanical vibration. The head resonates at vibration frequencies below 30 Hz.[9,15] Excessive mechanical energy transferred to the head can cause retinal detachment, visual disruptions, and cognitive impairment.[16,17] Knee flexion angles (KFAs) greater than 20° can effectively dampen mechanical vibration reaching the hip[12] and head during static squat postures.[9] Similar attenuation of vibration reaching the hip has been reported for slow squats[12] but has not been evaluated for the transmission to the head.

WBVE platforms are often used for dynamic exercise.[1,5,7,18-23] However, some evidence indicates that WBVE using dynamic movements appear to lead to different biodynamic responses than static exercises,[12] and accordingly dynamic exercises warrant additional research. The goal of this research was to evaluate transmissibility to the head during dynamic squats at 7 discrete input frequencies between 20 and 50 Hz from a WBVE platform. In addition, the concentric and eccentric phases of the squat are evaluated to

---

[1] School of Kinesiology, Western University, London, Ontario, Canada

Received 18 August 2018; received revised 28 December 2018; accepted 08 January 2019

Corresponding Author:
James P. Dickey, School of Kinesiology, Western University, London, Ontario N6A 3K7, Canada.
Email: jdickey@uwo.ca

determine whether the musculature is limited in its capacity to attenuate vibration during these different types of contraction. This research may provide insight for safer prescription of WBVE.

Materials and Methods

Participants and Study Design

Twelve healthy male volunteers 26.3 years of age (SD 2.1), 178.0 cm height (SD 6.0), and 79.5 kg weight (SD 11.5) were recruited to participate in this study. This sample size was calculated using commercially available software[24] (G*power version 3.1.9.3), based on 80% power to detect a large effect size (0.8), with alpha = 0.05. Due to exclusion criteria, none of these participants had a history of head trauma, cardiovascular diseases, joint implants, or low back pain. The study was approved by the research ethics board of the University of Western Ontario and each participant provided informed consent by signing the approved consent form. Participants completed a preliminary session on the day prior to testing to familiarize them with the postures, the vibrating exercise platform, and the attachment protocol of the instrumentation. Participants were asked to report any extreme discomfort or unusual symptoms; if these occurred then the experiment would be stopped.

Participants were instructed not to partake in any physical activity in the hours leading up to the experiment as muscular fatigue could alter vibration transmissibility.[25]

All trials were performed on a commercial vibrating exercise platform (WAVE® Manufacturing Inc, Windsor, ON, Canada) that generated vertical vibration. Participants were exposed to vibration at selected frequencies, 20, 25, 30, 35, 40, 45, and 50 Hz, at a nominal 1 mm displacement amplitude. Pilot testing validated the frequency output of the platform to the nominal frequency setting by calculating the frequency from time domain data. Each trial lasted 30 s and a 2-minute rest period was provided between each experimental trial to minimize muscular fatigue. The sequence of the different vibration frequency trials was randomized using a random number generator with a pick without replacement scheme to ensure that confounding factors of learning effect and fatigue did not affect the experimental outcomes.

Dynamic Squat Exercise

To investigate the effects of dynamic lower extremity movement on vibration transmissibility, participants performed dynamic squats through a knee angle range of 0°-40°. This range was selected to reflect commonly used KFAs reported in WBVE,[9,26] although some studies have assessed deeper squats.[21] The squat was timed to have a 4-second concentric and 4-second eccentric contraction phase of the knee extensors. This controlled the angular velocity of the flexion and extension phases of each squat. Participants were provided with sport socks to wear during testing and performed the experiment unshod as variations in footwear have different dampening properties.[27] Participants were instructed to position their feet shoulder width apart and maintain equal weight distribution between both feet. Each participant's stance width was measured and marked off on the platform to ensure that they remained in the same position across all trials. There is some evidence that changes in stance width and feet position can affect transmissibility.[28] To ensure that their feet did not slip or move during testing, sand paper was secured to the surface of the platform using double-sided tape.

