Journal of Physical Education and Sport ® (JPES), Vol. 21 (5), Art 336, pp. 2501 - 2506, September 2021
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Transmissibility and estimated vibration dose-value at different mechanical vibration frequencies

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Published online: September 30, 2021
(Accepted for publication September 15, 2021)
DOI:10.7752/jpes.2021.05336

Abstract:
The popularization of whole-body mechanical vibration training has made necessary to consider safety aspects of whole-body vibration training. In order to understand how vibration affects the human body, two important indices are calculated from acceleration data: transmissibility and estimated Vibration Dose Value (eVDV). This study aims to compare the acceleration and transmissibility to the head (TH) between different frequencies of WBV in the isometric semi-squat exercise as well as to classify the acceleration and eVDV from normative values established in literature. Twenty-four individuals (25.65 ± 5.22 years; 84.44 ± 21.91 kg; 1.73.80 ± 0.21 m; 14.28 ± 6.27% fat) who exercise regularly participated in the study. There were four, 30-second repetitions of semi-squatting in the frequencies of 5 Hz, 15 Hz, and 22 Hz, with a 30-second rest between the repetitions. One frequency per day was applied over the course of three days. The acceleration was previously measured at the base of the platform at each frequency and then measured in the head. A one-way ANOVA parametric test with repeated measures was performed to compare the acceleration and transmissibility to the head between frequencies, considering a significance equal to $p<0.05$. The 5 Hz frequency presented lower values of acceleration and higher transmissibility to the head in relation to the other frequencies. The training protocol adopted in this study can be considered safe regarding transmissibility to the head. On the other hand, considering the ISO-2631 normative values, the protocol can be considered uncomfortable regarding estimated Vibration Dose Value. As to the frequencies used, 5 Hz is more applicable considering acceleration and estimated Vibration Dose Value; however, it presents higher transmissibility to the head.
Key Words*:* **Accelerometry; Vibration Platform, Biomechanics; Accelerometer; Whole-Body Mechanical Vibration**

Introduction

The vibratory stimulus is typified as a stimulus composed of mechanical waves that propagate in continuity, following a pattern of behavior that can generate oscillatory movements, which are measured in hertz (Kelly et al., 2000). Mechanical vibration is present on a daily basis, for example, in the occupational field and in the means of transport, and it can be considered harmful in cases of excessive exposure (Palmer et al, 2000). However, it has also been used for performance, health, and rehabilitation purposes, mainly using equipment named vibration platforms, promoting Whole-Body Vibration (WBV), usually with sinusoidal pattern (Cormie et al., 2006).

Regarding the impact and interaction with the body, WBV may trigger different responses according to its characteristics. According to Cardinale et al. (2005), the biomechanical variables that determine its intensity are frequency and wave amplitude. From a neurophysiological perspective, since the 1960s, the literature has been investigating the behavior of the neuromuscular system towards vibration, when the Tonic Vibration Reflex (TVR) was found (De Gail et al., 1966). When the vibration comes into contact with the body, the muscle fibers stretch and activate the primary sensory receptors of the muscle spindle, which detects the change in length of the fibers and increases their firing rate. First the efferent response is the excitation of the alpha motor neurons of the extrafusal fibers, then the reflex contraction occurs in the homonymous muscle (De Gail et al., 1966). Over time, TVR has been pointed out as the main mechanism to explain increased performance due to training with mechanical vibrations (Bosco et al., 1999; Issurin,Tenenbaum, 1999). Although the action mechanisms of neuromuscular responses to vibrations have been well known since the 1960s, the responses related to biomechanical behavior to this stimulus are still not well understood, especially in the health field.

In order to understand how vibration affects the human body, two important indices are calculated from acceleration data: transmissibility and estimated Vibration Dose Value (eVDV). Transmissibility is the way that mechanical waves interact with body, a parameter that makes it possible to verify the transmission of vibration from the source to a given body segment, usually the head or hands (Mansfield, 2005). Transmissibility changes according to the body position (Caryn, Hazell, Dickey, 2014; Huang, Tang, Pang, 2018), and tends to reduce as

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the vibration frequency increases (Pollock et al., 2010; Caryn, Hazell, Dickey, 2014; Huang, Tang, Pang, 2018). The eVDV is a measurement related to the time of exposure, vibration intensity and the perception of discomfort of the individual and is applied only for WBV measures (Silva et al., 2011). Although eVDV is little explored in the application of WBV for health and performance, Abercromby et al. (2007) identified that 10 minutes of exposure at a 30-Hz frequency and 4-mm amplitude exceed the daily vibration exposure recommended by ISO 2631. This indicates the relevance of exploring the safety aspects involving WBV training, as well as its benefits.

