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Characterizing the magnitude of vibration imposed by stochastic whole-body vibration platforms used in rehabilitation and training: a preliminary study

Caracterização da magnitude da vibração imposta por plataformas vibratórias estocásticas de corpo inteiro utilizadas em reabilitação e treinamento: estudo preliminar

Leandro Vinhas de Paula[1,2]
https://orcid.org/0000-0003-0323-5182
André Gustavo Pereira Andrade[2]
http://orcid.org/0000-0003-3406-4558
Warley Henrique Duarte de Oliveira[2]
https://orcid.org/0000-0002-1304-0007
Gustavo Ramos Dalla Bernardina[2]
https://orcid.org/0000-0002-4566-9504
Pedro Vieira Sarmet Moreira[3,4]
https://orcid.org/0000-0001-6919-0904
Leszek Antoni Szmuchrowski[2]
https://orcid.org/0000-0002-8715-4226

[1] Federal University of Ouro Preto – UFOP. School of Physical Education. Ouro Preto, MG. Brazil.
[2] Federal University of Minas Gerais – UFMG. School of Physical Education, Physiotherapy and Occupational Therapy. Belo Horizonte, MG. Brazil.
[3] Federal University of Rio de Janeiro – UFRJ. Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering – COPPE. Laboratory of Biomechanics. Biomedical Engineering Program. Rio de Janeiro, RJ. Brazil.
[4] Tech4fight Sports Technology. Rio de Janeiro, RJ. Brazil.

Abstract – The use of devices that produce stochastic whole-body vibration as a resource for rehabilitation and training programs has been founded on the theory of stochastic resonance. However, the prescription of rehabilitation and training programs must be preceded by the verification of imposed-vibration magnitude and of how it can be affected by the presence of an individual on the devices. The aim of this research was to characterize and analyze the effect of an individual's mass on the vibratory stimulus provided by stochastic whole-body vibration (SWBV) devices. The sample consisted of 30 repetitions for each one of the 6 vibration levels of the SWBV device (level 02, 04, 06, 08, 10 and 12), performed in two experimental situations (Without Load; Load [70Kg]; ≈ 35 kg on the right and left surfaces of the platform). For the antero-posterior, latero-lateral, and vertical directions, all variables showed significant differences between treatments, levels and interaction between experimental factors ($p<.05$), except for the Disp variable between treatments ($p=.075$). To measure vibration magnitude, a triaxial accelerometer was attached at the center of the board of one of the platform surfaces. Load interferes with parameters of vibration imposed by SWBV platforms, increasing A_{RMS} and A_{PEAK} in the latero-lateral and antero-posterior directions, reducing these same parameters in the vertical direction.

Key words: Acceleration; Rehabilitation; Stochastic processes; Training; Vibration.

Resumo – *O uso de dispositivos que produzem vibração estocástica de corpo inteiro como recurso para programas de reabilitação e treinamento foi fundamentado na teoria da ressonância estocástica. Entretanto, a prescrição de programas de reabilitação e treinamento deve ser precedida da verificação da magnitude da vibração imposta e de como ela pode ser afetada pela presença de um indivíduo nos dispositivos. O objetivo deste estudo foi caracterizar e analisar o efeito da massa do indivíduo sobre o estímulo vibratório proporcionado por dispositivos de vibração estocástica de corpo inteiro. A amostra consistiu em 30 repetições para cada um dos 6 níveis de vibração de um dispositivo de vibração estocástica de corpo inteiro (nível 02, 04, 06, 08, 10 e 12), realizados em duas situações experimentais (Sem carga e Carga [70Kg], 35 kg nas superfícies direita e esquerda da plataforma). Para medir a magnitude da vibração, um acelerômetro triaxial foi fixado ao centro do assoalho de uma das superfícies da plataforma. Para os eixos ântero-posterior, látero-lateral e vertical, todas as variáveis mostraram diferenças entre tratamentos, níveis e interação entre fatores experimentais ($p<.05$), exceto para a variável de deslocamento pico – a – pico (Disp) entre tratamentos ($p=.075$). A carga interfere com parâmetros de vibração impostos sobre as plataformas de vibração estocástica de corpo inteiro, aumentando a aceleração média (A_{RMS}) e de pico (A_{PEAK}) nas direções látero-lateral e ântero-posterior, reduzindo estes mesmos parâmetros na direção vertical.*

Palavras-chave: *Aceleração; Reabilitação; Processos estocásticos; Treinamento; Vibração.*

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Corresponding author
Leandro Vinhas de Paula.
School of Physical Education, Physiotherapy and Occupational Therapy, Federal University of Minas Gerais – UFMG
Av. Presidente Antônio Carlos, 6627, 31270-901, Pampulha, Belo Horizonte (MG), Brazil.
E-mail: leandro.paula@ufop.edu.br

INTRODUCTION

Devices that generate whole-body vibration (WBV) have been largely used in human beings as a technological resource for rehabilitation and training[1-3]. In general, traditional WBV devices produce sinusoidal stimuli[2-5], characterized by presenting constant oscillation frequency, peak-to-peak displacement and acceleration as parameters, besides, to a lesser extent, stochastic stimuli[4-8], defined by non-constant frequency, displacement and linear acceleration; however, to the best of our knowledge, the vibration imposed by these devices have not yet been properly characterized.

