RBCDH Revista Brasileira de CINEANTROPOMETRIA e Desempenho Humano

DDOI: http://dx.doi.org/10.5007/1980-0037.2014v16n6p597

original article

The interference of body position with vibration transmission during training on a vibrating platform

A interferência da posição corporal na transmissibilidade vibratória durante o treinamento com plataforma vibratória

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Abstract – Whole-body vibration training on vibrating platforms is widely used for physical exercise, health promotion and physical rehabilitation. The position on the platform is one of the factors responsible for the transmission of vibrations to the body segments of individuals. Therefore, the objective of this study was to compare the characteristics of vibrations transmitted to the body segments of adults between two body positions and different vibration intensities. Twenty intentionally selected subjects (10 men and 10 women), with a mean age of 27.8 ± 2.9 years, participated in the study. The data were acquired with a triaxial accelerometer attached to the subject's body using a vibrating platform at frequencies of 20, 35, 50, and 70 Hz and displacement amplitudes of 2.0 and 6.0 mm in the extended and flexed positions. Descriptive and inferential statistics was applied ($p \leq 0.05$). Significant differences in the vibration magnitude and transmissibility were observed between body positions at all intensities analyzed, with greater attenuation of vibrations in the flexed position, especially during passage of the vibratory stimulus through the lower limbs. It was concluded that the body position adopted by the subjects on the vibrating platform directly affects the transmission of vibration. The flexed position was found to be the most suitable for the application of this training method by ensuring better body stability on the platform and promoting more effective attenuation of vibrations, thus preventing the occurrence of unintended acceleration in the head.

Key words: Accelerometry; Transmissibility; Vibration.

Resumo – *O treinamento vibratório de corpo inteiro sobre plataformas vibratórias tem sido muito difundido nos contextos do treinamento físico, promoção da saúde e reabilitação física, sendo o posicionamento sobre a plataforma um dos fatores responsáveis pela transmissão das vibrações às estruturas corporais dos indivíduos. Desta forma, o objetivo geral deste estudo foi comparar as características das vibrações transmitidas às estruturas corporais de adultos em duas posições corporais em diferentes intensidades de vibração. Vinte sujeitos (10 homens e 10 mulheres) com média de idade de 27,8 ± 2,9 anos, foram selecionados de forma intencional. Os dados foram adquiridos com acelerômetros triaxiais fixados ao corpo dos sujeitos sobre uma plataforma vibratória, nas frequências de 20, 35, 50 e 70Hz e amplitudes de deslocamento de 2,0 e 6,0mm, na posição estendida (PE) e posição flexionada (PF). Foi aplicada estatística descritiva e inferencial (*$p \leq 0{,}05$*). Foram identificadas diferenças estatisticamente significativas na magnitude e transmissibilidade vibratória entre as posições corporais, em todas as intensidades analisadas, com maior atenuação das vibrações na PF, principalmente, durante a passagem dos estímulos vibratórios pelos membros inferiores. Pode-se concluir que a posição corporal adotada pelos sujeitos sobre a plataforma vibratória interfere diretamente na transmissibilidade das vibrações, sendo a PF a mais adequada para aplicação desse método de treinamento, por garantir uma melhor estabilidade corporal sobre a plataforma e promover uma atenuação mais efetiva das vibrações, evitando, assim, a ocorrência de acelerações indesejadas na cabeça.*

Palavras-chave: *Acelerometria; Transmissibilidade; Vibração.*

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Received: 24 May 2013
Accepted: 19 March 2014

INTRODUCTION

Exposure of the human body to mechanical vibrations has been studied for many years. First, these studies investigated the relationship between vibration and the development of occupational disorders[1,2]. However, despite the long tradition of studies on its deleterious effects, reports have demonstrated that vibration can be beneficial to the human body[3]. Within this context, whole-body vibration (WBV) training has been used for different professional interventions such as physical, sports and functional training, physical rehabilitation[4], health promotion, and the prevention of diseases[5].

In WBV training, the acceleration provoked in the human body is considered to be the main training "stressor' and is therefore responsible for neural and morphological responses[3]. However, since vibration has been seen as harmful to the body for many years[1,2], it is necessary to focus on the forms of application of this training method. In this respect, although studies have indicated the efficiency of WBV training for different purposes[6-9], little is known about the safety of this method[3,10].