Despite the fact that in the sports field, WBV has promoted a significant increase in strength, muscle mass, bone density, and neuromuscular performance (Bemben et al, 2018; Ashnagar et al., 2016; Bosco et al., 1999; Prioreschi et al., 2012; Marin, 2012), Howarth and Griffin et al (1991) pointed out that exposure to mechanical shocks caused by vibration can generate acute and chronic discomfort. In the case of excessive exposure, as shown by Tamrin et al (2007) and Zack et al (2018), an association was observed between exposure to WBV and back pain in drivers. Aiming to reduces potential hazards of WBV, regulations such as ISO-2631 and BS 6841 classify the acceleration values from WBV on a discomfort scale and establish the tolerance limit according to the harmfulness and time of exposure to WBV.

On the other hand, in the field of physical activity, safety parameters are rarely considered in the protocols while the amount of time of exposure deemed safe is rarely discussed. Thus, although WBV can promote positive results in physical performance, it is important to evaluate the safety parameters for mechanical vibration training with respect to its intensity and time of exposure. Therefore, this study aims to compare the acceleration and transmissibility to the head (TH) between different frequencies of WBV in the isometric semi-squat exercise as well as to classify the acceleration and eVDV from normative values established in literature.

Material & methods

Participants

This study was approved by the Research Ethics Committee (49943915.1.0000.5541) and followed the resolution of the National Health Council (No. 466/2012) and the 1964 Helsinki Declaration. The sample consisted of 24 healthy males aged between 18 and 40 years, who exercised regularly at least three times a week. The volunteers had a mean age of 25.65 ± 5.22 years, body mass was 84.44 ± 21.91 kg, height 173.80 ± 21.13 cm and fat percentage of 14.28 ± 6.27%, measured by the Jackson and Pollock method (1978). Inclusion criteria were a negative of the following: a) history of lower or upper limb lesions in the last six months; b) diabetes; c) hypertension; d) pacemaker; e) using a prosthesis or orthesis; f) having suffered retinal detachment; and g) having metal pins, screws or plates implanted. Volunteers were recruited until the power value of 80% was reached, in order to meet the acceptable value of probability of occurrence of type-II error, considering $p<0.05$.

Procedures

The volunteers performed a training protocol with WBV in three different frequencies: 5 Hz, 15 Hz, and 22 Hz. Three days of experimental sessions were needed, and in each training session, one of the frequencies was used randomly. The WBV training protocol consisted of four repetitions of 30 seconds each, in the semi-squatting exercise on an oscillatory vibratory platform (KIKOS® P203). The knee angulation was established at 130°, identified by means of a manual goniometer. There was a 30 second rest and recovery interval between the series. During this time, the volunteers remained in an orthostatic position on the vibration platform off.

A triaxial accelerometer (EMG System do Brasil®) connected to a signal converter (EMG 800 - EMG System - Brasil®) was used to measure semi-squatting exercise series with WBV. The acceleration in the head (output) was measured with an acquisition rate of 2000 Hz and a 16-bit resolution. The acceleration at the base of the platform (input) was measured by placing the same accelerometer at the mid-point of the right foot support, without any mass applied on the platform.

The measurement of the acceleration was performed throughout the three frequencies used in this study. Three 30-second measurements were performed at each frequency, and the measurement started five seconds after the platform was turned on to avoid any ramp effect. EMGLab software (EMG System - Brazil®) collected the acceleration data, which were filtered with a 59 to 61 HZ Butterworth 2nd order reject filter to eliminate the electric network frequency.

Then, the Root Mean Square (RMS) of the acceleration was calculated to quantify the acceleration obtained in each axis and in each experimental situation. The resulting acceleration was then calculated as the square root of the sum of the squares of each accelerometer axes. From the RMS values of the resulting platform base (input) and head (output) acceleration, the TH was calculated according to the protocol already reported in the literature (Pel et al., 2009). The eVDV, which establishes a relationship between the magnitude of vibration and discomfort, was calculated using equation 1, in which "arms" is the RMS of the base vibration acceleration and "t" is the total exposure time, which was 120 seconds.

