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Whole-Body Vibration Exercise as an Intervention to Improve Musculoskeletal Performance

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Abstract

The exposure of individuals to mechanical vibrations produced in vibrating platform can generate whole-body vibration (WBV) exercise. This modality of exercise represents a less tiring alternative to sport, which could benefit mechanical human behavior and prevent sports injuries and musculoskeletal disorders. The specificity of the human body, articulated and connected segments, requires to take into account the biomechanical parameters in protocols involving WBV exercise. Moreover, work time, rest time between the bouts in each session number of sessions, extension of the intervention, and week periodicity must be also well established. Responses to WBV exercise are observed at musculoskeletal, neurological, endocrinological and vascular levels. With respect to the musculoskeletal level, it is verified increase of muscle strength, endurance and power, improvement of the balance, increase of bone mineral density and the decrease of risk of falls. There are several tools to evaluate the responses of the body to WBV exercise. The aim of this chapter is to highlight the relevance of the WBV exercise as an intervention of the physical therapy for the better human optimization.

Keywords: whole-body vibration, human movement analysis, musculoskeletal performance, vibrating platform, clinical effects, biomechanics

1. Introduction

The exposure of individuals to mechanical vibrations produced in vibrating platform can generate whole-body vibration (WBV) exercise when the referred physical agent is transmitted to body of a person that is in contact with the platform. This modality of exercise represents

a less tiring alternative to sport, that could benefit mechanical human behavior and prevent sports injuries, and musculoskeletal disorders [1, 2].

Although, the intervention with WBV is not recent, the way as this procedure is used nowadays, it started in the Soviet Union in the last century to the rehabilitation of astronauts after traveling outside the Earth. In comparison with the astronauts that remained in the Earth, the microgravity or zero gravity has contributed to lead to lack of muscle and bone mass [3]. Unfortunately some conditions in the daily life mimics the microgravity or zero gravity, such as, individuals that (i) have a disease and must be on bed for long time, or (ii) are sedentary and are not stimulated to perform a minimal of physical activity, or (iii) are immobilized due to an accident or (iv) have disability due to muscular or neurological conditions and must be on wheelchair or on bed. Considering these conditions, there is a common finding, that is, the lack of mechanical vibration added to the body. In general, in several simple daily activities, such as walking or running, or practicing sports, as biking, or driving a car, or being in a public transportation, mechanical vibrations are added to the body [1–4].

Naturally, depending on the occupational activity, the individual is also exposed to mechanical vibrations, as the driver of a bus or a truck or an agricultural tractor, the operator of a stone crusher or a drilling machine. These conditions must be also better studied because they might be dangerous to the professionals. Although, these considerations are relevant and must be pointed out due to elevate intensity of the mechanical vibration that can be transmitted to the body of the individual [1, 5, 6].

And, when people cannot do or are not stimulated to perform an activity to add mechanical vibrations to body through a physical activity? There is a simple answer. The individual can be exposed to mechanical vibrations produced in a vibrating platform.

2. Vibrating platform

Considering the movement of the base of the vibrating platform, there are three main types available commercially, as it is illustrated in **Figure 1**. **Figure 1A** represents the vertical vibrating platform, that can be synchronous or triplanar. In the synchronous, the base oscillating uniformly up and down, while in the triplanar, the vibration is applied in anterior/posterior, side to side, and up and down directions. **Figure 1B** shows the side-alternating platform, in which there is reciprocating vertical displacements on the left and right side in relation to a fulcrum, like to a teeterboard. **Figure 1C** indicates the horizontal vibrating platform, in which the base presents movement anterior/posterior alternatively [1, 4, 7].

The mechanical vibration produced in the vibrating platform presents an oscillatory, sinusoidal and deterministic displacement in relation to an equilibrium position. These characteristics are highly desirable and permit the use of this vibratory stimulus in controlled conditions in interventions in health and fitness areas. Nevertheless, the specificity of the human body, articulated and connected segments, requires us to take into account the comportment of biomechanical parameters in protocols involving WBV exercise such as frequency, peak-to-peak displacement and peak acceleration [1, 8].