One concern is related to the possible occurrence of the resonance phenomenon, i.e., an amplification of the vibration to which the body is submitted[3]. Each body structure vibrates at a specific frequency, called natural frequency. When an external vibration is applied at a frequency that coincides with the natural frequency of a given structure, the internal forces acting on the organism are enhanced, an event that can lead to different degrees of damage to the body[11], causing symptoms such as headache, nausea, dizziness[12], erythema and itching of the skin, prolonged numbness of the lower limbs[13], and visual disturbances[14]. The incidence of this phenomenon, as well as the neural and morphological changes expected from WBV training, depends on factors such as the frequency and amplitude of vibration and time of exposure[15], in addition to the position on the vibrating platform[16,17].

An incorrect position has been indicated as the main factor that interferes with the pattern of vibration transmission through body structures[16,18]. The contact surface with the plane of vibration, the position of the spine, the degree of tension in different muscle groups, and variations in upper and lower limb position can alter the elastic and damping properties of tissues, determining the distribution of body weight on the platform[16]. The attenuation of acceleration can be optimized by slight flexion of the lower limbs, causing a dealignment of the segments and consequently permitting better dissipation of the stimuli[16,17,19,20], and/or by putting the body weight on the forefoot, preventing the application of vibration directly under the heels[16,17]. Both techniques promote a reduction in the acceleration transmitted to the trunk and head, ensuring greater training safety, whereas acceleration in the upper part of the body increases significantly when the knees are completely extended[12,21-23].

In fact, the human body is considered to be a complex biomechanical apparatus and the analysis of its response to WBV training is a major challenge since this response is influenced by different factors[24]. However, scientific data as to how these interferences occur and which conditions of intensity and position guarantee training effectiveness and more reliable safety standards are outdated and further theoretical and practical insights are needed.

In this respect, the objective of the present study was to compare the characteristics of vibrations transmitted to the body segments of adults between two body positions and different vibration intensities.

METHODOLOGICAL PROCEDURES

This descriptive correlational study was approved by the Ethics Committee of Universidade Federal de Santa Catarina (Permit No. 37886/12).

Subjects

Twenty subjects, 10 men and 10 women, ranging in age from 20 to 35 years (mean of 27.8 ± 2.9 years; body weight: 71.2 ± 14.4 kg; height: 1.7 ± 0.1 m), living in the city of Florianópolis, Santa Catarina, Brazil, were evaluated. The subjects were selected by intentional sampling according to the following criteria: no regular practice of any type of vibration training; being in healthy physical conditions; no diagnosis of labyrinthitis or vestibular disorders; no history of moderate or severe musculoskeletal injuries to the lower limbs and hip in the last 6 months.

Measurement instruments

Body weight was measured to the nearest 100 g with a WISO digital scale (model W835; capacity of 180 kg) and height was measured with a Seca portable stadiometer (model 220; 220 cm) to the nearest 0.1 mm.

The following instruments were used in the WBV protocol: (a) a professional triplanar vibration platform, with an amplitude of vibration of 0 to 11 mm, frequency of vibration of 0 to 99 Hz, maximum capacity of 300 kg, and alternating plate vibro-oscillation system; (b) four ICP Integrated Circuit Piezoelectric triaxial accelerometers (PCB Piezotronics Brüel & Kjaer, model 4525B), with a sensitivity of ≈10 mV/g, frequency range of ±500 g peak, and mass of 6 g; (c) a clear plastic goniometer (20 cm) and protractor system of 0° to 360°.

The accelerometers were calibrated using a PCB Piezotronic vibration calibrator with a level of calibration of 1 g at 159.2 Hz (1%), distortion < 2% between 0 and 100 g and < 3% between 100 and 210 g, transverse excitation < 3%, and temperature of -100 to 550°C. During calibration of the platform, the accelerometers were attached to different points of the vibration plate. The signals were recorded at different frequencies (Hz), matching the vibration frequency selected in the platform system with the frequency recorded by the accelerometers. The signals were acquired with the MCS1000-V3 module (Lynx Tecnologia Eletrônica Ltda.), which consists of 16 configurable channels with an output tension of ±10 V, possibility of gain of up to 600 times and second-order Butterworth low-pass filtering, with a cutoff frequency of 1 to 50 Hz determined by the capacitors.

Procedures for data collection

The data were collected in the Studio of the Vibe Class Fitness System by appointment. Each data collection session lasted approximately 60 min, including the periods of instruction and clarifications, adaptation to the equipment, and data acquisition.