Equation 1:

$$eVDV = 1.4 \times a_{rms} \times t^{1/4}$$

Statistical Analysis

The dependent variables were acceleration in the head, TH, and eVDV, while the independent variable was the vibration frequency. The data are expressed as mean and standard deviation. The normality of the data distribution was tested through the Shapiro-Wilk test. To analyze the acceleration and TH, we adopted the mean of the four series performed in each experimental situation. The one-way ANOVA parametric test of repeated measurements was applied to compare acceleration and TH among the four different frequencies evaluated. Holm Sidak's post hoc test was applied when necessary. A Pearson correlation test was also applied to the acceleration data between the investigated vibration frequencies. The adopted significance level was $p<0.05$. The descriptive acceleration data and eVDV at each tested frequency were classified according to the values established in ISO 2631-1 (2013) and BS 6841 (1987).

Results

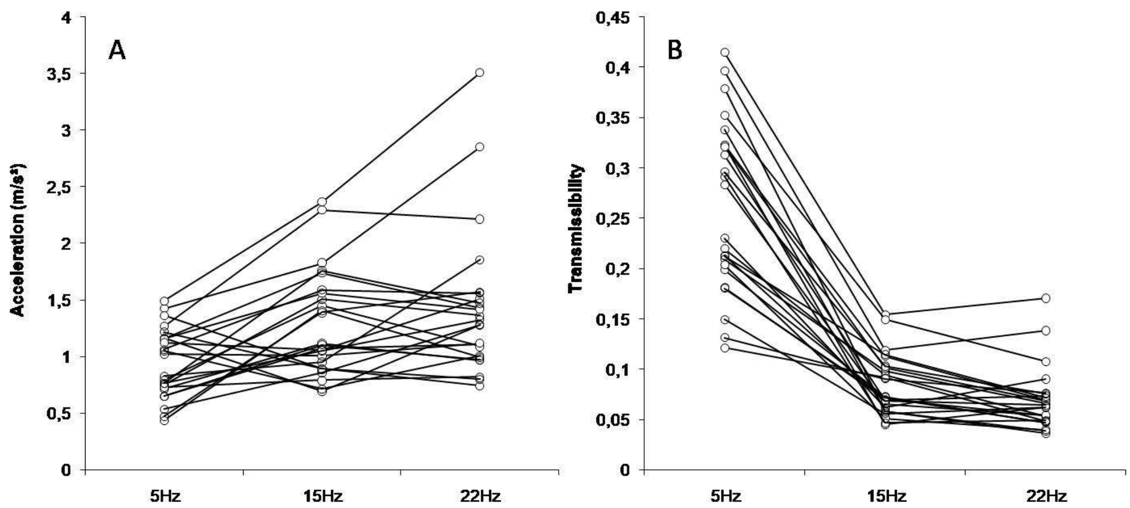
The average acceleration at the base of the platform was 3.594 m/s^2 at 5 Hz, 15.375 m/s^2 at 15 Hz, and 20.617 Hz at 22 Hz. The mean acceleration values in the head, TH, and eVDV obtained in each of the analyzed vibration frequencies are presented in Table 1. The acceleration in the head at the 5-Hz frequency was significantly lower than the acceleration in the head at the other frequencies ($F=12.691$; $p<0.001$). From the comparison of the data categorized by the perception of discomfort due to the measured acceleration according to ISO 2631-1 (2013) and BS 6841 (1987), it is noted that the acceleration at 5 Hz frequency was considered as "considerably uncomfortable" (0.5 m/s^2 to 1 m/s^2), while the others are above this zone, being classified as "uncomfortable". The TH was below "1" for all evaluated frequencies, indicating that there was no resonance in the body in the vibration frequencies studied. At 5 Hz frequency, the transmissibility was significantly higher than in the other evaluated frequencies ($F=132.637$; $p<0.001$). Figure 1 shows the scatter plot of acceleration and transmissibility data.

Table 1: Head acceleration, transmissibility and estimated Vibration Dose-Value (eVDV) on the three evaluated frequencies.

