

TRANSMISSIBILITY OF WHOLE BODY VIBRATIONS TO THE TRICEPS SURAE

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In order to evaluate potential risks of long term whole body vibration (WBV) training, the transmissibility of vibrations from the WBV platform to the muscles needs to be determined. The purpose of this study was to quantify the transmissibility of vibrations from the WBV platform to the triceps surae muscle. Sixteen healthy male subjects were exposed to WBV at 2.5 mm amplitude and to frequencies of 10, 17 and 28 Hz. Transmissibility of peak acceleration, frequency, and amplitude were quantified using tri-axial accelerometers. The results showed high transmissibility of acceleration and amplitude, especially at low platform frequencies. Since high amounts of acceleration were related to tissue damage, animal or computational muscle models might use the current results as input parameters to study eventual long term risks of WBV training.

KEY WORDS: Whole body vibration, injury, muscle mechanics.

INTRODUCTION: Whole-body vibration (WBV) training is a versatile intervention used to strengthen muscles and bones for healthy and diseased populations (Rittweger, 2010). With respect to muscular performance, the effectiveness of WBV training largely depends on the capability to elicit muscle contractions. It was shown that increasing vibration amplitude and vibration frequency of the WBV platform elevated muscle activity during WBV (Marin et al., 2009; Ritzmann et al., 2012). As a consequence, the strongest reflex contractions and presumably the largest training stimulus during WBV may be achieved at high vibration intensities.

However, the exposure of the body to high vibration stimuli may lead to comfort and safety issues. Therefore, with the introduction of WBV platforms as a training intervention, numerous studies have investigated the transmissibility (i.e. the ratio of vibrations measured at the body relative to the vibrations induced by the vibration platform) to the skeleton (Kiiski et al., 2008). In contrast, the transmissibility of vibrations to the soft tissue packages of the lower limbs has been neglected, despite the fact that adverse effects for the skin and muscle, such as erythema, oedema and itching, were reported (Rittweger et al., 2000). Also, vibration related pathological changes were observed in employees using hand-held vibrating tools. The changes included arteriosclerosis and lipid deposition together with loss of nerve fibers and myelin sheath (Takeuchi et al., 1986).

Generally, two components, vibration intensity and maximal allowed exposure time of WBV training need to be investigated in order to ensure that no adverse effects occur for soft tissues after short- or long-term WBV training. The focus of this study was to address the first component, vibration intensity, which is acting on the soft tissues of the lower limbs during different platform settings. Specifically, the study assessed the transmissibility of peak acceleration, frequency and movement amplitude from the vibration platform to the triceps surae soft tissue package. The hypotheses to be tested were that

- (H1) the tissue acceleration exceeds the platform acceleration,
- (H2) the tissue frequency exceeds the platform frequency,
- (H3) the tissue movement amplitude exceeds the platform amplitude.

METHODS: Sixteen healthy, physically active male volunteers (age: 26.7 ± 3.4 yr; body mass: 78.6 ± 10.1 kg; height: 180.3 ± 8.3 cm (mean \pm SD)) were instructed to stand freely on a side-altering vibration platform (Galileo Advanced, Novotec, Germany), in an upright posture without shoes and socks for 60 seconds. Each subject was tested at three different conditions where the vertical vibration amplitude of the vibration platform was constant at 2.5 mm (i.e., 5 mm peak-to-peak displacement) and the vibration frequencies were 10 Hz, 17 Hz,

and 28 Hz, in randomized order. This combination of vibration frequencies and amplitude was chosen to encompass a range of commonly used vibration frequencies during WBV training. All subjects were instrumented with a tri-axial accelerometer. The accelerometer was secured to the most prominent bulk of the triceps surae and between the medial and lateral aspects of the gastrocnemius muscles using stretch medical adhesive tape. The three axes of the accelerometer were oriented to be (1) axial (i.e. parallel to the long axis of the tibia), (2) medio-lateral (i.e. perpendicular to tibia in medio-lateral direction), and (3) antero-posterior (i.e. normal to the skin surface). A second tri-axial accelerometer was secured on the vibration platform. The data was recorded at 2400 Hz using a 12-bit data acquisition system. The vibration amplitude was calculated by transformation of the acceleration data into position data [mm] using a double integration in frequency space. The peak acceleration and amplitude were obtained by calculating the resultant acceleration and amplitude of the three measured axes and the mean was calculated over all subjects. The frequency content of the raw data was calculated using Fast Fourier transformation (0.037 Hz resolution). Local intensity maxima were identified for all power spectra, and the frequency at which the maximum intensity occurred was determined. Transmissibility was calculated by dividing the vibration data measured at the triceps surae by the data measured at the vibration platform. For statistical analysis, independent Student's t-tests were used with the level of significance set at $\alpha < 0.05$.