At the time of scheduling of the data collection, the subjects were asked not to perform any type of physical activity and not to consume alcoholic beverages or excess fluids 24 hours prior to collection, as well as to use comfortable clothing and sport shoes (sneakers) on the day of data collection.

Whole-body vibration protocol

After receiving detailed information about the objectives of the study, the subjects agreed to the procedures by signing the free informed consent form. Next, the subjects received instructions about the procedures for data collection, especially regarding the variations in body position during the WBV protocol. A period of 5 min for joint warm-up and familiarization with the platform was allowed.

The accelerometers were then attached to the following anatomical reference points: (1) on the ankle, 2 cm above the lateral malleolus; (2) on the leg, 2 cm proximal to the lateral malleolus of the right fibula; (3) on the L4 spinous process, and (4) on the face near the frontal bone of the skull. The accelerometer was attached with adhesive tape and compression bandages to avoid displacement of the device, thus preventing the occurrence of noise in the signal and undesired power spectra.

Next, the subjects were positioned on the platform with the limbs at an equal distance, head aligned to the trunk and hands at the height of the hip. The subjects were asked not to put the weight of the arms on the hip. Two different leg joint positions were evaluated: extended position (EP) and flexed position (FP). In EP, the subjects stood fully erect, with the body weight distributed on the rear foot. In FP, the subjects were asked to slightly flex the joints, inclining the trunk slightly forward and distributing the weight on the forefoot (Figure 1). The angle of knee flexion in FP (30º) was determined with a goniometer which was positioned at the side of the joint and then removed. During data acquisition, the maintenance of FP was monitored by the researcher.

The definition of the WBV protocol used here was based on protocols described in the literature[12,20,24,25]. Thus, the data were recorded at vibration frequencies of 20, 35, 50 and 70 Hz and displacement amplitudes of 2.0 and 6.0 mm. The combination of these parameters resulted in 16 series of 30-s exposure to WBV at intervals of 60 s, for a total of 8 min of exposure and 15 min of total data recording.

Additionally, in order to prevent undue interference of one variable with another, the order of the accelerometry recordings was randomized.

For this purpose, 10 random combinations of data recording were created and the subjects randomly chose one at the time of data collection. The duration of the complete evaluation was approximately 60 min.

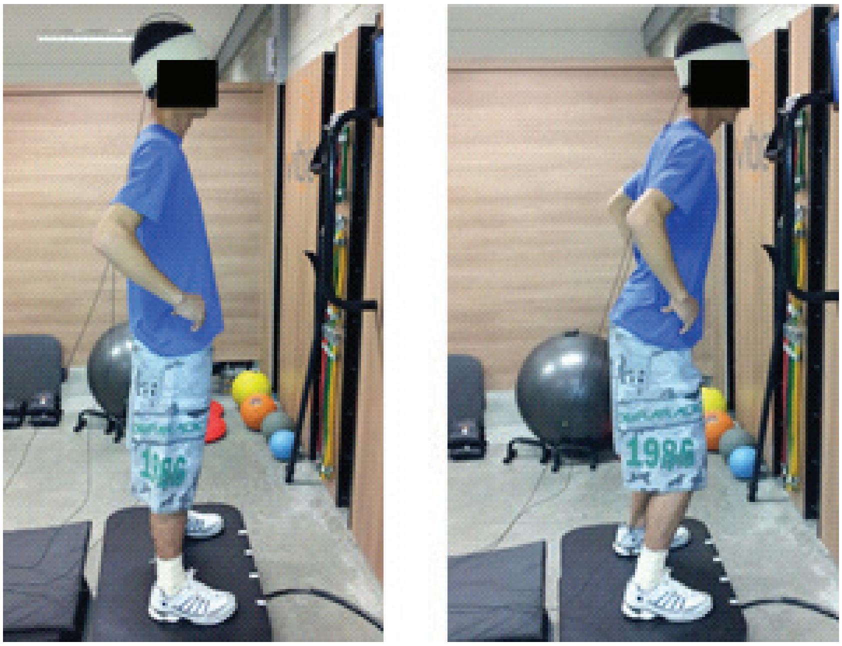

Figure 1. Body positions adopted during data acquisition. EP: extended position; FP: flexed position.

Data processing

The signals were acquired at a sampling frequency of 800 Hz to permit the simultaneous use of 12 channels (3 channels per accelerometer), as well as to preserve the integrity of the signal. The electrical load generated by the piezoelectric transducer in the three directions (x, y and z) during the procedure was transmitted through cables to the Lynx MCS 1000-V2 module.