Frequency	Head acceleration Mean ± SD (m/s^2)	SE (m/s^2)	Transmissibility Mean ± SD (m/s^2)	SE (m/s^2)	eVDV ($m/s^{1,75}$)
5Hz	0,939 ± 0,305*	0,062	0,261 ± 0,085*	0,017	16,65
15Hz	1,294 ± 0,465	0,095	0,084 ± 0,030	0,006	71,24
22Hz	1,424 ± 0,645	0,132	0,069 ± 0,031	0,006	95,53

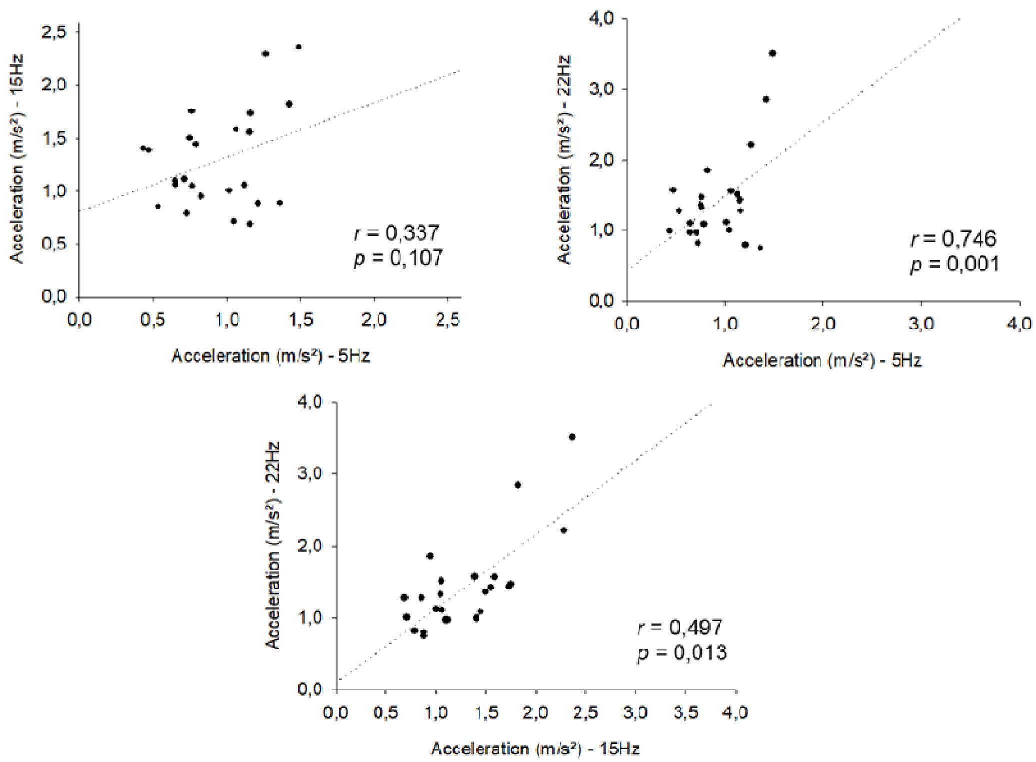
Note: SD = Standard Deviation; SE = Standard Error. *Significative difference from 15 and 22Hz ($p<0,05$).

Figure 1: A) Scatter plot of acceleration in the three different frequencies; B) Scatter plot of transmissibility in the three different frequencies.



There was a strong correlation for acceleration in the head between the frequencies of 15 and 22 Hz ($r=0.746$; $p<0.001$), a weak correlation between the frequencies of 5 and 22 Hz ($r=0.497$; $p=0.013$), and no significant correlation between the frequencies of 5 and 15 Hz ($p=0.107$) (Figure 2). Since TH data are calculated from head acceleration (output) and with similar input values for all subjects (platform base acceleration), the same correlation behavior observed for head acceleration is expected for TH.

Figure 3 – Correlation plot from head acceleration between all frequencies evaluated.



Regarding the eVDV classification, ISO-2631-1 determines as tolerance limit the eVDV of 17 $m/s^{1.75}$. As can be seen in Table 1, which presents the descriptive data of the eVDV, the exposure time during which the volunteers in this study were exposed (2 min) implied eVDV values approximating the limit of 17 $m/s^{1.75}$ at the 5-Hz frequency. The other frequencies showed values above what is considered healthy by safety standards, although the protocol did not exceed the recommended time limits for the frequencies used (BS-6841, 1987).