The use of devices that produce stochastic whole-body vibration (SWBV) as a resource for rehabilitation and training programs has been founded on the theory of stochastic resonance (SR)[6,9,10]. Basically, stochastic resonance (SR) is a phenomenon found in several biological systems, in which the response of a weak sinusoidal signal is optimized in the presence of a certain level of noise in the neural system, with said presence being evidenced by an amplified response from the proprioceptive system[6,9,10].

Additionally, it has been suggested that stochastic vibrations amplify information from the peripheral nervous system by reducing the sensorial threshold of different joints[9]. Due to the stochastic characteristic of vibration, the direction and behavior of the oscillatory movement are not predictable, so the human body is challenged to adapt by producing adjustments to control body posture[8,11].

The use of the stochastic resonance mechanism by means of SWBV devices has generated positive effects on the cerebral activity of caudate nuclei associated with the motor function[12], as well as on postural stability and control with application to patients that have Parkinson's disease, but needs to be further elucidated[8,13]. Turbanski et al.[8] found 14.9-24% of positive sub-acute effects on postural control and rigidity and tremor scores. In this sense, pharmacological intervention in the treatment of Parkinson's disease has been associated with the use of stochastic vibratory stimulation, since postural instability may not be treated with medication[7,8].

However, one must be attentive to the time of exposure to vibratory stimulus, given the harmful effects observed in chronically exposed individuals, especially in occupational environments. Reported negative effects include physiological and structural disorders on the spine and on the digestive, reproductive, visual and vestibular systems[14]. Thus, quantitative security measures have been standardized and applied for determining the severity of exposure to vibration by means of estimates on vibration dose value (eVDV), calculated based on the direction, frequency, acceleration and length of vibration imposed to humans in one single metric[15]. Potential health risks are classified when eVDV scores exceed the limit value of 17 $m.s^{-1.75}$ [15].

Thus, vibration parameters must be known for a reliable prescription of rehabilitation and training protocols with SWBV. To determine the magnitude of imposed vibration, intervention studies with WBV devices have suggested the need to report the commercial technical details of the device, in addition to type of generated vibration, vibration frequency (Hz), peak-to-peak displacement (mm), peak linear acceleration ($m.s^{-2}$), and the square root of the mean square (RMS) for linear acceleration values ($m.s^{-2}$)[2,16,17]. Studies with SWBV have reported frequencies of 2 to 12 Hz and 3 mm of peak-to-peak displacement, without registering these parameters experimentally[7,8,11-13,18,19].

However, Pel et al.[16] and Rauch et al.[17] defend the need to characterize the vibration parameters provided by WBV devices and to investigate whether they are reproducible in conditions of absence and presence of individuals on the equipment, a core matter oftentimes disregarded, since the magnitude of the vibration that reaches the target body region affects the adaptations to exercise protocols with vibrations, as a dose-response relationship[2,18]. Vibration magnitude can be expressed by peak acceleration and in RMS, obtained by measuring linear acceleration with the aid of a triaxial accelerometer placed on the surface of WBV devices[2]; however, it is not yet clear if the acceleration value, in RMS, of 20 ms^{-2}, verified with the absence of mass for a certain level of vibration, is maintained compared to the value obtained in a condition under which an individual stands on a SWBV device.

Thus, the prescription of rehabilitation and training programs must be preceded by the verification of imposed-vibration magnitude and of how it can be affected by the presence of an individual on the devices. Despite, little is known about the vibration imposed by SWBV devices, since, to the best of our knowledge, imposed-vibration parameters have not been monitored by means of linear acceleration values during the execution of protocols in the identified intervention studies[7,8,11-13,18-21]. Therefore, given the potential effects of SWBV and the importance of knowing stochastic vibration parameters, the aim of this research was to characterize and analyze the effect of an individual's mass on the vibratory stimulus provided by SWBV devices employed in rehabilitation and sport training programs. In this sense, the hypothesis herein is that placing an individual on the SWBV platform may affect vibration parameters, just as observed for traditional WBV platforms by Pel et al.[16].

METHOD

Sample

The sample consisted of 30 repetitions for each one of the 6 vibration levels, performed in two experimental situations (Without load and With Load, described in the following section), totaling 360 repetitions (sets) for each one of the antero-posterior, latero-lateral and vertical directions as to linear acceleration records. Stochastic vibrations are generated through the combination of a sinusoidal signal and a random signal, a uniform noise[8]. Vibration levels were selected from L02 to L12 (Levels - L02, L04, L06, L08, L10, and L12) and noise levels were noise from N01 to N05 (N01, N03 and N05). Thus, 10 repetitions were collected for each respective combination of vibration level and noise (30 repetitions / vibration level). The present study was approved by the local ethics committee, in compliance with the Helsinki declaration.