A video camera (HDR-XR550; Sony, Tokyo, Japan) was positioned 4-m away from the vibration platform to capture real-time sagittal plane images of the participant (Figure 1A), which were displayed on a monitor that was positioned in front of the vibration platform in the participant's field of view (Figure 1B). Participants were instructed to maintain an upright and erect upper body posture and keep their gaze on the video monitor during each experimental trial. A piece of acetate was taped over the screen and their upper body posture was drawn on with marker.

Knee angle data were displayed on a second video monitor, also made visible to the participant, to provide updated feedback about their degree of knee flexion (Figure 1B). This feedback provided the participant with the necessary timing of their dynamic squat. Trials were repeated if the participant had to grasp the machine to maintain balance, lost their footing noticeably from their original position, or if the participant did not perform a trial in the prescribed manner.

Instrumentation

A tri-axial piezoelectric accelerometer ($20 \times 26 \times 20$ mm^3, total mass = 20 g; Model# 356B08 PCB Piezotronics; Depew, New York) was magnetically attached to the center of the top surface of the platform to measure platform acceleration. Head accelerations were measured using a triaxial accelerometer ($15 \times 8 \times 15$ mm^3; total mass = 4 g; $+\ 2g$ peak acceleration; Model#7523A1; Dytran Instruments Inc., St. Chatsworth, California) attached to a head piece created from the liner of a safety helmet. The accelerometer was positioned atop the approximate center of the participant's frontal bone (forehead). The headpiece used a ratcheting mechanism to tighten the headpiece around the head. The strap and accelerometer had a combined mass of 98 g. This method has lower intra-subject variability over the bite bar method.[29] An electrogoniometer (Model#SG150 Biometrics; Penny and Giles Inc, Santa Monica, California) was taped to the lateral aspect of the right knee of all participants to monitor knee angle. During pilot testing, the electrogoniometer was calibrated against a manual plastic full circle goniometer with 18 cm arms and 1° measurement increments; the largest error across various joint angles was 5°. This measurement setup was also used in a previous publication investigating transmissibility during static squat WBVE.[9]

Data Acquisition and Processing

The two accelerometers and goniometer were assembled using a BNC connector (Model BNC-2111; National Instruments;

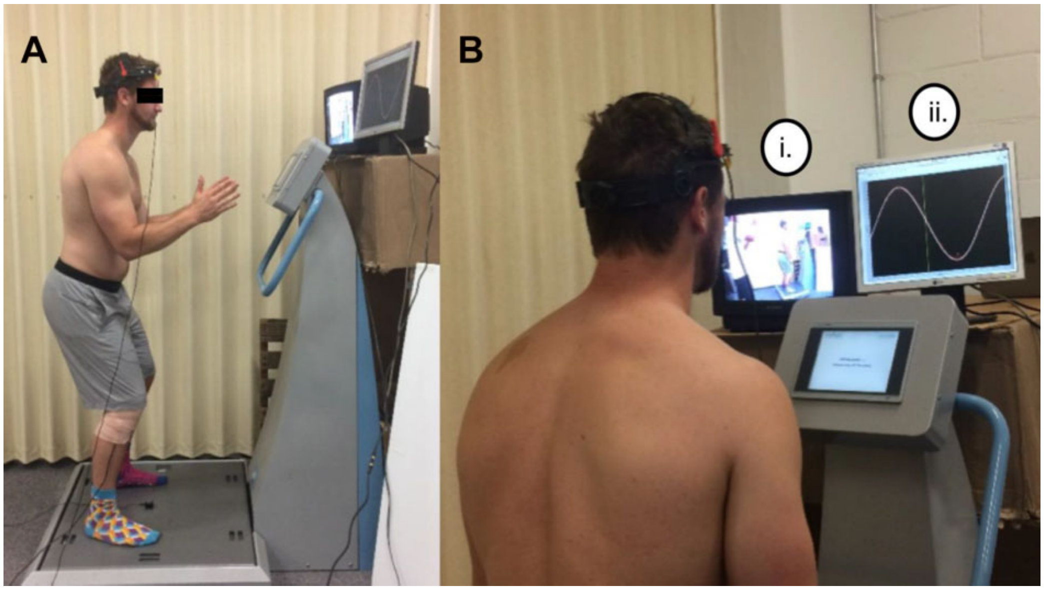

Figure 1. A, Sagittal plane view of a participant standing on the synchronous vertical whole-body vibration platform. B, Illustration of the postural feedback presented to the participant during testing. Video monitor (i) presents whole-body posture to the participant, while the computer monitor (ii) provides knee angle feedback from the electro-goniometer.

