Clinical Biomechanics 51 (2018) 82–90

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Transmissibility and waveform purity of whole-body vibrations in older adults

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ARTICLE INFO

Keywords:
Aging
Therapeutic
Osteoporosis
Exercise
Skeletal muscle

ABSTRACT

Background: This study examined the transmission power and waveform purity of vertical (synchronous) whole-body vibrations upon its propagation in the human body among older adults.

Methods: Forty community-dwelling older adults participated in the study (33 women; mean age: 60.3 (SD 5.7) years). Four vibration frequencies (25, 30, 35, 40 Hz), two amplitudes (0.6 and 0.9 mm), and six different postures were tested. Skin-mounted tri-axial accelerometers were placed at the medial malleolus, tibial tuberosity, greater trochanter, third lumbar vertebra, and forehead. The transmissibility of vibration was computed as the ratio of the root-mean-square-acceleration at different body sites to that of the platform. Signal purity was expressed by the percentage of total transmitted power within 1 Hz of the nominal frequency delivered by the platform.

Findings: Vibration frequency and amplitude were inversely associated with transmissibility in all anatomical landmarks except the medial malleolus. Amplification of signals was noted at the medial malleolus in most testing conditions. The effect of posture on whole-body vibration transmission depends on its frequency and amplitude. In general, toe-standing led to the lowest transmissibility. Single-leg standing had the highest vibration transmission to the hip, while erect standing had the highest transmissibility to the head. The purity of waveform of the vibration signals was well conserved as the vibrations were transmitted from the feet to the upper body.

Interpretation: Whole-body vibration transmissibility was highly influenced by signal frequency, amplitude and posture. These parameters should be carefully considered when prescribing whole-body vibration to older adults.

1. Introduction

Whole body vibration (WBV) is gaining increasing interest as a treatment modality in geriatric rehabilitation. WBV is usually delivered to the human body while the individual is standing on the vibration platform. Several studies have reported an increase in lower limb muscle activity during exposure to WBV, likely due to the activation of the tonic vibration reflex (Burke and Schiller, 1976; Lam et al., 2016; Machado et al., 2010). WBV was also found to improve proprioception (Fontana et al., 2005), modulate spinal reflex excitability (Armstrong et al., 2008), and modify motor cortex excitability (Mileva et al., 2009). WBV is also a form of dynamic mechanical loading that is a potent stimulation for osteogenesis (Turner et al., 2011). These proposed mechanisms may explain the improvement in lower limb muscle strength, balance, and bone health in the elderly after WBV intervention (Furness et al., 2010; Lam et al., 2012; Lau et al., 2011; Merriman and Jackson, 2009). However, two important issues have been raised regarding the application of WBV. The first is the lack of consensus on which WBV protocols are optimal for modifying different treatment outcomes (Lam et al., 2012; Lau et al., 2011; Marín et al., 2011; Marín and Rhea, 2010; Merriman and Jackson, 2009). The second issue is the safety of WBV applications (Bochnia et al., 2005; Ishitake et al., 1998; Lam et al., 2012). Established standards for WBV exposure limits, such as the British Standard (BS 6841) and the International Organization for Standardization (ISO 2631), focus on occupational exposure and cannot be fully applied as strict guidelines for WBV training. Investigating WBV transmissibility is thus important in identifying effective treatment protocols (effective transmission to lower limbs and spine), while ensuring safety (minimizing resonance and transmission to head).

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https://doi.org/10.1016/j.clinbiomech.2017.12.007
Received 13 April 2017; Accepted 13 December 2017

WBV transmission is complex, as vibration signal propagation is greatly influenced by nonlinearities in body biomechanics (Kiiski et al., 2008), WBV frequency and amplitude, and postures assumed while on the platform (Rubin et al., 2003). Previous studies have identified peak resonance frequencies < 20 Hz (Kiiski et al., 2008; Pollock et al., 2010; Rubin et al., 2003), and decrease in vibration signal transmissibility with increasing frequency (Cook et al., 2011; Kiiski et al., 2008; Pollock et al., 2010; Rubin et al., 2003). However, effects of body posture and WBV amplitude are relatively understudied. Only effects induced by changes in knee angles during squat positions have been examined previously (Abercromby et al., 2007; Avelar et al., 2013; Cook et al., 2011; Muir et al., 2013; Rubin et al., 2003; Tankisheva et al., 2013), and 5 of these 6 studies have small sample sizes ($n \leq 16$) (Abercromby et al., 2007; Cook et al., 2011; Muir et al., 2013; Rubin et al., 2003; Tankisheva et al., 2013). Regarding WBV amplitude, only one study has compared the transmissibility of vertical vibration signals of multiple amplitudes in the legs (Cook et al., 2011). In addition, only one has examined signal purity as vibrations are transmitted up the body during erect standing (Kiiski et al., 2008). This is an important issue, as the degree of signal distortion may directly affect therapeutic efficacy.

Despite the rising interest in the use of WBV in older adults as reflected by the increase in number of WBV clinical trials conducted in this population across different countries (Lam et al., 2012; Orr, 2015), most human studies on WBV transmission reported in the literature were conducted in young adults. During aging, musculoskeletal system changes occur, which may result in undesirable conditions, such as sarcopenia and osteoporosis (Keller and Engelhardt, 2013; McGregor et al., 2014; Zebaze et al., 2010). Since muscle and bone are the major pathways through which the WBV is transmitted, WBV transmissibility could be different between young and old adults.