Procedures

This study used an SWBV platform (SRT Zeptor training PLUS NOISE®, Frankfurt, Germany) that produces stochastic vibrations in the antero-posterior, latero-lateral and vertical directions ("x"; "y"; and "z", respectively) on two independent surfaces, with maximum load capacity of 150 Kg (Figure 1).

The SWBV platform has 12 vibration levels (L01 to L12) and 5 noise levels (N01 to N05), as described by the manufacturer. However, to characterize the devices, only vibration levels L02, L04, L06, L08, L10 and L12 were studied, similarly to the research by Blasimann et al.[18], combined with noise levels N01, N03 and N05, to make up the whole vibration and noise spectrum provided by the SWBV platform.

In this study, two experimental situations were executed; in without load situation, was applied to the surface of the platform, and in with load situation, an individual with mass of 70 Kg (≈ 35 kg on the right and left surfaces of the platform), which corresponds to the average weight of an adult man, stood on the device, being instructed to maintain a static, half-squat position, supporting himself on the safety side structures of the platform. The vibration levels (L02, L04, L06, L08, L10 and L12) and noise levels (N01, N03 and N05) were reprogrammed manually through the human-machine interface of the platform (Figure 1B). For each combination of vibration and noise levels, 10 sets were executed, with length of 20 seconds. The recording of the accelerometry data was carried out from the platform stabilization and beginning of the programmed protocol, visually signaled by the human - machine interface, after the end of the initial acceleration ramp of the device. The experiments were run on 6 days; on each day, 60 sets were performed for each level (30 for without load situation, and 30 for with load situation). To measure vibration magnitude, a triaxial accelerometer was attached to a signal acquisition system (8-channel ME6000T8 Biomonitor System, MEGA Eletronics, Kuopio, Finland) at the center of the board of one of the platform surfaces (Figure 1). Linear acceleration ($m.s^{-2}$) was measured at a sampling rate of 1 KHz during the experiments.

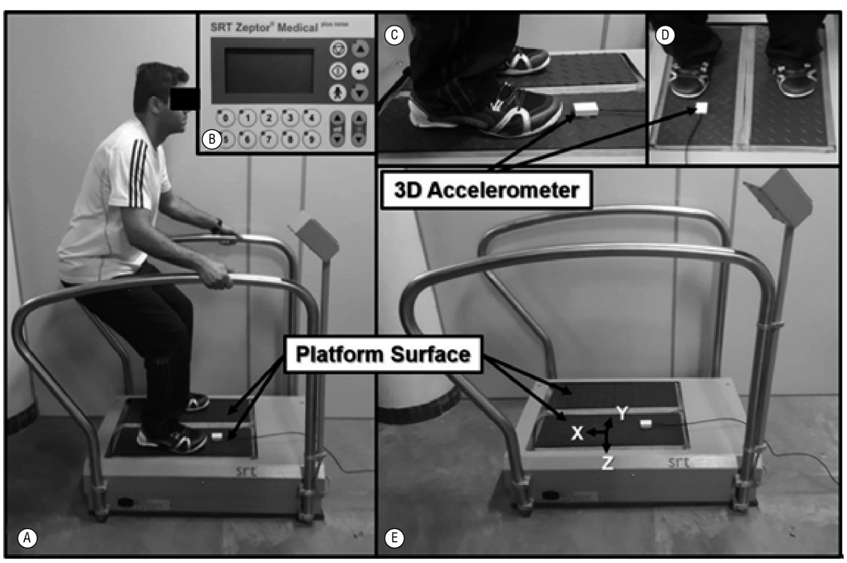

Figure 1. (A) Individual in half-squat position on the surface of the SWBV platform; (B) Human-machine interface for determination of vibration and noise level; (C) Foot position, surface and attachment point of the triaxial accelerometer (side view); (D) Foot position, surface and attachment point of the triaxial accelerometer (front view); (E) SWBV platform and vibration direction: “X”, antero-posterior; “Y”, latero-lateral; “Z”, superior-inferior (side view).

Data processing

Data for linear acceleration were filtered on a 4th-order, band-stop Butterworth filter of 59-61 Hz (Figure 2). Subsequently, the square root of the mean square for instantaneous values of linear acceleration (A_{RMS}, Equation 1) and peak acceleration (A_{PEAK}, Equation 2) were determined on the antero-posterior ("x"), latero-lateral ("y") and vertical ("z") directions for each combination of vibration and noise level.

$$A_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2} \tag{1}$$

$$A_{Peak} = A_{RMS} * \sqrt{2} \tag{2}$$

Then, a fast Fourier transform (F(t), Equation 3) was applied to the linear acceleration data in order to determine the frequency contents of the obtained signals and, consequently, of peak frequency (F_{Peak}).

$$F(t) = \sum_{n=-\infty}^{\infty} C_n e^{j\frac{2\pi n}{T}t}, where\, c_n = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)e^{-j\frac{2\pi n}{T}t} dt \tag{3}$$