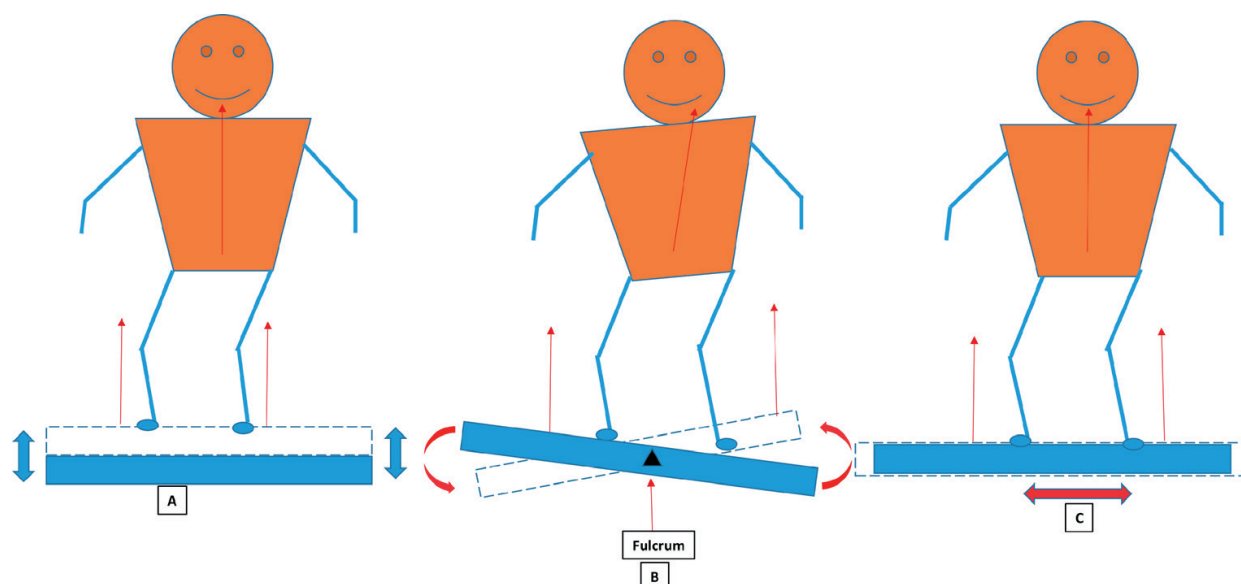


Figure 1. The main available types of vibrating platform: (A) represents the vertical, (B) side alternating and (C) horizontal vibrating platform. The red arrows indicate the movement of the base.

3. Biomechanical parameters of mechanical vibrations

Figure 2 illustrates the displacement of a sinusoidal mechanical vibration and some biomechanical parameters are indicated. It is possible to verify the displacement along of the time in an equilibrium position. The displacement between two successive points, as indicated by the arrows, is defined as the cycle, which is dimensionless parameter. The number of the cycles in the unit of time is the frequency. If it is considered 1 second, the frequency will express in Hertz (Hz) or s^{-1} . It is possible to verify that the displacement of the mechanical vibration has a highest and a lowest peak. This parameter is the peak-to-peak displacement that is measured, for example, in mm. In it, it is found the maximal rate of change in velocity during a cycle. Moreover, it is used to characterize the intensity of the exposition of the magnitude effect. In the highest peak, the highest acceleration, that is, the peak acceleration, measured in m/s^2 , or in number of the Earth acceleration ($\times g$) is found. These biomechanical parameters (frequency, peak-to-peak displacement and peak acceleration) are strongly relevant, due to, an individual that is in a vibrating platform will be submitted to them [1, 8].

In **Table 1**, additional information about the biomechanical is indicated of a sinusoidal mechanical vibration.

In addition, some studies with WBV exercise involve also combination intervention with other types of exercises, as the maximal voluntary contraction (MVC). Moreover, the individual can be standing in static position on performing dynamic exercises [9, 10].

Besides the biomechanical parameters, the work and rest time between the bouts in each session, number of sessions, extension of the intervention, week periodicity must be also well established. The biological responses to WBV exercise also depending on these parameters [1, 2, 7].

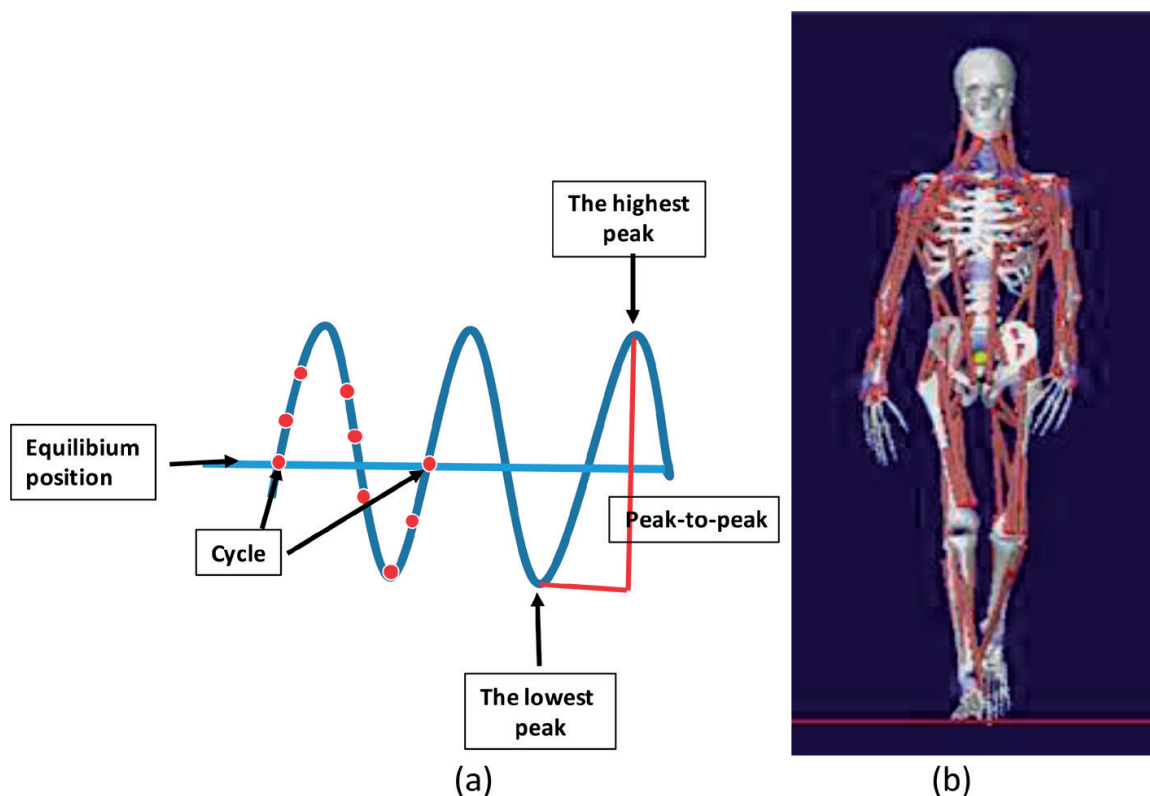


Figure 2. Illustration of a sinusoidal mechanical vibration (a) and articulated human movements (b).