RESULTS: Peak acceleration was significantly higher at the triceps surae compared to the input acceleration of the platform, at each of the three tested vibration frequencies (Fig. 1, left). The amplitude of vibrations was significantly higher at the triceps surae compared to the input amplitude for all three tested frequencies (Fig. 1, right). The tissue vibration frequency matched the one of the vibration platform in each individual vibration direction and there were no significant differences, except for 10 Hz at the triceps surae in the anterior-posterior vibration direction (Fig. 2). The transmissibility of vibrations from the platform to the triceps surae indicated that the peak acceleration and vibration amplitude can exceed twice the value of the input at 10 Hz, and becomes lower as frequency increases. Mean results for transmissibility over all subjects are shown in table 1.

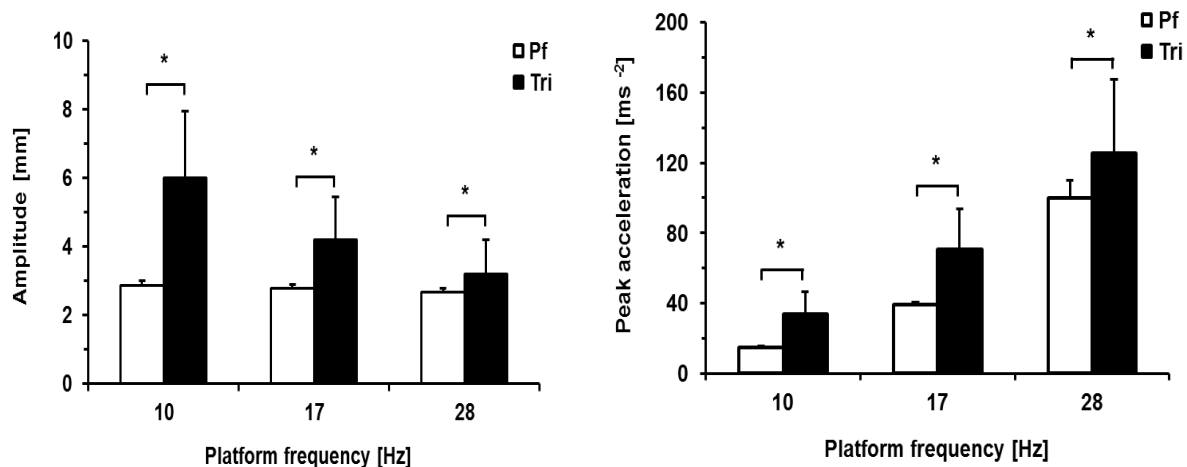


Figure 1: (Left) White bars indicate mean peak acceleration measured at the WBV platform (Pf) and black bars indicate the mean resultant peak acceleration measured at the triceps surae (Tri) of all subjects. **(Right)** White bars indicate the mean vibration amplitude measured at the WBV platform (Pf) and black bars indicate the mean resultant amplitude measured at the triceps surae (Tri) from all subjects. * denotes significant differences with $p < 0.05$.

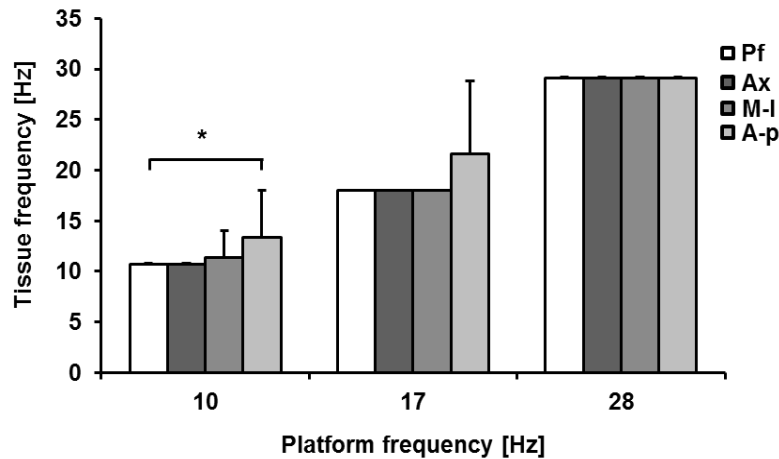


Figure 2: White bars indicate the mean vertical frequency measured at the WBV platform (Pf) and the dark grey, grey and light grey bars indicate the mean vibration frequency of the triceps surae in axial (Ax), medio-lateral (M-I) and antero-posterior (A-p) direction of all subjects, respectively. * denotes significant differences with $p < 0.05$.

