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Safety and severity of accelerations delivered from whole body vibration exercise devices to standing adults

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ABSTRACT

Objectives: Whole body vibration devices are used as a means to augment training, and their potential to treat a range of musculoskeletal diseases and injuries is now being considered. The goal of this work is to determine the degree to which acceleration delivered by whole body vibration devices at the plantar surfaces of a standing human is transmitted through the axial and appendicular skeleton, and how this mechanical challenge corresponds to the safety threshold limit values established by the International Standards Organization ISO-2631.
Design: Non-blinded laboratory assessment of a range of whole body vibration devices as it pertains to acceleration transmission to healthy volunteers.
Methods: Using skin and bite-bar mounted accelerometers, transmissibility to the tibia and cranium was determined in six healthy adults standing on a programmable whole body vibration device as a function of frequency and intensity. Measures of transmissibility were then made from three distinct types of whole body vibration platforms, which delivered a 50-fold range of peak-to-peak acceleration intensities (0.3–15.1 $g_{p\text{-}p}$; where 1 g is Earth's gravitational field).
Results: For a given frequency, transmissibility was independent of intensity when below 1 g. Transmissibility declined non-linearly with increasing frequency. Depending on the whole body vibration device, vibration ranged from levels considered safe by ISO-2631 for up to 8 h each day (0.3 $g_{p\text{-}p}$ @ 30 Hz), to levels that were seven times higher than what is considered a safe threshold for even 1 min of exposure each day (15.1 $g_{p\text{-}p}$ @ 30 Hz). Transmissibility to the cranium was markedly attenuated by the degree of flexion in the knees.
Conclusions: Vibration can have adverse effects on a number of physiologic systems. This work indicates that readily accessible whole body vibration devices markedly exceed ISO guidelines for safety, and extreme caution must be practiced when considering their use.

1. Introduction

For decades, attempts have been made to limit exposure of the human body to vibration, as these mechanical signals are readily recognized as a major contributor to a multitude of diseases and ailments, including low-back pain,[1] circulatory disorders,[2] and neural dysfunction.[3] Despite tremendous efforts to minimize the amplitude and duration of work-place exposure to limb-specific or whole body vibration,[4] occupational exposure to vibration continues to produce adverse health conditions in many workers, including pronounced lower back pain, hearing loss, blurred vision and chronic nerve and vascular damage to arms and hands.[5] So severe is the potential damage to organs and tissues that advisories for human tolerance limits for vibration have been introduced by the International Organization for Standardization,[6] in essence a warning which urges stringent oversight of duration limits as prescribed by threshold limit values (ISO-TLV) for a given intensity of vibration. These guidelines are endorsed by the U.S. Occupational Safety and Health Association (OSHA) and the National Institute for Occupational Safety and Health (NIOSH), who work toward reducing acute and chronic injuries ascribed to vibration in the environment and workplace.

Despite strong advisories to limit human exposure to vibration, there is growing interest in the voluntary use of whole body vibration (WBV) as a surrogate or supplement for exercise,[7] as well as an intervention in preventative medicine or physical therapy.[8] Consideration in this regard should not be particularly surprising, given the musculoskeletal system's strong sensitivity to mechanical loading,[9] whether WBV is used to strengthen the elite athlete[7] or augment rehabilitation[10] in the injured or infirm.

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As demonstrated in animal models, WBV introduced in the range of 20–90 Hz is anabolic to bone and muscle, and can prevent and reverse osteoporosis in these preclinical models as introduced by disuse, age, or endocrine dysfunction.[11,12]

Translated to the clinic, there is early – *albeit* inconclusive – evidence that WBV may someday be used as a non-drug therapy for the treatment of musculoskeletal injury and/or disease. Using extremely low-magnitude (0.3 *g*, where 1 *g* = Earth's gravitational field), 30 Hz vibrations have been shown as anabolic to bone and muscle in the hip and spine of young women with osteoporosis,[13] promote volumetric bone density in the proximal tibia of children with disabling conditions such as cerebral palsy,[14] enhance bone quality in adolescents with idiopathic scoliosis,[15] and help protect balance control in those subject to chronic bed rest.[16] Using WBV at much greater magnitudes (7.4 *g*), a 6-month study has shown in post-menopausal women that vibration can also inhibit the progression of osteoporosis.[17] But is the potential risk of vibration exposure worth the potential reward?

WBV devices are readily available to the general public, but concern for their safety has only recently been apparent,[18,19] with recommendations which call for the requirement of 1:1 supervision from those trained in the use of these devices.[20] Google-based internet searches on WBV devices identify close to 50 distinct devices from around the world that are readily available for immediate shipping, but very few of the key vibration characteristics of the devices are provided.