Parameter	Definition	Symbol	Unity (IS)	Formula	Comment
Cycle	Displacement between two successive points in the vibration	-	-	-	With repetition of the same characteristics
Frequency	Repetition rate of the cycle	f, ν	Hz (s^{-1})	-	-
Peak-to-peak displacement (Synonymous to peak-to-peak amplitude)	Displacement between the lowest and the highest point of the cycle	D	mm	-	Perpendicular distance between the lowest and the highest point of the cycle
Amplitude (Synonymous to Peak Amplitude)	Maximal displacement from the equilibrium position	A	mm	$A=D/2$	-
Peak Acceleration	Maximal rate of change in velocity during a cycle (magnitude effect)	a_{Peak}	$m.s^{-2}$	$a_{Peak}=2x\pi^2xf^2xD$	Often expressed as multiples of Earth's gravity*

*Earth's gravity (commonly symbol: g) is a constant (9.81 ms^{-2}) denotes the nominal acceleration due to gravity at the Earth's surface at sea level (adapted from Rauch et al, 2010 [8])

Table 1. Biomechanical parameters of a sinusoidal mechanical vibration.

4. Biological responses and tools used to evaluate musculoskeletal responses to the WBV

Responses to WBV exercise are observed at musculoskeletal, neurological, endocrinological and vascular levels. In general, related to the musculoskeletal level, increase of muscle strength and of the bone mineral density, endurance and power, improvement of the balance and the decrease of risk of falls have been reported in trained and untrained individuals. These findings can contribute to decrease the possibility of injury, as in the sports, in the improvement of the fitness and on the management of various diseases. WBV exercise can produce beneficial responses, including improvements in muscle strength in trained (athletes) and untrained individuals and in patients with several clinical conditions, such as, chronic obstructive pulmonary disease (COPD), Parkinson's disease (PD), metabolic syndrome (MetS), fibromyalgia (FM) and multiple sclerosis (MS) [11–15]. Moreover, improvements in the walking function, the bone mineral density (BMD) in elderly, the low back pain (LBP), health-related quality of life (QOL), fall risk, balance and gait have been described [1, 7, 16–20].

Considering the musculoskeletal responses to the WBV exercise, several tools have been used in the evaluations, such as the flexibility, the level of pain, rating of perceived effort, recruitment of muscle fibers using electromyography (EMG), infrared thermography (IRT), various Questionnaires and scales and, the human movement analysis [12, 14, 18–21, 23, 24]. These tools can be used by the physiotherapist. Some publications about the WBV exercise responses in various populations and the tools utilized are presented in this chapter. Approaches in rehabilitation considering individuals with several diseases and approaches in healthy (trained and untrained) related to the fitness and wellbeing are discussed.

4.1. Approaches of the whole-body vibration in rehabilitation

Abbasi et al. [19], evaluated the WBV effects (6-week) training on the strength and endurance of core muscles in MS individuals, that were divided in intervention (WBV-G) and no intervention (control-G) groups. Sorensen, flexion, and side bridge endurance tests were used to evaluate the endurance (core muscles), the strength with a dynamometer and the QOL aspects with the quality of life-54 questionnaire (MSQOL-54). The strength, endurance (core muscles) and the MSQOL-54 scores significantly improved in WBV group in comparison to control-G. While the within-group comparison showed significant improvement in the WBV-G, in the control-G, physical and mental components of MSQOL-54 impaired over the investigation. It was concluded that strength and endurance of core muscles as well as QOL of MS patients can be positively influenced by a 6-week WBV training.

Krause et al. [15], investigated if WBV might attenuate the processing functional and neuromuscular degeneration of postural control in MS individuals. Performance in postural control was assessed before and after 6 weeks of a control group (CG) and a WBV intervention period. The center of pressure displacement (COP), muscle activity and co-contraction indices of muscles soleus (SOL), gastrocnemius medialis (GM), tibialis anterior (TA), biceps (BF) and rectus femoris (RF) as well as SOL H/M-ratios were evaluated. In the CG, it was verified that COP enhanced with reduced muscle activity in RF and diminished shank

muscle co-contraction. No alterations were found in COP and neuromuscular control after WBV. However, over time, TA activity was diminished, with no changes in muscle activation of SOL, GM and BF or H/M-ratios. It was concluded that in the CG, MS patients experienced substantial deteriorations in postural control which have previously been associated with greater postural instability. No further disease-associated deteriorations were observed following the intervention. Thus, WBV might alleviate neurodegeneration of postural control in people with MS. Abbasi et al. [19] also pointed out that the WBV program was well-tolerated by patients and no adverse event was observed.