After acquisition, the signals were filtered and converted using a digital analog converter (Lynx, model AC116x) with 16-bit resolution per entry (4-kHz samples per channel), stored, and exported with the AqDAnalysis 7.0.14 software (Lynx) for processing with the Matlab R2012a software. Specific programming routines were created for data processing in each condition: (1) zero correction (offset); (2) application of the coefficient of calibration; (3) verification of the values of the variables to be analyzed in each test of the subject, and (4) exportation of the values to files in *.txt format. The data were then organized in spreadsheets using the Microsoft Excel 2003 software.

The root mean square of the time series (m/s^2) was also calculated and spectral analysis (Fast Fourier Transform) was performed using a Hamming window, represented by the power spectral density. After this procedure, the spectral values of the signals were transformed to acceleration values (g) and the transfer function (TF) was then calculated. This function permits to estimate the attenuation or gain of vibration between one point and another (transmissibility) as follows: TF = = $10\log_{10}$ (acceleration at the final point/ acceleration at the initial point).

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences for Windows (SPSS 17.0). First, descriptive statistics was used, calculating means and standard deviations. The normality of the data was tested by the Shapiro-Wilk test. For inferential statistics, the Student *t*-test for dependent samples was applied. The corresponding nonparametric test was used for data that showed no normal distribution. A level of significance of 95% ($p \leq 0.05$) was adopted.

RESULTS

Table 1 shows the acceleration values according to body position.

Table 1. Comparison of acceleration values between body positions.

Anatomical point	Body position	Displacement amplitude/ Vibration frequency							
		2 mm/ 20 Hz	2 mm/ 35 Hz	2 mm/ 50 Hz	2 mm/ 70 Hz	6 mm/ 20 Hz	6 mm/ 35 Hz	6 mm/ 50Hz	6mm/ 70 Hz
Ankle	EP	3.6(1.0)	21.1(4.4)	17.4(3.0)	26.0(3.3)	4.2(1.4)	23.8(4.1)	20.4(3.2)	29.3(3.6)
	*FP	2.6(0.9)	17.0(3.8)	11.9(2.5)	20.8(3.6)	2.9(0.8)	18.9(4.4)	14.2(2.2)	23.8(3.3)
Knee	EP	3.3(0.9)	16.9(4.5)	10.7(4.4)	15.3(4.7)	4.6(1.0)	19.9(4.8)	14.4(5.3)	18.6(5.8)
	*FP	2.2(0.8)	11.8(3.4)	6.3(2.5)	10.8(3.7)	2.6(0.8)	13.9(3.3)	7.5(2.6)	12.2(3.5)
Lumbar spine	EP	2.0(0.7)	8.6(3.0)	5.7(2.6)	6.3(2.9)	2.5(1.0)	11.5(3.4)	7.9(3.2)	8.2(3.7)
	*FP	1.3(0.7)	5.0(1.9)	2.4(1.1)	2.7(1.5)	1.7(0.7)	5.9(2.1)	3.4(1.7)	3.2(2.0)
Head	EP	1.3(0.5)	2.5(0.7)	1.9(0.5)	2.2(0.7)	1.6(0.6)	3.0(0.8)	2.3(0.6)	2.7(0.8)
	*FP	0.7(0.3)	1.4(0.3)	1.2(0.3)	1.3(0.3)	0.9(0.3)	1.6(0.3)	1.3(0.4)	1.5(0.3)

Values are the mean (standard deviation). EP: extended position; FP: flexed position. * $p<0.001$.

The results showed significant differences in the acceleration values between the body positions analyzed, with the observation of higher accelerations in EP compared to FP. At the ankle point, a reduction of 20 to 35% in the magnitude of acceleration was observed in FP compared to EP, while this reduction was 30 to 45% at the knee point. An even more significant reduction was observed for the lumbar spine and head (30 to 60% and 40 to 50%, respectively).

With respect to the pattern of vibration transmissibility, comparison between positions also showed significant differences in these patterns for the three moments of vibration transmission: (T1) from the ankle to the knee; (T2) from the knee to the lumbar spine, and (T3) from the lumbar spine to the head. At the first transfer moment (T1), a significant difference in vibration transmissibility was observed between EP and FP under all conditions analyzed ($p=0.015$ for tests performed at 2 mm/20 Hz; $p=0.004$ for 2 mm/50 Hz; $p<0.001$ for the remaining conditions), with higher values in FP compared to EP (Figure 2).