Dicussion

The first objective of this study was to compare the acceleration in the head and the TH between different frequencies of WBV in the isometric semi-squatting exercise. The results showed that in the lower frequency (5 Hz), the acceleration in the head was lower, while the TH was higher. These results corroborate those of Alizadeh-Meghrazi et al. (2012), who despite analyzing frequency ranges different from the present study, showed that head acceleration was higher at the lower frequency (25 Hz) than at the highest frequency (45 Hz). The same authors also suggested that TH was significantly different among all tested frequencies (25, 35, 45 Hz), and that it decreases with frequency increase. Aji et al. (2013) compared frequencies of 20, 30, 40, 50 and 60 Hz, and also found lower TH at higher frequencies in semi-squat position. Similar results were also observed by Pollock et al. (2010), Caryn, Hazell, Dickey (2014) and Huang, Tang, Pang (2018). In the present study, both head acceleration and TH were similar between 15 and 22-Hz frequencies. The absence of significant differences between them may be due to the proximity of the tested values when compared to the frequency ranges investigated in the above studies. It is possible to consider, therefore, that the TH tends to be higher at lower frequencies of vibration, indicating greater difficulty of the body in absorbing the impacts from mechanical vibration at low frequencies.

Despite the lower acceleration and higher TH at the lower frequencies, the scatter plot does not show a symmetrical pattern, suggesting that the individuals presented a different biomechanical behavior among the vibration frequencies. The lack of pattern in vibration damping is further reinforced by the results of correlation analysis, which showed no correlation between frequencies of 5 and 15 Hz, and weak correlation between 5 and 22 Hz. This fact can be explained by the anatomical and body composition differences between the subjects, which affects the way the vibrations propagate through the body (Liu, Nig, 2000), or even by the capacity of the neuromuscular system of each individual to absorb the vibration.

Additionally, this study aimed to classify acceleration and eVDV from reference values established by international standards. An average acceleration of 0.939 m/s² was observed in the 5-Hz frequency, an intensity considered uncomfortable according to ISO-2631. As reported by BS-6841, between 2 and 4 hours would be needed at this frequency to reach an action limit (safe time) and 8 to 16 hours for the tolerance limit (health risk). The other frequencies reached an average acceleration above 1.2 m/s², corresponding to a sensation considered "very uncomfortable" by ISO-2631, 1 to 2 hours being necessary to reach the action limit, and 2 to 4 hours for the tolerance limit according to BS-6841. These results suggest that vibration platform exercises with up to a 22-Hz frequency and less than one hour of exposure remains below the action limit time, but it is important to notice that the frequencies investigated in this study (5, 15, 22 Hz) are considered low for vibration platform training protocols. When using equipment that allows higher frequencies, up to 60 Hz, for example, it is necessary to be cautious about the exposure time, because the acceleration values achieved will probably be higher when compared to those obtained in this study, resulting in reduced action limit and tolerance times.

The eVDV parameter combines exposure time and vibration magnitude. As addressed by BS-6841, eVDV values above 9.1 $m/s^{1.75}$ are considered moderate risk, while ISO-2631 considers 17 $m/s^{1.75}$ eVDV as the tolerance limit. In this study, all frequencies presented an eVDV higher than those pointed out by BS-6841, and frequencies of 15 and 22 Hz resulted in an eVDV above the tolerance limit pointed out by ISO-2631. High eVDV values on vibration platforms were also found in other studies, such as Abercromby et al. (2007), which found eVDV values above the limits set by ISO-2631 at a frequency of 30 Hz and exposure of 10 minutes, and Nawayseh (2018), which found an eVDV of 5.74 and 6.29 $m/s^{1.75}$ in the frequencies of 17 and 20 Hz, respectively, with exposure time of only 5 seconds. Both the eVDV data from the present study and those observed in other studies suggest that most protocols with WBV exceed the eVDV limit suggested by ISO-2631 and BS-6841 standards.