Pin et al. [16], in a pilot study examined the feasibility and tolerance of WBV intervention for children and adults with moderate severity of cerebral palsy (CP) being graded as levels III or IV on the Gross Motor Function Classification Scale (GMFCS). Individuals received WBV intervention when standing still on the vibrating platform for three 3-min bouts of vibration (20 Hz, 2 mm amplitude), 4 days/week for 4 weeks. It was carried out assessment at baseline and completion of the intervention included the Gross Motor Function Measure-66 Item Set (GMFM-66 IS), 2-min walk test (2MWT), Timed Up and Go test (TUG) and Pediatric Evaluation of Disability Inventory (PEDI). Fourteen participants (GMFCS level III n = 13, 92%) completed the study. It was concluded that WBV training protocol was feasible, safe and well-tolerated by the individuals with moderate severity of CP, justifying future investigations with larger samples and more rigorous study design. It is also informed that, in this study, the attendance rate was over 90% with no adverse events. All participants tolerated the protocol which was satisfactorily delivered in a clinical setting.

Haas et al. [12] pointed out that is well known that applying vibrations to men influences multiple physiological functions and analyzed post effects of WBV on motor symptoms in PD. They were randomly subdivided into WBV-G and CG. Motor symptoms were assessed by the UPDRS (Unified Parkinson's Disease Rating Scale) motor score. The intervention was with five series of WBV (60 seconds each). On average a significant improvement of 16.8% in the UPDRS motor score was found in the WBV-G. Only marginal changes ($p > 0.05$) were found in the CG. The cross-over procedure showed comparable treatment effects (14.7% improvement after intervention). Considering different symptom clusters, only small changes were observed in limb akinesia and cranial symptoms. Tremor (25%) and rigidity (24%) scores were improved. It was concluded that, considering the structure of symptom changes, it is unlikely that these findings are explainable on peripheral sensory level, exclusively. In addition, considering the results of other investigations one can suppose about alterations in activation of the supplementary motor area and in neurotransmitter functions.

Lee et al. [7] evaluated the effect of WBV in the horizontal direction on balance and gait ability in chronic stroke (CS) survivors, that were randomly allocated into two groups (WBV-G) and CG. In the WBV-G, WBV training in the horizontal direction was conducted for 6 weeks, and a conventional rehabilitation for 30 min, 3 days per week for a 6-week period, was conducted in WBV-G and CG. Outcome variables included the static balance and gait ability measured before training and after 6 weeks. On comparing the outcome variables before and after training in the WBV-G, significant differences were observed in the cadence and single support time of gait ability. However, there were no significant differences in other variables,

including velocity, step length, stride length, and double support time. In addition, after training, no significant differences in all variables were observed between the two groups. The results suggest that WBV training in the horizontal direction has few positive effects on balance and gait function in CS survivors.

Huang et al. [22] studied the influence of WBV intervention frequency, amplitude, and body posture on lower limb muscle activation among people with CS. It was also evaluated whether the EMG response to vibration stimulus differed between paretic and non-paretic side and the relationship between muscle activation and WBV transmission. Individuals with CS performed three different exercises on the WBV vertical vibrating platform with various vibration conditions (frequency: 20, 30, 40 Hz; amplitude: 0.8, 1.5 mm), or without vibration. Muscle activity in bilateral vastus medialis (VM), medial hamstrings (MH), TA, and GM was measured by surface EMG. Tri-axial accelerometers were used to measure the acceleration at the platform and bilateral hips and knees. Muscle activity was significantly greater in the bilateral GM, TA, and MH, but not VM, compared with the same exercises without WBV. A great augmentation of muscle activation was observed with WBV with higher amplitude or higher frequency. Leg muscle activation was affected by the body posture. Considering paretic and non-paretic sides, WBV-induced muscle activation was largely similar, except to the TA. The lower WBV transmissibility (measured at the more proximal joints) was related to greater WBV-induced leg muscle activation. It was concluded that adding WBV to exercise significantly increased muscle activation in the GM, TA, and MH on both the paretic and non-paretic sides of CS survivors, and the increase was dependent on the WBV amplitude, frequency, and body posture.

Zheng et al. [18] verified effects of WBV exercise on lumbar proprioception in nonspecific low back pain (LBP) patients that performed an exercise 3 times a week for a total of 12 weeks of WBV exercise. The lumbar proprioception was measured by joint position sense. Outcomes were lumbar angle deviation and visual analogue scale (VAS) score. After the 12-week WBV exercise, lumbar flexion angle deviation was reduced from $3.65 \pm 2.26^\circ$ to 1.90 ± 1.07 , and extension angle deviation was reduced from $3.06 \pm 1.85^\circ$ to 1.61 ± 0.75 , significantly lower than baseline. After participating in the 12-week WBV exercise, a significant pain reduction was observed. Men in the whole group indicated significantly lower angle deviations in flexion and extension, whereas women indicated significantly lower flexion angle deviation, and no significant difference was found in extension angle deviation. However, by subdividing the entire group into poor and good proprioceptive groups, WBV exercise presented significant enhancement of lumbar proprioceptive ability in the poor flexion proprioception subgroup, poor extension proprioception subgroup, and good extension proprioception subgroup, but not in the subgroup with good flexion proprioceptive ability. It was concluded that lumbar flexion and extension proprioception as measured by joint position sense was significantly enhanced and pain was significantly reduced after 12-week WBV exercise in nonspecific LBP patients. However, the participants with good flexion proprioceptive ability had limited proprioceptive enhancement.