The peak-to-peak displacement observed on the different axes was determined by means of the relation above (Disp, Equation 4), according to Rauch et al.[17] and Rittweger[2].

$$Disp = \frac{Apeak}{\left(2\pi^2 Fpeak^2\right)} \tag{4}$$

Additionally, the eVDV (Equation 5) was calculated in accordance with procedures defined by the ISO 2631-1 standard[15], in which aw is total magnitude of vibration; awx is defined as acceleration in frequency-weighted RMS on the "x" direction; awy is acceleration in frequency-weighted RMS on the "y" direction; awz is acceleration in frequency-weighted RMS on the "z" direction; T is the length of daily exposure in seconds; and kx, ky and kz are multiplying factors ($k_x = 1.4; k_y = 1.4; and\, k_z = 1$).

$$eVDV = 1.4 a_w T^{1/4}, where\, a_w = \left(k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2\right)^{1/2} \tag{5}$$

The analyses were run through software Matlab®, R2016a (Mathworks, Natick, USA).

Statistical analysis

A_{RMS}, A_{PEAK}, F_{PEAK} and Disp values for each proposed combination are described in terms of mean and standard deviation. To check the reliability, the absolute standard error of measurement (SEM; standard deviation of the differences divided by the square root of 2) was computed. To make comparisons among combinations for the studied variables, normality and homoscedasticity assumptions were verified (Shapiro-Wilk and Fligner tests, respectively). Afterwards, an analysis of variance as to interaction of experimental factors was applied (Mass vs. Vibration level, ANOVA two-way) for each one of the studied variables. When necessary, a log transformation was applied, and the normality and homoscedasticity tests were run again. If the value of the F statistic was significant in the acute or residual responses, a Tukey's test for multiple comparisons was applied to verify where differences occurred between treatments. The effect sizes were calculated using partial eta-squared test (η^2p). The adopted level of significance was *p*<.05. For the analyses, statistical software R, version 3.3.0, was employed.

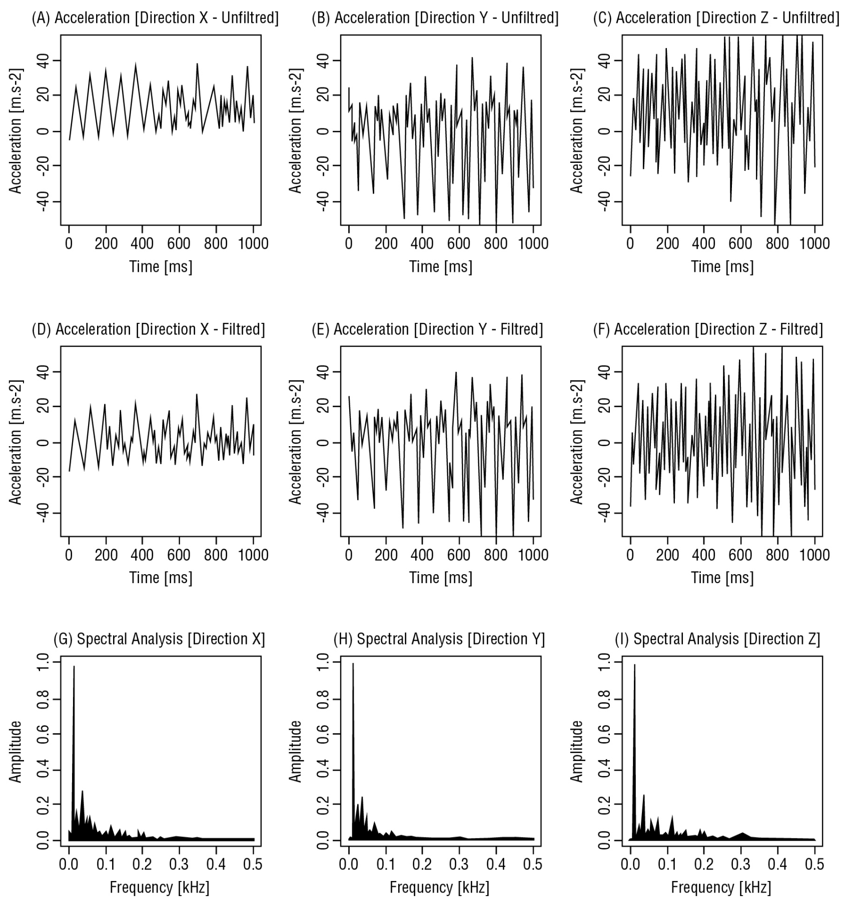

Figure 2. Examples of unfiltered signals ([A] Acceleration [m.s-2] vs. Time [ms], Direction X; [B] Acceleration [m.s-2] vs. Time [ms], Direction Y; [C] Acceleration [m.s-2] vs. Time [ms], Direction Z), filtered ([D] Acceleration [m.s-2] vs. Time [ms], Direction X; [E] Acceleration [m.s-2] vs. Time [ms], Direction Y; [F] Acceleration [m.s-2] vs. Time [ms], Direction Z) and spectral analysis ([G] Amplitude vs. Frequency [kHz], Direction X; [H] Amplitude vs. Frequency [kHz], Direction Y; [I] Amplitude vs. Frequency [kHz], Direction Z) - Level 12, Noise 5.