To address these knowledge gaps, this study investigated the main effects and interactions of WBV frequency, amplitude, and body posture on WBV transmissibility, as well as signal purity during transmission, among older adults. We hypothesized that the transmissibility of the vibration signals would be affected by 1) WBV frequency; 2) WBV amplitude; 3) posture assumed on the vibration platform. We also hypothesized that 4) there would be significant interaction among WBV frequency, amplitude, and postures on WBV transmissibility.

2. Methods

2.1. Experimental approach to the problem

A one-group experimental study with cross-over design was adopted. The transmission of WBV to the medial malleolus, tibial tuberosity, and greater trochanter on the right leg, third lumbar vertebra (L3), and forehead of older adults were measured when they were exposed to WBV of different frequencies and amplitudes while assuming different body postures. Therefore, the dependent variables were the transmissibility and waveform purity of WBV signals at various body parts, while the independent variables were WBV frequency, amplitude, and body posture.

2.2. Subjects

2.2.1. Sampling

Community-dwelling older adults were recruited via advertising in Hong Kong from September 2013 to April 2014. Inclusion criteria were 1) aged ≥ 50 years, 2) medically stable, 3) able to stand for at least 1 min with minimal hand support, and 4) able to understand simple verbal commands. Exclusion criteria were: 1) any neurological conditions (e.g., stroke), 2) significant musculoskeletal conditions (e.g., amputation), 3) metal implants in the leg, 4) previous leg fracture, 5) osteoporosis, 6) vestibular disorders, 7) peripheral vascular disease, and 8) other serious illnesses or contraindications to exercise.

Table 1
Demographic data of participants.

	Mean (SD)			
	Male (n = 7)	Female (n = 33)	All (n = 40)	P-value
Age (years)	59.9 (8.4)	60.1 (5.6)	60.3 (5.7)	0.728
Body mass index (kg/m^2)	22.9 (3.8)	23.7 (3.2)	23.6 (3.3)	0.577

2.2.2. Sample size estimation

Studies that compared transmissibility among different WBV frequencies in younger adults yielded large effect sizes (Cohen's d = 1.6–2.4) (Rubin et al., 2003). An analysis of variance (ANOVA) indicated that 34 participants were needed to detect differences with an effect size f = 0.35, α of 0.05, and power of 0.8.

2.2.3. Ethical approval

This study conforms to the ethical principles of the World Medical Association Declaration of Helsinki — Ethical Principles for Medical Research Involving Human Subjects. Ethical approval of the study was granted by the Human Research Ethics Subcommittee of the university. Written informed consent was obtained from each participant.

2.2.4. Demographic characteristics

Forty community-dwelling older adults were enrolled (33 women; mean age: 60.3 (SD = 5.7) years). Demographic data are shown in Table 1. The age and body mass index (BMI) of men and women showed no significant difference ($P \geq 0.557$).

2.3. Procedures

2.3.1. Testing conditions

All participants attended a single session of experiment. A vibration platform (Fitvibe Medical, GymnaUniphy NV, Bilzen, Belgium) that generated vibration frequencies of 25 Hz, 30 Hz, 35 Hz, and 40 Hz and amplitudes of approximately 0.6 mm and 0.9 mm was used for testing. As vibration frequency increased, the protocol yielded platform peak acceleration of 1.70 units of gravitational constant (G = 9.81 ms^{-2}), 2.25G, 2.90G, and 3.65G if an amplitude of 0.6 mm was used, and 2.50G, 3.40G, 4.35G, and 5.50G if an amplitude of 0.9 mm was used.

During WBV exposure, participants assumed six different postures: (1) erect standing (knee flexion, 20°), (2) semi-squat (knee flexion, 45°), deep squat (knee flexion, 70°), (4) toe-standing, (5) forward lunge, (6) single-leg standing (right leg knee flexion, 20°) (Fig. 1). An electronic goniometer monitored participants' knee angle (Twin Axis Goniometer SG150; Biometrics Ltd., Newport, UK). The selected postures were commonly used in previous studies (Lam et al., 2012; Lau et al., 2011). During testing, participants held onto the rail lightly for safety and were asked not to put weight on it unless they lost balance. A new trial would be done if the subject lost balance during testing. In postures with bilateral stance, feet were placed shoulder-width apart. Participants stood barefoot on the platform to avoid external damping. The body posture, frequency, and amplitude combinations yielded 48 conditions. For each condition, WBV was sustained for 10s. To minimize potential order-effect bias, the testing conditions were randomly sequenced. Participants rested intermittently to minimize fatigue.

2.3.2. Measurement of acceleration

After calibration, five tri-axial accelerometers (Dytran 7523A5; Dytran Instruments, Inc., CA) were attached to the vibration platform with double-sided tape to measure accelerations at the platform level, for 10 s for each of the 8 frequency and amplitude combinations. A total of five trials were performed and the average was used as the platform acceleration. The platform acceleration was measured in both unloaded and loaded conditions. In the former condition, nobody was standing on