Austin, Texas) and sampled at 2000 Hz using a 16-bit analog-to-digital converter (Model PCI-6221; National Instruments). The raw acceleration data were smoothed using a second-order low-pass Butterworth filter with a cutoff frequency of 120 Hz and the DC offset was removed. Raw knee angle data were smoothed using a second-order low-pass Butterworth filter with a cutoff frequency of 20 Hz. Resultant accelerations were calculated using the root sum square of the X, Y, and Z components. This method was picked to represent the sum of total energy generated at the platform and all measurement locations on the body. The running root-mean-square (rms) value of the signal was calculated using a 500-ms moving window. The amount of energy contained in the vibration is related to the average acceleration, thus rms is most commonly used for quantifying the severity of human vibration exposure.[30] Running rms values at the input (platform surface) and output (head) were used to calculate "instantaneous" transmissibility ratios (Equation 1).[31]

$$Transmissibility = \frac{Running\ rms\ OUTPUT\ (head)}{Running\ rms\ INPUT\ (platform)}. \qquad (1)$$

One dynamic squat maneuver was extracted for each trial and was subsequently separated into the concentric and eccentric components. The transmissibility data for each of these components were binned into 4 knee joint flexion angle categories: 0° to 10°, 10° to 20°, 20° to 30° and 30° to 40°. The average transmissibility in each of these knee flexion categories was calculated for each participant. All data acquisition and signal processing were performed using a custom written program in LabVIEW (LabVIEW 2012; National Instruments; Austin, Texas).

Statistical Analyses

Statistical analyses were performed using commercial software (SPSS 25; IBM Corp., Armonk, New York). A repeated measures (RM) 3-way ANOVA was used to investigate the interaction of squat exercise phase, vibration frequency, and KFA on platform-to-head transmissibility. Mauchly's sphericity test was performed, and Greenhouse-Geisser corrections were performed if the assumption of sphericity was violated. Significant interactions were followed up with 2-way and 1-way RM ANOVAs, and post hoc tests with Bonferroni adjustments for multiple comparisons, as appropriate. $P < .05$ was considered significant for all tests.

Results

The platform-to-head transmissibility changed continuously with KFA as the participants performed the dynamic squat exercise (Figure 2). The vibration was amplified (transmissibility > 1.0) with vibration frequencies of 20 and 25 Hz, for shallow KFAs (<20° at 20 Hz, and <10° at 25 Hz; Figure 3). Intersubject variability was larger at low vibration frequencies and small KFAs (Figure 3).

The assumption of sphericity was not met for the vibration frequency, KFA, and squat phase × KFA interaction ($P < .0005$, $P = .001$, $P = .008$, respectively). Results of the 3-way ANOVA indicated that the 3-way interaction (squat phase × vibration frequency × KFA interaction) was not statistically significant ($P = .177$). The KFA × vibration frequency 2-way interaction was statistically significant ($P < .0005$). The other 2-way interactions were not statistically significant ($P = .897$ and $P = .262$, for the squat phase × KFA

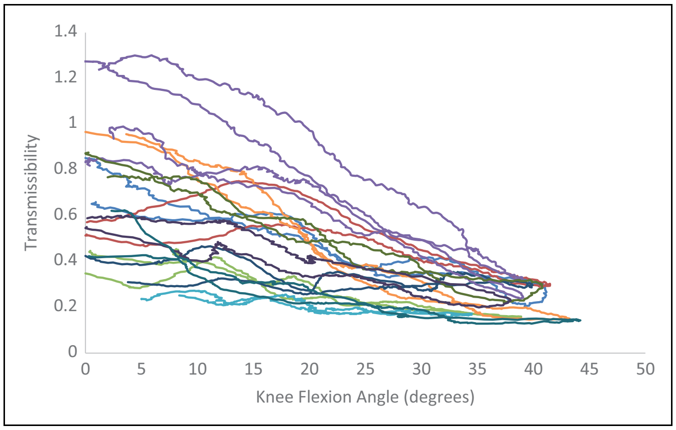

Figure 2. Platform to head transmissibility during dynamic squats at 30 Hz. The different lines represent the concentric and eccentric squat phases for the individual participants.

and squat phase × vibration frequency interactions, respectively). The main effect of squat phase was significant ($P = .025$) with the transmissibility being larger during the concentric phase (average transmissibility = 0.484) than the eccentric phase (average transmissibility = 0.469).