Without knowledge of the intensity of the acceleration delivered by the WBV device, it is impossible to extrapolate how close a platform approaches the ISO-TLV. The majority of WBV websites provide no more than DISPLACEMENT (*D*) and/or the FREQUENCY (Hz) at which a platform might operate. However, ISO-TLV focuses on the INTENSITY of the vibration, which is reported in "g", or *g*-force, as calculated by:

$$g = \frac{[D(2\pi \times \mathrm{Hz})^2]}{9.81}$$

Without addressing the efficacy of any of these devices, the work presented here was designed to quantify the vibration exposure delivered by three distinct WBV platforms available on the market, and report the results with respect to the TLV advisories made on human exposure limits to vibration as determined by ISO-2631.

2. Methods

This study was reviewed and approved by the Stony Brook University's Committee on Research in Human Subjects. Investigators ran the study with the understanding that ISO-2631 guidelines advised against even brief exposure beyond extremes of the TLV boundaries. Six young, active, healthy adults were recruited from the undergraduate and graduate student population at Stony Brook University through campus postings.

Tri-axial accelerometers, sensitive within the range of ±10 *g* (CXL10HF3 Crossbow Technology Inc., California), each weighing 27 g, were used to measure transmission of plantar-based WBV to specific weight bearing regions of each volunteers as they stood through a range of flexed-knee positions. Acceleration measurements were made at the medial aspect of the proximal tibia, 10 cm below the knee, affixing an accelerometer to the skin with two-sided adhesive tape, covered by elastic wrap. Despite the limitations of skin-mounted accelerometers,[21] they provide an accurate first-order approximation of vibration.[22] Acceleration at the cranium was approximated by attaching the accelerometer to a bite bar, which was clenched between opposing molars. An accelerometer was also fixed to the top surface of each WBV platform, to determine the specific amount of acceleration delivered by that device.

Accelerometers were connected to a National Instruments SCXI-1000 data acquisition system through a SCXI-1531 8 channel Accelerometer Input Module (National Instruments Corp., TX), connected to a laptop using a DAQCard-6036E 16 Input 200 kS s^{-1} acquisition card. A custom LABVIEW 7.1 program collected 15 s samples, at 1000 Hz, data from the three accelerometers, in all three planes. Accelerometer output was digitized and reported as *g*-force, where:

$$1\,g = 9.81\ \mathrm{m\ s^{-2}}$$

The signal was filtered with a 30 Hz band pass filter centered on the primary frequency to remove high frequency noise and low frequency signal drift due to the volunteer's postural motions.[16] Average peak to peak (p-p) acceleration was calculated from the filtered signal, while RMS acceleration and the resultant vector magnitude were calculated from the raw signal. Acceleration was measured in all three axes, where $R_{\text{p-p}}$ is the resultant vector acceleration.

$$R_{\text{p-p}} = \sin(a_z)(a_x^2 + a_y^2 + a_z^2)^{-1/2}$$

In the first phase of the protocol, each volunteer stood on a custom-made, programmable WBV platform, designed such that both frequency and intensity could be independently controlled by the investigator. Frequency ranges from 30 to 99 Hz, introduced at intensities ranging from 0.05 to 0.6 *g*, were examined (n.b., as these studies required extended subject exposure, higher *g*-forces could not be evaluated due to restrictions enforced by the University IRB). Drive frequency was first set at 30 Hz, and intensity increased from 0.05 *g* to 0.6 *g*, as performed in 25 steps. Intensity was then set at 0.2 *g*, and the frequency varied from 30 to 99 Hz, as performed in 33 steps of 3 Hz. Steps in this phase of the protocol were not randomized, and the sequence of events followed the increases as presented. Transmission was calculated as the ratio of acceleration measured at the cranium or tibia to that measured at the plate surface, and reported as transmissibility:

$$\text{Transmissibility} = \left(\frac{\text{body acceleration}}{\text{plate acceleration}}\right) \times 100$$

The second phase of the protocol evaluated the delivered acceleration and transmissibility of three distinct types of WBV devices: uni-directional high magnitude WBV platform, uni-directional low magnitude WBV platform, and a multi-directional high magnitude WBV platform. The first platform (Power Plate, Badhovendorp, Netherlands) provided a fixed-frequency vertical acceleration at two operator settings ('low' and 'high'), both of which were ≫3.0 *g*. The second plate (LivMD, Marodyne Inc., Lakeland, FL) delivered a fixed frequency vertical acceleration at a single fixed acceleration (≪1.0 *g*). The third plate (Vibrafit GmbH, Solms, Germany) delivered a horizontal rotational vibration combined with a vertical component, at five acceleration intensities as selected by the user, with each setting also varying the frequency.

Acceleration measurements were collected with volunteers in four different stances: a deep knee bend, with the angle of the knee joint set to 90°, moderate flexion of 135°, legs straight with knees relaxed, and legs straight and knees locked. Data were collected 3× in each position, with the volunteer stepping off the platform between measures. The sequence of platform use was randomized using a computer program.

Acceleration was reported as the mean peak to peak (p-p) intensity averaged over each of the 15 s recordings. For each device, the surface acceleration of the plate and the resultant vector acceleration on the body were also compared. Data are also presented as they relate to ISO-2631 TLV.[6]