Platform frequency	Transmissibility				
	Peak acceleration	Amplitude	Frequency axial	Frequency medio-lateral	Frequency antero-posterior
10 Hz	2.33 (0.89)	2.10 (0.67)	1.00 (0.00)	1.06 (0.24)	1.25 (0.43)
17 Hz	1.81 (0.55)	1.51 (0.45)	1.00 (0.00)	1.00 (0.00)	1.20 (0.40)
28 Hz	1.27 (0.46)	1.21 (0.38)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)

Table 1: Transmissibility of acceleration, amplitude and frequency, calculated as the ratio between the vibrations of the tissue and the platform. Values indicate mean and standard deviation in brackets.

DISCUSSION: Peak acceleration: Confirming the first hypothesis, the results showed that the peak acceleration measured at the triceps surae significantly exceeded the input peak acceleration of the WBV platform at every frequency (Fig. 1, left) and the transmission of acceleration to the triceps surae was particularly high at low vibration frequencies (Tab. 1). This result may be explained by the high transmissibility of vibration amplitude rather than the vibration frequency. While the transmissibility of frequency was close to 1, the transmissibility of amplitude was substantially higher, especially at lower frequencies (Fig. 1, right). Since peak acceleration (ACC_{peak}) is a function of frequency (f) and amplitude (A) ($ACC_{peak} = (2\pi f)^2 A$), the significantly higher peak acceleration measured at the triceps surae can be attributed to changes in transmitted amplitude.

Frequency: The frequency of the soft tissue was practically the same as the WBV platform frequency, and therefore the second hypothesis must be rejected. One exception occurred at vibrations in anterior-posterior direction at 10 Hz, where the tissue vibrated significantly faster than the platform. The difference was caused by only four subjects, where tissue vibrated stronger at the second harmonic (i.e. double the input frequency) of the WBV platform. Most subjects showed harmonics in their power spectra but had the higher peak at the first harmonic (i.e. the input frequency) from the WBV platform. It may be speculated that the second harmonics were caused by phase-shifted vibrations in axial or medio-lateral direction. Amplitude: The amplitude was significantly higher at the tissue compared to the vibration platform (confirming H3) and the transmissibility decreased with higher frequencies. It is speculated that the low transmissibility of amplitude at higher frequencies is related the

natural frequency of the triceps surae. If the input frequency to a system is close to its natural frequency, then resonance effects can occur that may cause vibrations at amplitudes higher than the input amplitude. The natural frequency of the triceps surae is between 10 Hz and 20 Hz (Wakeling et al., 2001) and may be the reason for the high transmissibility of amplitude at the two lower input frequencies, which were at 10 Hz and 17 Hz.

The findings of the current study demonstrate that vibrations acting on the soft tissues can well exceed the ones induced by the WBV platform. The data provides a basis to compare vibrations that are directly acting on soft tissues during WBV training to others that were shown to be detrimental. For example, it was shown that endothelial cells of rat tail arteries show signs of injury after being exposed to 4 hours of continuous vibrations at 60 Hz (Curry et al., 2002). While WBV training is usually not done at such high frequencies and long durations, the measured acceleration acting on the triceps surae at 28 Hz in the current study was in fact about 2.6 times higher than the one acting on the rat tail (125 ms^{-2} vs. 49 ms^{-2}). Future studies need to evaluate at which combinations of vibration intensity and exposure time harmful effects may be expected during WBV training. The presented data could be used as input parameters for animal or computational muscle models that try to assess injury risk by the acting stresses and strains on muscles, nerves and the vascular system during WBV platform training. This may be an important step, since many vibration related diseases or injuries only occur after exposure to vibrations over years (Takeuchi et al., 1986). Clearly, more work needs to be done to make sure that no long term damage is induced by WBV training.

CONCLUSION: The transmissibility of vibrations was dependent on the platform frequency and the data showed that the soft tissues of the body may be exposed to substantially stronger vibrations than the vibration platform settings may suggest. The accelerations acting on the triceps surae were higher than levels related to vascular damage and potential soft tissue injury when using whole body vibration platforms for extended periods of time cannot be excluded. In the future, animal or computational muscle models may be used to evaluate the long term effects of vibrations and the current data may serve as a foundation to use proper model input parameters.

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