It is important to emphasize that the data produced by the standards used in this study were obtained by protocols in the frequencies between 0.5 Hz and 80 Hz, by low amplitude waves, in which the volunteers remained in sitting, lying down, and standing positions, while in this study we adopted the semi-squatting position, usually used in training and rehabilitation protocols using vibration platforms. Some studies show that postural alteration affects the way the vibration reaches and spreads through the body (Nawayseh, 2018; Abercromby et al., 2007; Wakeling et al., 2002), possibly altering the level of discomfort and, consequently, the time limit of exposure depending on the magnitude of the vibration. Nawayseh (2018) tested four positions in a protocol that included 36 series of 5 seconds (3 total minutes in each position), assigning a rest of 20 seconds between series for 9 different frequencies (17 to 60 HZ). The transmissibility was higher in the unipodal position, and lower in the positioning with slight knee flexion, while the eVDV average for the four positions at the 20-Hz frequency was 6.69 $m/s^{1.75}$. Abercromby et al. (2007) demonstrated that transmissibility for head and trunk can be reduced by increasing knee flexion from 10 to 30 degrees, while Wakeling et al. (2002) suggest that transferring body weight to the forefoot can considerably reduce the transmissibility for head and trunk. These findings lead to the conclusion that the protocol of the present study performed with differently positioned individuals will result in different values of acceleration in the head.

In view of so many circumstances to be observed, the classification values should be evaluated with caution, since there are variables capable of modifying the interaction of vibration with the body. Moreover, most studies measuring eVDV are aimed at assessing risks in the occupational field. A limiting aspect of this study is the fact that it does not consider the potential effects of protocols applied to human performance. Moreover, in procedural terms, Nawayseh (2018) fixed the accelerometer in the oral region of the participants for data collection, which may cause a divergence between the values collected from this article, which fixed the accelerometer in the cranial region. Unlike the studies analyzed, this study chose to perform each frequency on a different day to ensure proper recovery of the neuromuscular system. In view of the different human responses to mechanical vibrations, it is essential to develop further studies to understand whether, from training with mechanical vibration at a chronic level, the neural system would be able to adapt to a more intense and lasting exposure, and whether such exposure would be safe for other body systems. Thus, although many WBV training protocols may have shown positive results in acute and chronic settings, further studies need to be conducted in order to adopt safe parameters for mechanical vibration training.

Conclusions

It is possible to state that the training protocol used in this study can be considered safe for the health of the volunteers when related to TH and head acceleration. On the other hand, taking the eVDV data into consideration, the protocol can be considered uncomfortable and exceed the tolerance limit value of 17 $m/s^{1.75}$ suggested by ISO-2631 for the frequencies of 15 and 22 Hz. Thus, the 5 Hz frequency was more applicable considering acceleration and eVDV, but with higher TH values, suggesting lower vibration damping capacity by volunteers at lower frequencies. The results of this study are limited to safety issues, but are not related to motor performance or physiological responses.

Conflicts of interest – There is no conflict of interest.

References

Abercromby, A. F., Amonette, W. E., Layne, C. S., McFarlin, B. K., Hinman, M. R., & Paloski, W. H. (2007). Vibration exposure and biodynamic responses during whole-body vibration training. *Medicine and science in sports and exercise*, *39*(10), 1794.

Aji, Y. E., Crequy, S., Chiementin, X., & Bertucci, W. (2013). Vibration transmissibility in different body positions with various vibration frequencies in a vertical vibration platform. *Computer methods in biomechanics and biomedical engineering*, *16*(sup1), 52-53.

Alizadeh-Meghrazi, M., Masani, K., Popovic, M. R., & Craven, B. C. (2012). Whole-body vibration during passive standing in individuals with spinal cord injury: effects of plate choice, frequency, amplitude, and subject's posture on vibration propagation. *Pm&r*, *4*(12), 963-975.

Ashnagar, Z., Shadmehr, A., Hadian, M., Talebian, S., & Jalaei, S. (2016). The effects of whole body vibration on EMG activity of the upper extremity muscles in static modified push up position. *Journal of back and musculoskeletal rehabilitation*, *29*(3), 557-563.

Bemben, D., Stark, C., Taiar, R., & Bernardo-Filho, M. (2018). Relevance of whole-body vibration exercises on muscle strength/power and bone of elderly individuals. *Dose-Response*, *16*(4), 1559325818813066.