RESULTS

For the antero-posterior direction ("x"), the A_{RMS}, A_{PEAK} and F_{PEAK} variables showed significant differences between treatments (A_{RMS}, F(1,348) = 297.17, p<.001, η^2_p = 0.46 [0.40, 0.51]; A_{PEAK}, F(1,348) = 297.16, p<.001, η^2_p = 0.46 [0.40, 0.51]; and F_{PEAK}, F(1,348) = 85.23, p<.001, η^2_p = 0.20 [0.14, 0.26]), among levels (A_{RMS}, F(5,348) = 28.68, p<.001, η^2_p = 0.29 [0.22, 0.35]; A_{PEAK}, F(5,348) = 28.70, p<.001, η^2_p = 0.29 [0.22, 0.35]; and F_{PEAK}, F(5,348) = 4.27, p<.001, η^2_p = 0.06 [0.02, 0.09]), and significant interaction between treatment experimental factors and vibration level (A_{RMS}, F(5,348) = 5.76, p<.001, η^2_p = 0.08 [0.03, 0.11]; A_{PEAK}, F(5,348) = 5.75, p<.001, η^2_p = 0.08 [0.03, 0.11]; and F_{PEAK}, F(5,348) = 36.27, p<.001, η^2_p = 0.34 [0.27, 0.40]). The Disp variable showed marginal differences between treatments (Disp, $F(1,348) = 3.18$, $p=.075$, $\eta^2_p = 0.00$ [0.00, 0.03]), significant differences among levels (Disp, $F(5,348) = 4.63$, $p<.001$, $\eta^2_p = 0.06$ [0.02, 0.10]), and interaction among the studied factors (Disp, $F(5,348) = 20.19$, $p<.001$, $\eta^2_p = 0.22$ [0.16, 0.28]). In Table 1, the A_{RMS}, A_{PEAK}, Disp and F_{PEAK} variables and SEM are described for the "x" direction, and differences between treatments are reported for the respective vibration levels and within each treatment among vibration levels for each variable.

Table 1. A_{RMS} ($m.s^{-2}$), A_{PEAK} ($m.s^{-2}$), Disp (m), and F_{PEAK} (Hz) vibration parameters on vibration levels and standard error measurement (SEM) in situations without load and with load for the "x" direction.

Treatment/ Level		VARIABLES			
		A_{RMS} ($m.s^{-2}$)	A_{PEAK} ($m.s^{-2}$)	F_{PEAK} (Hz)	Disp (m)
Without Load	L02	7.19±4.84A	10.17±6.75A	2.72±1.37ABCD*	0.011±0.012ABCDE*
	L04	2.39±0.72ABCDE*	3.38±1.02ABCDE*	6.31±0.17EF*	0.005±0.002A
	L06	5.23±2.80BEF*	7.40±3.96BFG*	9.56±0.01A	0.004±0.002B
	L08	5.78±3.38CG*	8.18±4.78CH*	12.23±1.29BE	0.003±0.001C*
	L10	7.79±2.33DE*	11.03±3.30DF*	9.70±1.02C	0.006±0.002D
	L12	8.57±1.89EFG*	12.12±2.68EGH*	11.74±1.04DF	0.005±0.002E
	SEM	2.124	3.005	0.940	0.005
Load	L02	9.79±1.89ab	12.99±2.67ab	17.64±5.95abcd*	0.004±0.002ab*
	L04	9.61±2.67cd*	13.59±3.78cd*	20.24±11.62efgh*	0.004±0.003cd
	L06	10.25±2.82e*	14.49±3.99ef*	10.78±10.48ae	0.006±0.005e
	L08	11.22±2.89f*	15.87±4.09g*	9.18±1.84bf	0.010±0.004acef*
	L10	12.61±2.52ac*	17.83±3.57ace*	10.57±0.16cg	0.008±0.001bd
	L12	14.36±2.64bdef*	20.31±3.74bdfg*	12.54±0.22dh	0.007±0.001f
	SEM	2.283	3.228	6.87	0.003

Note: [A,B,C,D,E,F,G,H] Equal capital letters indicate significant differences between levels of the "without load" treatment for each variable ($p < 0.05$); [a,b,c,c,e,f,g,h] Equal lowercase letters indicate significant differences between levels of the "load" treatment for each variable ($p < 0.05$); *Asterisks indicates differences between treatments at each respective vibration level for each variable ($p < 0.05$).