One-way RMs ANOVAs were performed to evaluate transmissibility differences between the 7 vibration frequencies, for each of the KFA ranges, and for the different squat phases. These tests revealed consistent patterns for all of the KFA ranges and squat phases: the transmissibilities were not significantly different between 20 and 25 Hz vibration frequencies, and the transmissibilities were not significantly different between the higher vibration frequencies (e.g., 30-50 Hz for KFA 0°-10° for the concentric phase, and KFA 30°-40° for both the concentric and eccentric phases, and 40-50 Hz for KFA 0°-10° for the eccentric phase).

Discussion

This study measured the transmissibility from a commercially available WBVE platform to the head during controlled dynamic squats across a range of vibration frequencies. We observed that the vibration to the head was amplified (transmissibility > 1.0) for shallow KFAs at vibration frequencies of 20 and 25 Hz and that the vibration amplitudes were attenuated for larger knee angles (>30°). We observed that the head vibrations were attenuated for vibration frequencies between 30 and 50 Hz for all KFAs. Abercromby et al[10] measured head acceleration across varying degrees of knee flexion at 1 vibration condition (30 Hz and 4 mm p-p). They found a linear decrease in rms head acceleration with increasing KFAs from 10° to 30°. Above 30° of knee flexion, they found that the ability of the legs to reduce head acceleration decreased. Our results found a similar reduction in head transmissibility as knee angle increased; however, the reduction was nonlinear for lower frequency vibrations, and we did not see an increase in transmissibility above 30° of knee flexion. Some participants did show peaks in transmissibility as they went through a certain range of knee flexion; however, this was not consistent across all participants. The difference in transmissibility between the eccentric and concentric phases was statistically significant, but small (3.28%) and not considered important relative to the influence of KFA and vibration frequency. Accordingly, the results of the study illustrate that both the eccentric and concentric phases have similar transmissibility across knee angle ranges between 0° and 40°. There is no reason to advocate an individual to use more of the concentric phase versus an eccentric squat during WBVE.

At lower input frequencies (20-30 Hz), smaller KFAs resulted in amplification of mechanical energy at the head. Our findings with dynamic squat exercise are similar to those for static KFAs.[9,32] We found resonance of the head at these knee angles during 20 and 25 Hz platform vibration. Approximately 20° of knee flexion appears to reduce the stiffness of the body and cause a reduction in vibration transmission through the body to the head. Vertical head transmissibility displays multiple peaks between 0.25 and 25 Hz.[15,28] Previous literature has reported that the eyeball resonates around 20 Hz, and disruptions to visual perception have been reported between 20 and 25 Hz.[17] A case report found that individuals with intraocular prostheses can have had spontaneous dislocation after WBVE.[16] This indicates that energy reaching the head during WBVE can be injurious and have detrimental impacts to vision. Platform users should be advised to maintain at least 20° of knee flexion during static and dynamic squats.

Platform to head transmissibility depends strongly on the KFA. Accordingly, it is important that research using WBVE should control KFA during static and dynamic squats and should report the ranges of knee flexion. While some investigations report KFAs,[5,18-20] unfortunately many do not report these details.[1,4,7,21,22,33-36] Our findings show that the platform vibrations can be attenuated or amplified as they are transmitted through the skeleton, and the KFA is an important parameter that should be controlled and reported.