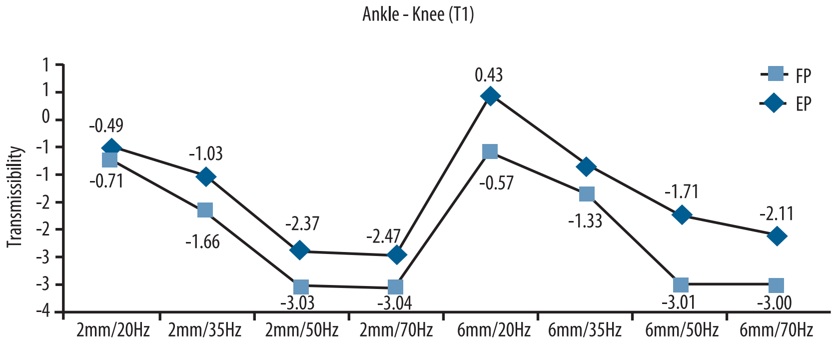

Figure 2. Vibration transmissibility at T1 in the extended (EP) and flexed (FP) positions.

At T2 (Figure 3), transmissibility also differed significantly between body positions in most of the conditions analyzed (p=0.003 for 6 mm/20 Hz; p=0.002 for 6 mm/50 Hz; p<0.001 for the remaining conditions), except for the test performed at 2 mm/20 Hz (p=0.212), with the observation of higher values in FP.

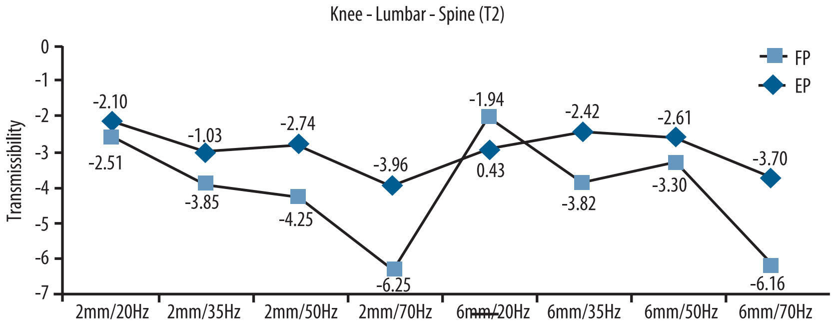

Figure 3. Vibration transmissibility at T2 in the extended (EP) and flexed (FP) positions.

Finally, at T3, significant differences in the attenuation of vibration between positions were observed for the condition of 6 mm/20 Hz (p=0.002), with attenuation being higher in FP, and for the conditions of 2 mm/50 Hz, 2 mm/70 Hz, 6 mm/50 Hz and 6 mm/70 Hz (p≤0.001), with higher values in EP. There were no significant differences in the tests performed at 2 mm/20 Hz (p=0.078), 2 mm/35 Hz (p=0.738) or 6 mm/35 Hz (p=0.179) (Figure 4).

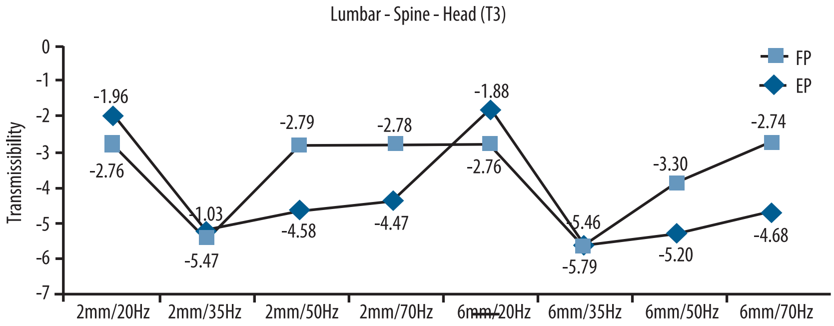

Figure 4. Vibration transmissibility at T3 in the extended (EP) and flexed (FP) positions.