On the latero-lateral direction ("y"), all variables showed differences between treatments (A_{RMS}, $F(1,348) = 221.61$, $p<.001$, $\eta^2_p = 0.39$ [0.33, 0.45]; A_{PEAK}, $F(1,348) = 221.60$, $p<.001$, $\eta^2_p = 0.39$ [0.33, 0.45]; Disp, $F(1,348) = 60.47$, $p<.001$, $\eta^2_p = 0.15$ [0.10, 0.21]; and F_{PEAK}, $F(1,348) = 19.06$, $p<.001$, $\eta^2_p = 0.05$ [0.02, 0.09]), among levels (A_{RMS}, $F(5,348) = 274.65$, $p<.001$, $\eta^2_p = 0.80$ [0.77, 0.82]; A_{PEAK}, $F(5,348) = 274.65$, $p<.001$, $\eta^2_p = 0.80$ [0.77, 0.82]; Disp, $F(5,348) = 7.48$, $p<.001$, $\eta^2_p = 0.10$ [0.04, 0.14]; and F_{PEAK}, $F(5,348) = 52.34$, $p<.001$, $\eta^2_p = 0.43$ [0.36, 0.48]), and significant interaction among experimental factors (A_{RMS}, $F(5,348) = 4.02$, $p=.001$, $\eta^2_p = 0.05$ [0.01, 0.09]; A_{PEAK}, $F(5,348) = 4.01$, $p=.001$, $\eta^2_p = 0.05$ [0.01, 0.09]; Disp, $F(5,348) = 12.07$, $p<.001$, $\eta^2_p = 0.15$ [0.09, 0.20]; and F_{PEAK}, $F(5,348) = 16.82$, $p<.001$, $\eta^2_p = 0.19$ [0.13, 0.25]). In Table 2, the A_{RMS}, A_{PEAK}, Disp and F_{PEAK} variables are described for the "y" direction, and differences between treatments are reported for the respective vibration levels and within each treatment among vibration levels for each variable.

On the other hand, for the vertical direction ("z"), the A_{RMS}, A_{PEAK}, Disp and F_{PEAK} variables showed significant changes between treatments (A_{RMS}, $F(1,347) = 9.27$, $p=.002$, $\eta^2_p = 0.06$ [0.03, 0.11]; A_{PEAK}, $F(1,347) = 9.28$, $p<.002$, $\eta^2_p = 0.06$ [0.03, 0.11]; Disp, $F(5,347) = 6.28$, $p<.01$, $\eta^2_p = 0.02$ [0.00, 0.05]; F_{PEAK}, $F(1,347) = 13.88$, $p<.001$, $\eta^2_p = 0.04$ [0.01, 0.08]), among levels (A_{RMS}, $F(5,348) = 508.17$, $p<.001$, $\eta^2_p = 0.92$ [0.91, 0.93]; A_{PEAK}, $F(5,347) = 508.17$, $p<.001$, $\eta^2_p = 0.92$ [0.91, 0.93]; Disp, $F(5,347) = 524.28$, $p<.001$, $\eta^2_p = 0.88$ [0.87, 0.90]; and F_{PEAK}, $F(1,347) = 103{,}158$, $p<.001$, $\eta^2_p = 1.00$ [1.00, 1.00]), and significant interaction between treatment factors and vibration level (A_{RMS}, F(5,347) = 54.74, p<.001, η^2_p = 0.44 [0.38, 0.49]; A_{PEAK}, F(5,348) = 54.74, p<.001, η^2_p = 0.44 [0.38, 0.49]; Disp, F(5,347) = 61.409, p<.001, η^2_p = 0.47 [0.41, 0.52]; F_{PEAK}, F(5,347)=38.42, p<.001, η^2_p = 0.36 [0.29, 0.41]). In Table 3, the A_{RMS}, A_{PEAK}, Disp and F_{PEAK} variables are described for the "z" direction, and differences between treatments are reported for the respective vibration levels and within each treatment among vibration levels for each variable.

Table 2. A_{RMS} (m.s^{-2}), A_{PEAK} (m.s^{-2}), Disp (m) and F_{PEAK} (Hz) vibration parameters on vibration levels and standard error measurement (SEM) in situations without load and with load for the "y" direction.

Treatment/ Level		VARIABLES			
		A_{RMS} (m.s^{-2})	A_{PEAK} (m.s^{-2})	F_{PEAK} (Hz)	Disp (m)
Without Load	L02	2.00±0.09ABCD*	2.83±0.14ABCD*	21.75±5.58ABCDE*	0.002±0.007ABCDE*
	L04	3.01±0.27EFG*	4.25±0.38EFG*	11.05±7.94AF*	0.008±0.007A*
	L06	3.94±0.39AHIJ*	5.57±0.55 AHIJ*	5.68±0.65BFG	0.009±0.002B
	L08	6.14±0.47BEHKL*	8.69±0.67BEHKL*	7.64±0.68C	0.008±0.001C
	L10	9.35±1.36CFIKM*	13.22±1.92CFIKM*	9.15±1.13D	0.008±0.002D
	L12	11.51±1.05DGJLM*	16.28±1.49DGJLM*	11.01±1.37EG	0.007±0.002E
	SEM	0.145	0.205	4.330	0.004
Load	L02	3.82±4.49abcde*	5.40±6.35abcde*	12.47±10.13abc*	0.014±0.013ab*
	L04	6.11±4.66afgh*	8.65±6.59afgh*	5.38±3.31ade*	0.017±0.006cdef*
	L06	6.56±0.27bijk*	9.28±0.39bijk*	6.22±0.09bfg*	0.012±0.004c
	L08	8.89±0.23cfilm*	12.58±0.32cfilm*	8.06±0.21ch	0.009±0.001d
	L10	12.72±0.28dgjln*	17.98±0.40dgjln*	10.45±0.21df	0.008±0.001ae
	L12	16.38±0.96ehkmn*	23.17±1.36ehkmn*	12.09±0.38egh	0.008±0.001bf
	SEM	1.973	2.791	4.330	0.006