At frequencies of 40 Hz and higher, acceleration values at the head remained below 50% that of the platform across all KFAs. Frequencies above 30 Hz may be the safest for WBVE as at these frequencies the vibration is localized primarily to the lower extremity.[11] These frequencies, used in previous training studies, lead to documented changes in muscle activation[20] and muscular strength[5,6,21] but may not be anabolic to the skeletal system.[8,37]

We observed greater intersubject variability at low frequencies (20-25 Hz) and smaller knee angles (<20°). These findings are likely related to differences in the segment resonant frequencies between individuals,[28] differences in shock-absorbing capacity between individuals,[38] as well as the large influence of differences in posture.[15]

This investigation was limited to evaluating dynamic squats during WBVE. This work complements our previous reports of static squat exercises;[9] we have previously reported measures of vibration transmissibility to the head during static squat exercises at KFAs of 0°, 20°, and 40°, using 7 platform vibration frequencies between 20 and 50 Hz, and at two peak-to-peak displacement settings (1 and 2 mm nominal). While other studies have measured vibration transmission to other parts of

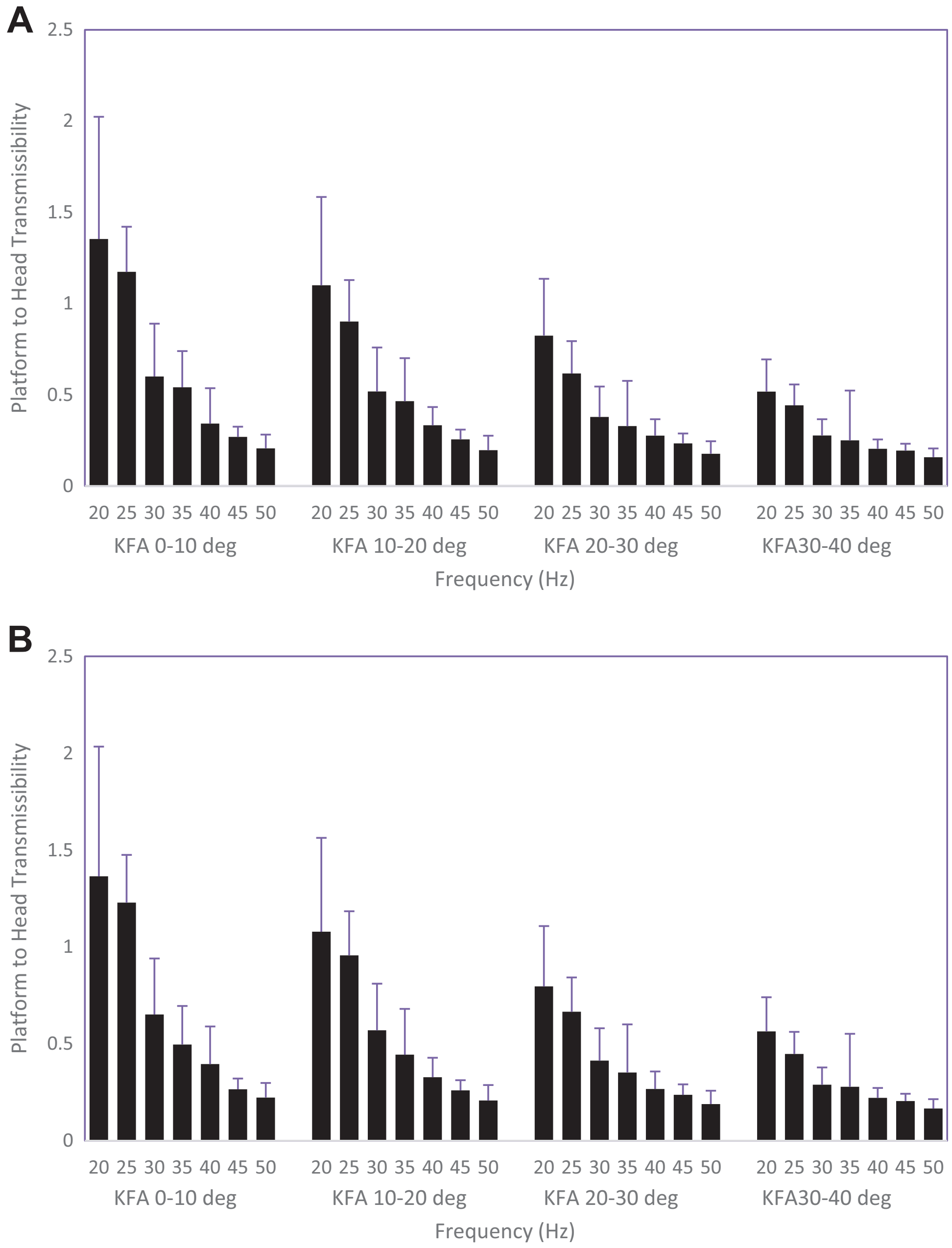

Figure 3. Mean (SD) platform-to-head transmissibility as a function of specific ranges of knee flexion angle (KFA): 0° to 10°, 10° to 20°, 20° to 30° and 30° to 40°—at each vibration frequency tested during eccentric (A) and concentric (B) squat phase. A transmissibility value of 1.0 indicates that the amplitude of the vibration is equal at the head and the platform surface.

the skeleton, such as the hip and spine,[39] and the ankle, knee, hip, and spine,[11] we have focused on transmission to the head. We observed that mechanical vibration can be amplified as it is transmitted through the skeleton and that knee flexion is an important factor for limiting the amount of vibration