Bosco, C., Cardinale, M., & Tsarpela, O. (1999). Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *European journal of applied physiology and occupational physiology*, *79*(4), 306-311.

British Standards Institution. (1987). *Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*. BSI.

Cardinale, M. A. J. W., & Wakeling, J. (2005). Whole body vibration exercise: are vibrations good for you?. *British journal of sports medicine*, *39*(9), 585-589.

Caryn, R. C., Hazell, T. J., & Dickey, J. P. (2014). Transmission of acceleration from a synchronous vibration exercise platform to the head. *International journal of sports medicine*, *35*(04), 330-338.

Cormie, P., Deane, R. S., Triplett, N. T., & McBride, J. M. (2006). Acute effects of whole-body vibration on muscle activity, strength, and power. *The Journal of Strength & Conditioning Research*, *20*(2), 257-261.

De Gail, P., Lance, J. W., & Neilson, P. D. (1966). Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *Journal of neurology, neurosurgery, and psychiatry*, *29*(1), 1.

Howarth, H. V. C., & Griffin, M. J. (1991). Subjective reaction to vertical mechanical shocks of various waveforms. *Journal of Sound and Vibration*, *147*(3), 395-408.

Huang, M., Tang, C. Y., & Pang, M. Y. (2018). Use of whole body vibration in individuals with chronic stroke: Transmissibility and signal purity. *Journal of biomechanics*, *73*, 80-91.

Issurin, V. B., & Tenenbaum, G. (1999). Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *Journal of sports sciences*, *17*(3), 177-182.

Kelly, S. G. (1992). Fundamentals of mechanical vibrations.

Liu, W., & Nigg, B. M. (2000). A mechanical model to determine the influence of masses and mass distribution on the impact force during running. *Journal of biomechanics*, *33*(2), 219-224.

Mansfield, N. J. (2004). *Human response to vibration*. CRC press.

Marín, P. J., Santos-Lozano, A., Santin-Medeiros, F., Vicente-Rodriguez, G., Casajús, J. A., Hazell, T. J., & Garatachea, N. (2012). Whole-body vibration increases upper and lower body muscle activity in older adults: potential use of vibration accessories. *Journal of electromyography and kinesiology*, *22*(3), 456-462.

Palmer, K. T., Griffin, M. J., Bendall, H., Pannett, B., & Coggon, D. (2000). Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey. *Occupational and environmental medicine*, *57*(4), 229-236.

Pel, J. J. M., Bagheri, J., Van Dam, L. M., Van Den Berg-Emons, H. J. G., Horemans, H. L. D., Stam, H. J., & Van der Steen, J. (2009). Platform accelerations of three different whole-body vibration devices and the transmission of vertical vibrations to the lower limbs. *Medical engineering & physics*, *31*(8), 937-944.

Pollock, R. D., Woledge, R. C., Mills, K. R., Martin, F. C., & Newham, D. J. (2010). Muscle activity and acceleration during whole body vibration: effect of frequency and amplitude. *Clinical biomechanics*, *25*(8),

Prioreschi, A., Oosthuyse, T., Avidon, I., & McVeigh, J. (2012). Whole body vibration increases hip bone mineral density in road cyclists. *International journal of sports medicine*, *33*(8), 593.

Silva, H., Lourenço, A., Tomás, R., Lee, V., & Going, S. (2011, May). Accelerometry-based study of body vibration dampening during whole-body vibration training. In *2011 IEEE International Symposium on Medical Measurements and Applications* (pp. 98-102). IEEE.

Tamrin, S. B. M., Yokoyama, K., Jalaludin, J., Aziz, N. A., Jemoin, N., Nordin, R., ... & Abdullah, M. (2007). The association between risk factors and low back pain among commercial vehicle drivers in peninsular Malaysia: a preliminary result. *Industrial health*, *45*(2), 268-278.

Wakeling, J. M., Nigg, B. M., & Rozitis, A. I. (2002). Muscle activity damps the soft tissue resonance that occurs in response to pulsed and continuous vibrations. *Journal of applied physiology*, *93*(3), 1093-1103.

Zack, O., Levin, R., Krakov, A., Finestone, A. S., & Moshe, S. (2018). The relationship between low back pain and professional driving in young military recruits. *BMC musculoskeletal disorders*, *19*(1), 110.