Note: A,B,C,D,E,F,G,H,I,J,K,L,M,N Equal capital letters indicate significant differences between levels of the "without load" treatment for each variable (p < 0.05); a,b,c,c,e,f,g,h,i,j,k,l,m,n Equal lowercase letters indicate significant differences between levels of the "load" treatment for each variable (p < 0.05); *Asterisks indicates differences between treatments at each respective vibration level for each variable (p < 0.05).

Table 3. A_{RMS} (m.s^{-2}), A_{PEAK} (m.s^{-2}), Disp (m) and F_{PEAK} (Hz) vibration parameters on vibration levels and standard error measurement (SEM) in situations without load and with load for the "z" direction.

Treatment/ Level		VARIABLES			
		A_{RMS} (m.s^{-2})	A_{PEAK} (m.s^{-2})	F_{PEAK} (Hz)	Disp (m)
Without Load	L02	10.48±0.05ABC	14.82±0.07ABC	2.49±0.01ABCDE	0.012±0.01ABC
	L04	10.45±0.06DEF*	14.78±0.09 DEF*	4.24±0.01AFGHI*	0.018±0.01ADEF*
	L06	10.86±0.04GHI	15.36±0.05 GHI	6.34±0.01BFJKL	0.019±0.001BGHI
	L08	12.65±0.12ADGJK	17.90±0.17ADGJK	8.43±0.02CGJMN	0.012±0.001DGJK
	L10	17.13±0.50BEHJL*	24.23±0.71BEHJL*	10.69±0.06DHKMO*	0.010±0.001EHJ*
	L12	21.52±0.48CFIKL*	30.44±0.68CFIKL*	12.39±0.02EILNO*	0.010±0.001CFIK*
	SEM	0.131	0.186	0.015	0.0001
Load	L02	11.17±2.50abcde	15.80±3.53abcde	2.50±0.13abcde	0.012±0.01abcd
	L04	12.46±3.28afgh*	17.62±4.64afgh*	4.06±0.21afghi*	0.025±0.01aefgh*
	L06	11.41±0.24bfijk	16.14±0.34bfijk	6.40±0.17bfjkl	0.018±0.004beijk
	L08	12.66±0.27cfilm	17.90±0.39cfilm	8.49±0.02cgjmn	0.012±0.001film
	L10	15.01±0.80dgjln*	21.21±1.13dgjln*	10.87±0.35dhkmo*	0.009±0.001cgjl*
	L12	18.19±0.61ehkmn*	25.72±0.87ehkmn*	12.66±0.03eilno*	0.004±0.001dhkm*
	SEM	0.593	1.405	0.127	0.002

Note: A,B,C,D,E,F,G,H,I,J,K,L,M,N,O Equal capital letters indicate significant differences between levels of the "without load" treatment for each variable (p < 0.05); a,b,c,c,e,f,g,h,i,j,k,l,m,n,o Equal lowercase letters indicate significant differences between levels of the "load" treatment for each variable (p < 0.05); *Asterisks indicates differences between treatments at each respective vibration level for each variable (p < 0.05).

Finally, the determination of the standard error of absolute measurement (SEM) showed that the amount of random variation between series is greater for all parameters of vibrations and directions quantified in the situation with load, in relation to the situation without load. The eVDV values obtained for each one of the levels in situation B ("load") were, respectively, 33.67 m.s$^{-1.75}$ (L02), 37.51 m.s$^{-1.75}$ (L04), 34.59 m.s$^{-1.75}$ (L06), 38.51 m.s$^{-1.75}$ (L08), 45.66 m.s$^{-1.75}$ (L10) and 55.52 m.s$^{-1.75}$ (L12).