energy reaching the head. We have not evaluated exercises involving vibration passed to the body while sitting on the platform (eg, abdominal crunches or sit-ups),[6] sitting off the platform with feet on the platform,[40,41] placing hands on the vibration platform (eg, planks or push-ups),[5,6,42-44] or performing bicep curls and tricep extensions holding nylon straps attached to the vibration platform.[45] We advocate caution as these postures may result in excessive vibration energy reaching the head as the vibration is transmitted to the upper body, bypassing the knees and the vibration attenuation that knee flexion provides.

Conclusions

This study found that the response to dynamic exercise is similar to static postures: transmission of vibration to the head is reduced with KFAs greater than 20°. This finding is consistent with previous research that larger knee angles should be advocated when using WBVE platforms,[11] especially at frequencies below 30 Hz where resonance of the head is likely. There do not appear to be large difference in transmissibility between the eccentric and concentric phases of the squat. Our results add further evidence that the head has a natural frequency between 20 and 30 Hz, and this frequency value may vary between individuals and the posture adopted. Since excessive vibration energy may have a detrimental effect on the visual,[16,17] auditory,[46] and vestibular systems,[47] these frequencies should be avoided.

Acknowledgments

The authors acknowledge the commitment of the research participants, and WAVE Manufacturing Inc. for loaning the vibration platform used in this study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was funded by a discovery grant from the Natural Sciences and Engineering Research Council of Canada [RGPIN-2016-05187], and scientific instrumentation was funded by an infrastructure grant from the Canadian Foundation for Innovation [CFI number 23521]. Robert Caryn was supported by a scholarship at Western University.