DISCUSSION

The significant reduction in the magnitude of vibration observed in FP compared to EP suggests a very expressive interference of the body position adopted on the vibration platform with the characteristics of vibrations transmitted through the body segments. Abercromby et al.[20] observed a similar behavior of the biodynamic responses to WBV training, wit an almost 50% reduction in the acceleration reaching the trunk and head when the knees were flexed between 26 and 30º, an angle similar to that used in the present study. According to Harazin and Grzesik[18], this finding can be explained by the dealignment of body segments due to flexion of the joints and consequent activation of the muscles involved in the maintenance of posture. The increased muscle activation promotes changes in the elastic and damping properties of musculoskeletal tissues, resulting in a significant reduction in the acceleration transmitted to the subject's body.

With respect to vibration transmissibility through body segments, interpretation of the transfer function applied to the data indicates lower transmissibility in FP at times T1 and T2, suggesting more effective attenuation of the vibratory stimuli in this position, thus minimizing the magnitude of accelerations that are transmitted to the following body segment. On the other hand, at T3, the attenuation of vibration was higher for EP in most conditions (4/5) in which a significant difference was observed, suggesting lower transmission of acceleration to the head. In other words, although the body position exerts a major influence on the attenuation of vibrations, this interferences occurs more isolated and more expressively at the first two moments of transmission (T1 and T2) during passage of the vibratory stimuli through the lower limbs.

One possible explanation for this behavior is that, in view of the greater attenuation at T1 and T2, the magnitude of vibration that reached the point of the lumbar spine was not as expressive and therefore less susceptible to variation, i.e., there were no longer many stimuli available for transfer to the head. Harazin and Grzesik[18] also found that the influence of position is more evident at the level of the hip. According to that study, this behavior is related to the fact that, above the hip, vibration is strongly attenuated by the internal organs of the trunk, with no significant difference between one position and the other since this segment is maintained in extension in both positions.

The action of the lower limbs has also been emphasized by Lafortune et al.[16] who observed that, during WBV training, the triceps surae is the main muscle responsible for the attenuation of vibration between the ankle and knee, and the most participatory leg muscle. Similarly, one may suppose that the thigh, quadriceps and hamstring muscles also contribute strongly to the damping or attenuation of vibration originating from the platform.

Knee flexion increases the tension on the posterior muscles of the lower limbs, with a positive impact on the action of the plantar flexor muscles, in this case the triceps surae, which results in greater attenuation of vibration[25]. Greater activation of these muscles as a result of knee and hip flexion seems to permit a more intensified participation in the attenuation of vibrations, which continue to propagate after induction of the triceps surae, reducing the vibratory range and resulting in lower accelerations to the trunk and head.

In addition to reducing vibration transmissibility, the dealignment of body segments permits a more stable position on the platform, thus contributing to body balance[16]. Furthermore, the foot provides a large amount of proprioceptive information due to the receptors located in the midfoot region, around the head of the metatarsal bones and hallux, and in lumbrical muscles[26]. This fact may have influenced the results found since in FP the greatest contact of the foot with the vibratory surface occurs in this region of the plantar surface. One can thus infer that the body proprioception of the individual is greater in FP, with a more efficient activation of the muscles necessary to attenuate acceleration, in contrast to EP in which acceleration is not sufficiently attenuated[20-24]. These findings demonstrate that the body position adopted by the subjects on the vibrating platform directly interferes with the transmission of vibration through body segments, preventing more marked accelerations in the trunk and head and consequently reducing the chances of occurrence of resonance peaks both in internal organs of the trunk, where they occur in the range of 3 to 6 Hz, and in the head, where they occur at 30 Hz[27].

However, analysis of the transmission of vibrations as a whole revealed significant differences only for the conditions of 2 mm/20 Hz ($p=0.001$), 2 mm/35 Hz ($p<0.001$) and 6 mm/35 Hz ($p<0.001$), with higher values in FP, indicating more significant attenuation of acceleration in this position at these vibration intensities. These findings led us to believe that the contribution of body position to vibration transmission is enhanced at lower frequencies and that these frequencies are determinant factors of this process. However, this analysis was not performed in the present study.

CONCLUSIONS

The present results demonstrate that the body position adopted by the subjects on the vibration platform during WBV training directly interferes with the transmissibility of vibration through the body segments of individuals. The extended position on the platform was less favorable to the attenuation of vibrations transmitted to the human body, increasing the vibration range and reaching the head segment with more intensity. Since head accelerations should be avoided, this position is considered inadequate and should therefore not be applied or reproduced. The flexed position was confirmed to be more adequate for WBV training since it ensures better body stability on the platform and promotes more effective attenuation of vibratory stimuli, thus preventing the occurrence of unintended acceleration in the head.

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