DISCUSSION

The objective of the present study was to characterize and analyze the effect of using an individual on the vibratory stimulus provided by SWBV devices. The established hypothesis was largely confirmed because, on all axes, for most vibration levels, vibration parameters were affected by the presence of an individual on the SWBV platform. The applied treatments interacted with the vibration levels for the A_{RMS}, A_{PEAK}, Disp and F_{PEAK} parameters, in the antero-posterior, latero-lateral and vertical directions. Additionally, there was a main treatment effect (presence of mass) and, naturally, among the vibration levels proposed for all axes. For example, from the results found, if a professional prescribes a protocol with level-10 vibration (L10) for an individual, an increase is expected in the antero-posterior direction of all studied parameters (A_{RMS}, 38.22%; A_{PEAK}, 38.13%; F_{PEAK}, 8.23%; Disp, 25%), in the latero-lateral direction for vibration magnitude (A_{RMS}, 26.49%; A_{PEAK}, 26.47%) and F_{PEAK} (12,44%) and F_{PEAK} (12.44%), and a respective reduction in the vertical directions of vibration magnitude (A_{RMS}, 12.37%; A_{PEAK}, 12.46%) and Disp (10%) in each set. As far as we know, this is the first study to characterize and show that mass interferes with the magnitude of vibration imposed on SWBV devices used as a means for rehabilitation and training.

In short, the presence of mass on the device increased A_{RMS} and A_{PEAK} in the antero-posterior and latero-lateral directions. Mean and peak acceleration values showed an increase of 21.70% to 75.13% in the antero-posterior direction, and 26.4% to 50.8% in the latero-lateral direction. In practice, the values found for the treatment without load were close to 1g and 1.5g, reaching 1.5g and 2g with load. An increased acceleration in the latero-lateral and antero-posterior directions must impose a greater disturbance to balance and a greater difficult in maintaining stability[22], affecting the understanding of biomechanical responses based only on previously chosen vibration parameters because, to the best of our knowledge, intervention studies with SWBV platforms have not reported vibration parameters during the execution of protocols[8,18,19]. Peak-to-peak displacement and peak frequency registered on the antero-posterior and latero-lateral axes are not uniform, oscillating substantially among vibration levels (3-11mm and 2.72-20.24Hz), differing with presence of load, especially on lower vibration levels (L02 and L04).

In the vertical directions ("z"), peak-to-peak displacement seems to reduce progressively as of L04 as peak frequency rises progressively. The mean displacement obtained (Table 3) for each one of the levels in the experimental situations in the present study was higher than the values (3mm) reported in different studies that have used SWBV devices[7,8,12,13,18,19]. On the other hand, despite differences between experimental situations, the increase in peak frequency observed in the load situation is clearly very small in relation to the situation without load, in which the values found on the "z" direction are similar to those reported by intervention studies[7,8,12,18,19]. However, the magnitude of imposed vibration seems to rise lightly and progressively up to L08, declining with more intense vibration levels.

Just as the benefits related to use of vibration, potential damages from chronic exposure to mechanical vibrations must be taken into account for the prescription of rehabilitation and training protocols. In this sense, by calculating the eVDV, it was possible to observe that acute exposure to 600 seconds vibration exceeded, on all vibration levels, the limit value of 17 $m.s^{-1.75}$. The estimated value of the vibration dose (eVDV, ISO 2631-1) oscillated progressively from 31.31 to 64.20 (without load; L02 – L12) and from 33.67 to 55.53 (with load; L02 – L12). Therefore, professionals who administer chronic treatments or training with stochastic vibrations should monitor this control parameter.

Although presence of mass influences vibration parameters in all directions, it is not possible to state that the magnitude of imposed vibration depends on the magnitude of mass on the platform. The present study employed approximately 46.66% or ≈ 23.33% per surface (70 Kg; ≈ 35 kg on the right and left surfaces of the platform) of the load capacity of the equipment to determine vibration parameters; the volunteer was selected according to the researchers' convenience, with a body mass similar to that of a normal adult individual. Thus, this stands as one of the limitations for characterizing the equipment, and, as a recommendation, one should study vibration parameters with all the load capacity supported by the device (0 Kg to 150 Kg). Moreover, in this study, vibration parameters were characterized on only one of the surfaces of the platform (right portion), so it is not possible to affirm that the calculated parameters are similar among surfaces for the respective vibration levels during the execution of rehabilitation and training protocols.

CONCLUSION

To summarize, mass or load interferes with parameters of vibration imposed by SWBV platforms, increasing A_{RMS} and A_{PEAK} in the latero-lateral and antero-posterior directions, reducing these same parameters in the vertical directions, especially on levels with higher vibration magnitude (L10 and L12). The calculation of the eVDV, it was possible to observe that acute exposure to 600 seconds vibration exceeded, on all vibration levels, the limit value of 17$m.s^{-1.75}$. The calculation of the eVDV, it was possible to observe that acute exposure to 600 seconds vibration exceeded, on all vibration levels, the limit value of 17 $m.s^{-1.75}$. The provided information is of paramount importance in rehabilitation and training programs that employ SWBV devices.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee –Federal University of Minas Gerais and the protocol (no. 0353.0.203.000-11) was written in accordance with the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Conceived and designed the experiments: LVP, PVSM. Performed the experiments: LVP, WHDO, GRDB. Analyzed the data: LVP, AGPA. Contributed reagents/materials/analysis tools: LVP, LAS. Wrote the paper: LVP, WHDO, GRDB, AGPA, PVSM.

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