ORCID iD

James P. Dickey https://orcid.org/0000-0002-4101-835X

References

1. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc*. 2003;35(6):1033-1041.
2. Rubin C, Turner AS, Muller R, et al. Quantity and quality of trabecular bone in the femur are enhanced by a strongly anabolic, noninvasive mechanical intervention. *J Bone Miner Res*. 2002; 17(2):349-357.
3. Liphardt AM, Mundermann A, Koo S, et al. Vibration training intervention to maintain cartilage thickness and serum concentrations of cartilage oligometric matrix protein (COMP) during immobilization. *Osteoarthritis Cartilage*. 2009;17(12): 1598-1603.
4. Bruyere O, Wuidart MA, Di Palma E, et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil*. 2005;86(2):303-307.
5. Goudarzian M, Ghavi S, Shariat A, Shirvani H, Rahimi M. Effects of whole body vibration training and mental training on mobility, neuromuscular performance, and muscle strength in older men. *J Exerc Rehabil*. 2017;13(5):573-580.
6. Maeda N, Urabe Y, Sasadai J, Miyamoto A, Murakami M, Kato J. Effect of whole-body-vibration training on trunk-muscle strength and physical performance in healthy adults: preliminary results of a randomized controlled trial. *J Sport Rehabil*. 2016;25(4): 357-363.
7. Torvinen S, Kannus P, Sievanen H, et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res*. 2003;18(5):876-884.
8. Kiel DP, Hannan MT, Barton BA, et al. Low-magnitude mechanical stimulation to improve bone density in persons of advanced age: a randomized, placebo-controlled trial. *J Bone Miner Res*. 2015;30(7):1319-1328.
9. Caryn RC, Hazell TJ, Dickey JP. Transmission of acceleration from a synchronous vibration exercise platform to the head. *Int J Sports Med*. 2014;35(4):330-338.
10. Abercromby AF, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Vibration exposure and biodynamic responses during whole-body vibration training. *Med Sci Sports Exerc*. 2007;39(10):1794-1800.
11. Kiiski J, Heinonen A, Jarvinen TL, Kannus P, Sievanen H. Transmission of vertical whole body vibration to the human body. *J Bone Miner Res*. 2008;23(8):1318-1325.
12. Munera M, Bertucci W, Duc S, Chiementin X. Transmission of whole body vibration to the lower body in static and dynamic half-squat exercises. *Sports Biomech*. 2016;15(4):409-428.
13. Wilder DG, Woodworth BB, Frymoyer JW, Pope MH. Vibration and the human spine. *Spine*. 1982;7(3):243-254.
14. Griffin MJ. *Handbook of Human Vibration*. London, England: Academic Press; 1990.
15. Paddan G, Griffin M. The transmission of translational floor vibration to the heads of standing subjects. *J Sound Vib*. 1993; 160(3):503-521.
16. Vela JI, Andreu D, Diaz-Cascajosa J, Buil JA. Intraocular lens dislocation after whole-body vibration. *J Cataract Refract Surg*. 2010;36(10):1790-1791.
17. Ishitake T, Ando H, Miyazaki Y, Matoba F. Changes of visual performance induced by exposure to whole-body vibration. *Kurume Med J*. 1998;45(1):59-62.
18. Liao LR, Pang MYC. Effect of whole-body vibration on neuromuscular activation of leg muscles during dynamic exercises in individuals with stroke. *J Strength Cond Res*. 2017;31(7): 1954-1962.
19. Di Iorio F, Cesarelli M, Bifulco P, Fratini A, Roveda E, Ruffo M. The effect of whole body vibration on oxygen uptake and electromyographic signal of the rectus femoris muscle during static and dynamic squat. *J Exerc Physiol Online*. 2012;15(5):18-32.
20. Hazell TJ, Kenno KA, Jakobi JM. Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. *J Strength Cond Res*. 2010;24(7):1860-1865.
21. Rosenberger A, Beijer A, Johannes B, et al. Changes in muscle cross-sectional area, muscle force, and jump performance during 6 weeks of progressive whole-body vibration combined with progressive, high intensity resistance training. *J Musculoskelet Neuronal Interact*. 2017;17(2):38-49.
22. Von Stengel S, Kemmler W, Bebenek M, Engelke K, Kalender WA. Effects of whole-body vibration training on different devices

on bone mineral density. *Med Sci Sports Exerc*. 2011;43(6): 1071-1079.