Kim et al. [21] assessed the effect of a 12-week horizontal vibration exercise (HVE) in chronic (LBP) patients as compared to vertical vibration exercise (VVE). Individuals were assigned

to the HVE or VVE groups and they performed the intervention (according each group) for 30 min each day, three times a week, for 12 weeks. The level of pain (VAS) and the functionality (Oswestry Disability Index—ODI) were evaluated. The lumbar muscle strength (isokinetic dynamometer), transverse abdominis (TrA) and multifidus muscle thicknesses (ultrasonography), and standing balance (balance parameters) were determined prior to treatment, 6 and 12 weeks after the first treatment, and 4 weeks after the end of treatment (that is, 16 weeks after the first treatment). Significant improvements with time on VAS, ODI, standing balance score, lumbar flexor, and extensor muscle strength without any significant changes in TrA or multifidus muscle thickness were found. No significant differences between HVE and VVE groups according to time in any of the assessments were observed. It is concluded that HVE is as effective as VVE in reducing pain, strengthening the lumbar muscle, and improving the balance and functional abilities of chronic LBP patients. Vibrational exercise increases muscle strength without inducing muscle hypertrophy. Moreover, it was pointed out no adverse events during treatment in either group.

Wang et al. [25] studied effects of WBV exercise for pain intensity and functional disability in individuals with non-specific chronic LBP in a single-blind randomized controlled trial that were randomly allocated to either the intervention group or the CG. The intervention group received WBV exercises and the CG general exercise protocol three times a week for 12 weeks. The pain level (VAS) and functional disability (ODI) were measured. Lumbar joint position sense, QOL (Short Form Health Survey 36) and overall treatment effect (Global Perceived Effect—GPE) were also verified. After the interventions (12 weeks), compared with the CG, the mean VAS and ODI scores significantly decreased by additional 1 point (95% confidence interval (CI) = -1.22 to -0.78), 3.81 point (95% CI, -4.98 , -2.63) based on adjusted analysis in the intervention group (WBV exercise). The intervention group provided additional beneficial effects for in terms of lumbar joint position sense, QOL, and GPE. It was concluded that WBV exercise could provide more benefits than general exercise for relieving pain and improving functional disability in patients with non-specific chronic LBP.

Tantawy et al. [26] investigated the effect of WBV exercise on stress urinary incontinence (SUI) after prostate cancer surgery. Individuals with mild SUI after radical prostatectomy were divided in Group 1, who performed pelvic floor muscle training (PFMT) and WBV exercise with a frequency and amplitude of 20 Hz/2 mm for the first two sessions and 40 Hz/4 mm for the rest of the intervention, and Group 2, who performed PFMT training alone. The interventions were conducted three times per week for 4 weeks (both groups). Incontinence VAS (I-VAS) score, International Consultation on Incontinence Questionnaire-Urinary Incontinence-Short Form (ICIQ-UI-SF) score and 24-hour pad test result (24HPT). I-VAS score, ICIQ-UI-SF score and 24HPT results showed significant within-group differences at each assessment (exception of the baseline and post-intervention I-VAS score in Group 2). Group 1 I-VAS score had a median difference of 3.9 cm [95% CI -4.0 to -3.8] from baseline to first follow-up, and a median difference of -2.0 cm (95% CI -2.2 to -1.8) at 4-week follow-up. After 4 weeks of intervention and at follow-up for all measured parameters, comparisons between the groups demonstrated significant differences favoring the Group 1. In conclusion, WBV exercise was an effective modality for treating patients with SUI after prostatectomy.

Sá-Caputo et al. [13] assessed effects of WBV exercise on functional parameters of MetS individuals. The biomechanical parameters of the mechanical vibration were frequency (from 5 up to 14 Hz) and the peak-to-peak displacements (from 2.5 up to 7.5 mm). In each session the individuals performed 1 min-bout of working time with 1 min-bout of passive rest in the peak-to-peak displacements for three-times. The WBV exercise protocol was applied twice per week for 5 weeks. Anterior trunk flexion, gait speed, sit-to-stand test and handgrip strength were investigated. Physiological parameters, as blood pressure and heart rate (HR) were also determined. No significant changes were observed in physiological parameters (arterial blood pressure and HR). Significant improvements were found in trunk flexion, gait speed, sit-to-stand test and handgrip strength after the WBV exercise: It was concluded that WBVE may induce biological responses that improve functional parameters in participants with MetS without interfering in physiological parameters, comparing before and after a 5-week WBV exercise.

Rigamonti et al. [9] evaluated the exercise-induced responses in Growth hormone (GH) isoforms in obese subjects. The acute effects of WBV exercise or maximal voluntary contraction (MVC) alone and the combination of MVC with WBV exercise (MVC + WBVE) on circulating levels of 22 and 20 kDa-GH were evaluated. Considering the stimulation of 22 and 20 kDa-GH secretion, it was found that MVC alone or combined with WBV exercise was significantly effective, but WBV exercise alone was ineffective. Related to the 22 and 20 kDa-GH peaks, after MVC + WBVE and MVC higher values were found in comparison with WBV exercise alone. Moreover, only 22 kDa-GH peak was significantly higher after MVC + WBV than MVC. In addition, the ratio of circulating levels of 22–20 kDa-GH was constant throughout the time window of evaluation after exercise and similar among the three protocols of exercise. It is suggested that the MVC, alone and in combination with WBV exercise stimulated 22 and 20 kDa-GH secretion in obese individuals. Since the ratio of 22–20 kDa-GH is constant after exercise and independent from the interventions in normal-weight subjects; hyposomatotropism (GH deficiency) in obesity does not seem to depend on an unbalance of circulating GH isoforms.

Yang et al. [20] evaluated the effects of WBV exercise on reducing risk of slip-related falls in obese individuals that were randomly assigned in vibration or placebo groups. They received 6-week vibration and placebo intervention on a side-alternating vibrating platform, respectively. Before and after the intervention, isometric knee extensors strength capacity was measured. The individuals (both groups) were also exposed to a standardized slip induced by a treadmill during gait prior to and following the intervention. Dynamic stability (DS) and fall incidences responding to the slip were also evaluated. WBV exercise significantly augmented the muscle strength and improved DS control at recovery touchdown after the slip occurrence. The improved DS could be associated with the enhanced trunk segment movement control, which may be related to the strength increment caused by the WBV exercise. The decrease of the fall rates from the pre-training slip to the post-training slip was greater among the whole-body vibration group than the placebo group (45 vs. 25%). It was concluded that vibration-based training could be a promising alternative or additional modality to active exercise-based fall prevention programs for people with obesity.

Pleguezuelos et al. [11] evaluated cardiac, metabolic, and ventilatory changes during the WBV exercise with three different frequencies in individuals with COPD in a prospective, interventional trial. They completed three sessions of WBV exercise in a vertical platform once a week using frequencies of 35, 25 Hz and no vibration in isometric squatting position. Cardiac, metabolic, and ventilator parameters were monitored (ergospirometer) during the sessions. Changes in oxygen pulse response (VO_2/HR) at the used frequencies were the primary outcome. Compared to the reference of 35 Hz, VO_2/HR at no vibration was 10.7% lower. No significant differences were observed on the comparison between the frequencies of 35 and 25 Hz. The median oxygen uptake (VO_2) was significantly lower 9.43% (25 Hz) and 13.9% (no vibration) in comparison to that was obtained at 35 Hz. The median expiratory volume without vibration was 9.43% significantly lower than the VO_2 at the end of the assessment at 35 Hz vibration. It was concluded that vertical WBV exercise sessions show greater cardiac, metabolic, and respiratory responses compared with the squat position. On comparing the two frequencies used, it was observed that the frequency of 35 Hz provides higher cardiorespiratory adaptation.

Ribeiro et al. [14] characterized the intensity of the WBV stimulation in women diagnosed with FM compared to a CG of healthy women (HW). It was investigated the effect of a single session of WBV intervention on inflammatory responses and the levels of adipokines, soluble tumor necrosis factor receptors (sTNFr1, sTNFr2), and brain-derived neurotrophic factor (BDNF) were determined. Oxygen consumption (VO_2) was estimated (portable gas analysis system), HR was measured (HR monitor), and perceived exertion (RPE) was evaluated (Borg scale of perceived exertion). Acutely mild WBV increased VO_2 and HR similarly in both groups. There was an interaction (disease versus vibration) in RPE, showing a significant higher RPE in FM compared to HW at rest, which further increased in FM after acute WBV, whereas it remained unchanged in HW. A significant interaction (disease vs. vibration) on plasma levels of adiponectin, sTNFR1, sTNFR2, leptin, resistin, and BDNF was found. It was concluded that a single acute session of mild and short WBV can improve the inflammatory status in FM individuals, reaching values close to those of HW at their basal status. Probably, it is possible to speculate that neuroendocrine mechanism seems to be an exercise-induced modulation towards greater adaptation to stress response in these evaluated individuals.

Lai et al. [17] investigated the effect of high-frequency and high-magnitude WBV on the BMD of the lumbar spine in postmenopausal women that were randomized in a WBV group or a CG for a trial of 6 months. The WBV exercise group was exposed to 30 Hz high-frequency and 3.2 g high-magnitude WBV, in a full-standing posture for 5 min, three times per week. The measurement of the lumbar BMD of the two groups before and after the intervention was with dual-energy X-ray absorptiometry. The BMD of the WBV group had significantly increased by 2.032%, while that of the CG had decreased by 0.046% 6 months later. The comparison between the CG and WBV exercise group revealed that the BMD of the WBV exercise group increased significantly. It was concluded that 6 months of high-frequency and high-magnitude WBV yielded significant benefits to the BMD of the lumbar spine in postmenopausal women, and could therefore be provided as an alternative exercise.

4.2. Approaches of the whole-body vibration in fitness of trained and untrained individuals

Chen et al. [27] evaluated how WBV exercise and their interactions influence core muscle activity in healthy young adults. The activities of muscle multifidi (MM), rectus abdominis muscle (RM), erector spinae (ES), abdominis obliquus externus (AOE), and abdominis obliquus internus (AOI) were measured through surface EMG while participants were performing four different exercise forms under three WBV conditions in a vibrating platform generating vertical vibration (condition 1: 5 Hz, 2 mm; condition 2: 10 Hz, 2 mm; and condition 3: 15 Hz, 2 mm) and a no-WBV condition in single experimental sessions. WBV frequency of 15 Hz was the best vibration stimulation for core muscles in all the exercises. Single bridge is a better exercise for RM and AOE compared with other exercises, and crunches was the best exercise for MM, AOI, and ES. Significant interaction effect was observed in different frequencies and exercises except for AOI. It is concluded that high vibration frequencies can lead to enhanced exercise benefits within an appropriate frequency range, and different exercises have diverse effects on various muscles.