23. Marin PJ, Garcia Rioja J, Bernardo-Filho M, Hazell TJ. Effects of different magnitudes of whole-body vibration on dynamic squatting performance. *J Strength Cond Res*. 2015;29(10):2881-2887.
24. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175-191.
25. Mercer JA, Bates BT, Dufek JS, Hreljac A. Characteristics of shock attenuation during fatigued running. *J Sports Sci*. 2003; 21(11):911-919.
26. Abercromby AF, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc*. 2007;39(9):1642-1650.
27. Light LH, McLellan GE, Klenerman L. Skeletal transients on heel strike in normal walking with different footwear. *J Biomech*. 1980;13(6):477-480.
28. Harazin B, Grzesik J. The transmission of vertical whole-body vibration to the body segments of standing subjects. *J Sound Vib*. 1998;215(4):775-787.
29. Wang W, Rakheja S, Boileau PE. Effect of back support condition on seat to head transmissibilities of seated occupants under vertical vibration. *J Low Freq Noise V A*. 2006;25(4):239-259.
30. ISO 2631 -1. *Mechanical Vibration and Shock - Evaluation of Human Exposure to Whole-Body Vibration - Part 1: General Requirements*. Geneva, Switzerland: International Standards Organization; 1997.
31. International Organization for Standardization. *ISO 10326-2: Mechanical Vibration - Laboratory Method for Evaluating Vehicle Seat Vibration - Part 2: Application to Railway Vehicles*. Geneva, Switzerland: International Standards Organization; 2001.
32. Lam FMH, Tang CY, Kwok TCY, Pang MYC. Transmissibility and waveform purity of whole-body vibrations in older adults. *Clin Biomech*. 2017;51:82-90.
33. Roschel H, Barroso R, Tricoli V, et al. Effects of strength training associated with whole-body vibration training on running economy and vertical stiffness. *J Strength Cond Res*. 2015;29(8): 2215-2220.
34. Vry J, Schubert IJ, Semler O, Haug V, Schonau E, Kirschner J. Whole-body vibration training in children with Duchenne muscular dystrophy and spinal muscular atrophy. *Eur J Paediatr Neurol*. 2014;18(2):140-149.
35. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res*. 2004;19(3):352-359.
36. Kaeding TS, Karch A, Schwarz R, et al. Whole-body vibration training as a workplace-based sports activity for employees with chronic low-back pain. *Scand J Med Sci Sports*. 2017;27(12): 2027-2039.
37. Wysocki A, Butler M, Shamliyan T, Kane RL. Whole-body vibration therapy for osteoporosis: state of the science. *Ann Intern Med*. 2011;155(10):680-686, W206-W613.
38. Voloshin A, Wosk J, Brull M. Force wave transmission through the human locomotor system. *J Biomech Eng*. 1981;103(1):48-50.
39. Rubin C, Pope M, Fritton JC, Magnusson M, Hansson T, McLeod K. Transmissibility of 15-hertz to 35-hertz vibrations to the human hip and lumbar spine: determining the physiologic feasibility of delivering low-level anabolic mechanical stimuli to skeletal regions at greatest risk of fracture because of osteoporosis. *Spine*. 2003;28(23):2621-2627.
40. Menendez H, Ferrero C, Martin-Hernandez J, Figueroa A, Marin PJ, Herrero AJ. Chronic effects of simultaneous electromyostimulation and vibration on leg blood flow in spinal cord injury. *Spinal Cord*. 2016;54(12):1169-1175.
41. Sa-Caputo DC, Paineiras-Domingos LL, Oliveira R, et al. Acute Effects of Whole-Body Vibration on the Pain Level, Flexibility, and Cardiovascular Responses in Individuals With Metabolic Syndrome. *Dose Response*. 2018;16(4):1559325818802139.
42. Hand J, Verscheure S, Osternig L. A comparison of whole-body vibration and resistance training on total work in the rotator cuff. *J Athl Train*. 2009;44(5):469-474.
43. Wunderer K, Schabrun SM, Chipchase LS. Effects of whole body vibration on strength and functional mobility in multiple sclerosis. *Physiother Theory Pract*. 2010;26(6):374-384.
44. Morel DS, Marin PJ, Moreira-Marconi E, Dionello CF, Bernardo-Filho M. Can whole-body vibration exercises in different positions change muscular activity of upper limbs? A randomized trial. *Dose Response*. 2018;16(4):1559325818804361.
45. Carr KM, Lachance CC, Kenno K, McNevin N, Horton S, Weir PL. Whole-body vibration training in older adults: retention of the strengthening effects. *Crit Rev Phys Rehab Med*. 2012;24(1-2): 51-67.
46. Seidel H, Harazin B, Pavlas K, et al. Isolated and combined effects of prolonged exposures to noise and whole-body vibration on hearing, vision and strain. *Int Arch Occup Environ Health*. 1988;61(1-2):95-106.
47. Bochnia M, Morgenroth K, Dziewiszek W, Kassner J. Experimental vibratory damage of the inner ear. *Eur Arch Otorhinolaryngol*. 2005;262(4):307-313.