Oliveira et al. [10] considered that mechanical vibration is a common neuromuscular training technique used in sports training programs to generate acute increases in muscle strength and compared the individual optimal vibration frequency (IOVF) identified by EMG activity and force production in strength training in well-trained volunteers. They performed a familiarization and two interventions sessions, which included MVC (five) of the elbow flexors with a duration of 10 seconds and 5-min intervals between each MVC. Firstly, MVC was performed without mechanical vibration followed by four MVC (randomized) with application of mechanical vibration in the direction of the resultant muscle forces' vector (VDF) or WBV exercise using different frequencies (10, 20, 30, or 40 Hz). Consequently, the mechanical vibration stimulus was superimposed during the MVC. Individual optimal mechanical vibration frequency (identified by EMG) did not coincide with IOVF (identified by force production). Low agreement was observed between the vibration frequencies in generating the higher EMG activity, maximal force, and root mean square of force. These results indicate that the magnitude of the mechanical vibratory stimulus response might be individualized. In conclusion, if the objective is to use acute mechanical vibration in conjunction with strength training, a preliminary mechanical vibration exposure should be performed to determine the individualized mechanical vibratory stimulus of the individual, and, in consequence, the training effects can be optimized.

Moreira-Marconi et al. [23] evaluated the behavior of the skin temperature (Tsk) on regions of the lower limbs from an acute bout of WBV exercise. Using IRT, Tsk and thermal symmetry of the posterior lower extremities (thigh, knee, calf and heel) were examined in healthy participants. IRT was assessed during 60-second WBV exercise (exposures of 0, 30 and 50 Hz generated in a vertical vibrating platform). From the adjusted linear mixed effects model, mechanical vibration frequency, time and regions of the lower extremity were significant. But, as the variable laterality was not significant and it was excluded from the adjusted statistical model. It was verified that the adjusted model was significant and all variables in the model were significant. This indicates that Tsk decreases with the time, independently of

the mechanical vibration frequency. The mathematical model of the current study may be useful to justify the patterns observed for all vibration frequencies between and 0 and 50 Hz. It was concluded that the acute exposure of 60-second mechanical vibration has influence on the behavior of Tsk of the posterior region of the lower limbs. Probably, this would be likely associated with a decrease on the blood flow due to WBV exercise. Moreover, it is possible to speculate that during WBV exercise a greater supply of blood would be required where the body responds by shunting blood flow from the skin to working muscle, at least, in the first seconds of the WBV exercise.

Karim et al. [28] examined the immediate effect of WBV exercise on first position sauté height, and on static and dynamic balance professional contemporary dancers. Following instruction, a warm-up, and a training session, participants received a 75-second randomly assigned WBV intervention under four conditions: static demi-plié (0 Hz), static demi-plié (30 Hz), dynamic demi-plié (0 Hz), and dynamic demi-plié (30 Hz). Before and immediately after intervention, participants performed three sautés on the Just Jump® Mat System, provided dynamic balance data via the Star Excursion Balance Test, and static balance data via the Balance Error Scoring System. Dancers from the static first position demi-plié group were found to jump higher than those from the dynamic first position demi-plié group, regardless of WBV frequency. The 30 Hz frequency resulted in significantly improved static balance for both static and dynamic demi-plié. Therefore, the use of WBV exercise is worthy of consideration as a quick method of improving static balance, and use of the static first position demi-plié may be beneficial for improving sauté height.

Wallmann et al. [24] evaluated acute effects of WBV exercise on vertical jump, power, balance, and agility for untrained individuals (who are not collegiate or professional athletes). They were assessed for vertical jump height and power (Myotest accelerometer), balance (NeuroCom Balance Master System), and agility (modified T-test). Each session consisted of (i) five-minutes treadmill warm-up, (ii) practice test, (iii) baseline measurement, (iv) two-minute rest period, (v) WBV exercise at 2 mm and 30 Hz for 60 seconds, and (vi) final measurement. Three different counterbalanced testing sessions were spaced by a minimum of 48 hours between sessions aiming to minimize fatigue. Significant differences were found for both genders for main effect of time for Agility; end point excursion Left; and maximum end-point excursion Left. Differences for main effect of gender showed females performed better than males in: end point excursion Right; end point excursion Left; maximum endpoint excursion Right; and maximum endpoint excursion Left. Considering the males, they performed better than females in Agility and Power. It was verified a significant interaction between time and gender for vertical jump. Simple main effects showed males jumped higher than females during both pre and post intervention. Females had an important and significant decrease in the vertical jump post intervention. It is concluded that WBV, acutely, would produce significant differences in the main effect of time and agility, and end point and maximum end point excursion Left for both genders. Furthermore, females performed better in balance compared to males and poorer in vertical jump, but males performed better in agility and power.

Zaidell et al. [29] characterized the acceleration transmission and neuromuscular responses to rotational vibration (RV) and vertical vibration (VV) at different frequencies and amplitudes.

Individuals finished two experimental trials (RV versus VV) in which mechanical vibration was delivered during either squatting (30°; RV versus VV) or standing (RV only) with frequencies of 20, 25, and 30 Hz, at peak-to-peak displacement of 1.5 and 3.0 mm. Vibration-induced accelerations were measured with triaxial accelerometers on base of the vibrating platform and bony landmarks at ankle, knee, and lumbar spine. At all frequency/peak-to-peak displacement combinations, accelerations at the ankle were greater during RV with the greatest difference verified at 30 Hz, 1.5 mm. Transmission of RV was also significantly influenced by body posture (standing versus squatting). Irrespective of mechanical vibration type, mechanical vibration transmission to all studied bony landmarks was generally greater at higher peak-to-peak displacement but not at higher frequencies. This was verified mainly above the ankle joint. Acceleration at the lumbar spine increased with greater vibration peak-to-peak displacement but not frequency and was highest with RV during standing. It was concluded that the transmission of the mechanical vibration during WBV is dependent on intensity and direction of mechanical vibration as well as on the body posture. For targeted mechanical vibration loading at the lumbar spine, RV of higher peak-to-peak displacement and lower frequency mechanical vibration while standing is suggested. These findings will contribute to assist with the prescription of WBV to achieve desired levels of mechanical vibration loading at landmarks in the human body.

Yang et al. [30] described that vertical and side-alternating WBV can improve muscle power performance but have a limited efficacy for enhancing change-of-direction (COD) ability. They studied the acute effect of dual- or single-frequency WBV exercise on squat jumps (SJs), countermovement jumps (CMJs), eccentric utilization ratios (EURs), and COD ability in rugby players. Rugby players performed a 4 min partial squat with three types of WBV interventions on a dual-plate WBV machine, including 1 dual-frequency WBV protocol (DFW) with the dominant leg receiving 35 Hz and the non-dominant leg receiving 45 Hz, and 2 single-frequency WBV protocols (SFWs) with 35 or 45 Hz provided to both legs (SFW35Hz and SFW45Hz) in three different days. All the mechanical vibration interventions significantly improved SJ and CMJ performances. However, no significantly change EURs was found. In addition, only the DFW significantly improved COD ability. It was concluded that a 4 min dual-frequency WBV session improved both vertical jumping and COD ability in rugby players, suggesting that this could be a potential warm-up protocol for athletes.

5. Undesirable and unpleasant effects of the whole-body vibration

Despite the positive effects of the WBV exercise that were reported in topics 4.1 and 4.2, undesirable and unpleasant side-effects of these exercises can occur. Crewther et al. [31] verified that untrained participants exposed to acute mechanical vibration frequencies (10, 20 and 30 Hz), amplitudes (1.25, 3.0 and 5.25 mm) and postures (standing, squat) described side-effects, such as hot feet, itching of the lower limbs, vertigo and severe hip discomfort. Moreover, Cronin et al. [32] published that untrained participants suffered side-effects, such as vibration pain of jaw, neck and lower limbs in acute intermittent WBV. Cochrane, [2] discussed that the findings described by Crewther et al. [31] and Cronin et al. [32] are not usual,

but it was highlighted the importance of the training of professionals on the use of mechanical vibration technology.

Monteleone et al. [33] published a case of clinical of a significant morbidity following one session of WBV training in a patient with asymptomatic nephrolithiasis. Franchignoni et al. [34] referenced that a healthy elite athlete (steeplechase runner) had two episodes of hematuria after WBV training. Concerning to this, Franchignoni et al. [34] suggested that platforms providing side-alternating vibration may pose some health risks with high amplitudes (the feet are positioned too far from the axis of rotation in this kind of platform).

Hwang et al. [35] applied WBV at different vibration frequencies to CS subjects and examined its immediate effect on their postural sway. The individuals were randomly allocated to one of the two vibration frequency groups (10 and 40 Hz). Before and after the intervention with WBV exercises, the subjects performed quiet standing for 30 seconds. COP parameters (range, total distance, and mean velocity) were analyzed. The 10 Hz WBV exercise did not affect the postural sway of CS subjects, however, the 40 Hz WBV increased postural sway in the ML direction. It was concluded that WBV application to CS individuals in the clinical field may have adverse effects and therefore caution is necessary. In addition, previously, Cochrane [2] pointed out that some of the related side-effects to the use of WBV would be due to lack of familiarization of the participants with the WBV.

6. Conclusion

Considering the findings that were discussed WBV exercise, in general, is a safe, suitable and inexpensive intervention that can be used for the physiotherapists. There is a special relevance the use of WBV exercise in the rehabilitation of individuals with various diseases, but it is also highly relevant in different types of sports and to trained and untrained individuals when the fitness and the wellbeing are considered. Furthermore, it is strongly desired precaution in the use of WBV exercise due to the undesirable and unpleasant side-effects. In consequence, it is relevant to study and to learn more about the parameters used in the protocols with WBV exercise and the clinical conditions of the individuals that will be exposed to mechanical vibrations generated in vibrating platform. It was highlighted the relevance of the WBV exercise as an intervention of the physical therapy for the better human optimization. Putting together, these facts, this chapter was prepared to aid the physiotherapists that have interest in WBV exercise to use properly this intervention.

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Conflict of interest

The authors declare no conflict of interest.

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