Whole Body Vibration and Post-Activation Potentiation: A Study with Repeated Measures

Abstract

The objective of this study was to assess the acute effect of different intensities of whole body vibration (WBV) on muscle performance. Eight recreationally trained males were randomly subjected to one of 3 experimental conditions: (A) WBV 2 mm [45 Hz and 2 mm], (B) WBV 4 mm [45 Hz and 4 mm], and (C) no WBV. To assess PAP, the peak concentric torque of knee flexors and extensors was measured during a set of 3 unilateral knee flexor-extensions at 60°/s−1 in an isokinetic dynamometer. The power output and height during vertical jumps were also evaluated. These measurements were performed both before and after the experimental conditions and then compared. Comparing the knee flexion data from the conditions with and without WBV indicate that WBV potentiated the peak torque during unilateral knee flexion in the isokinetic test (p<0.05). In addition, the power output (p=0.01) and vertical height of jump (p=0.03) were also potentiated by WBV. However, increasing the vibratory stimulus did not further potentiate the results. Thus, it is suggested that WBV be used before explosive events competition because WBV promotes post-activation potentiation.

Introduction

Coaches and trainers who work with sports that involve strength and explosive exercises should know techniques for improving performance during competition to better plan and control training sessions. These sessions can then define the more appropriate preparatory procedures to be followed prior to competition. Recently, whole body vibration (WBV) has been an alternative method of exercise that is increasingly used to improve muscle power [1,7,12,15,16,26,27], muscle strength [24,26,27,35] and flexibility [1,24]. The mechanisms related to the effects produced by this training mode have not been fully elucidated in the literature. However, the primary hypothesis is related to the tonic vibration reflex. According to this hypothesis, the mechanical stimuli produced by the vibratory platform are transmitted to the body by stimulating the sensory receptors, which are most likely neuromuscular spindles. This simulation activates α motoneurons [5,17]. However, several studies do not confirm the increase in muscle activation, even with improvements in physical performance [1,10,16,29]. A study conducted by our group [1] demonstrated an increase in sprint cycle performance in physically active subjects after vibration stimulus. However, this improvement was not accompanied by increased electromyography activation of the vastus lateralis [1]. These findings corroborate other studies involving WBV and muscle performance [9,16,29]. When comparing exercise with and without vibration, Cormie et al. [16] reported an increase in physical performance after acute WBV during vertical jumps with no change in electromyography activity. In addition, similar results were reported in the study of McBride et al. [29], in which the authors reported that the addition of WBV to the squat increased the maximal muscular strength of the triceps surae muscles. However, this improvement in physical performance was not followed by a significant increase in motor neuronal arousal or muscular activation. This finding suggested that the improvement in physical performance might be associated with post-activation potentiation [29]. Post-activation potentiation (PAP) refers to the phenomena by which muscular performance characteristics are acutely enhanced as a result of their contractile activity prior to a performance test. This occurrence can be explained by 2
possible mechanisms. One is the phosphorylation of myosin regulatory light chains (CLR), and the other is an increase in the recruitment of high activation threshold motor units. There is also evidence to suggest that changes in the tilt angle of the muscle fibers could contribute to PAP [36]. However, for the occurrence of PAP, the preparatory activity must typically be performed at maximal intensity or at an intensity close to maximal [4, 33, 36]. Once the vibratory stimulus appears to impose an additional load compared to the exercise without vibration [2, 6, 11, 21, 22, 30, 31], this additional stimulus might predispose the occurrence of a PAP. A PAP would rationalize the use of WBV as a preparatory activity before tests for evaluating muscular performance.

The objective of this study was to test WBV as a conditioning activity to induce PAP on torque output during knee flexion and extension and vertical jump performance. It is hypothesized that WBV can enhance muscle torque and the power of lower limbs, and that this potentiation would be proportional to the intensity of the vibration stimulus.

Materials and Methods

Subjects

The study included 8 regularly and recreationally trained men (VO2peak: 57.28 ± 3.23 mL O2·kg⁻¹·min⁻¹, mean age: 31.13 ± 4.94 years, height: 1.76 ± 0.06 cm, body mass: 65.64 ± 13.77 kg). Volunteers with signs of acute hernia, history of musculoskeletal diseases, diabetes and epilepsy were excluded. All of the volunteers engaged in national competitions (running and cycling), and their training frequency (5 times per week) targeted neuromuscular components (power, strength and muscle endurance). All tests were performed during the athletes’ competitive season, corresponding to autumn in the southern hemisphere (May). The participants were notified about the potential risks involved in the study and gave their written informed consent. This study was approved by the Federal University of Jequitinhonha and Mucuri Valleys and followed the Ethical Standards in Sport and Exercise Science Research [20].

Study design

The study design consisted of a preliminary session, followed by 3 experimental conditions. All procedures were performed under a thermoneutral condition: 21–24°C dry temperature and 50–75% relative humidity, according to Clark and Edholm [8].

The experimental session consisted of the verification of anthropometric measurements (weight and height) and familiarization with the experimental procedures and evaluation tests of the physical performance. The experimental sessions occurred on different days, at least 7 days after the preliminary session, with randomized intervals of 24 h among the experimental conditions (Fig. 1), according to the Latin Square design. To minimize circadian influences, the participants performed the experimental conditions at the same time of day [11].

Experimental sessions

The first test in each experimental session consisted of concentric muscle torque of knee flexors and extensors of the dominant limb. This test was performed after at least 5 min at rest (Pre) and 3 min after (Post) one of the 3 experimental conditions: A) WBV 2 mm – squat exercises (SE)+WBV with frequency of 45 Hz/2 mm; B) WBV 4 mm – SE+WBV with frequency of 45 Hz/4 mm; C) Without WBV – SE without WBV. Thereafter, the volunteer remained at rest for approximately 7 min and was subjected to a second battery of tests, which consisted of assessing the muscular power of the lower limbs through the vertical jump test. The vertical jump test was performed before (Pre) and 3 min after (Post) the same experimental conditions randomized to that day of experiment. The 2 performance tests were conducted by the same examiner (Fig. 1).

The time between the physical tests and the experimental conditions was based on the study of Avelar et al. [1]. In that study, the authors showed that allowing 3 min after performing SE with WBV was sufficient for improving sprint cycling performance. Moreover, Sale [33] suggested that at least 3 min of rest are required to eliminate the fatigue before a test. The rest time of approximately 7 min between the 2 batteries of tests was based on a pilot study in which this duration was found to be sufficient for a return to homeostasis. Furthermore, Cochrane et al. [10] showed that residual effects from WBV occur no later than 5 min after the cessation of a vibratory stimulus.

Experimental conditions: The experimental session consisted of the performance of the SE with or without vibratory stimulus.
For the SE, the volunteers were asked to stand barefoot on the vibration platform [28] with their feet apart at a distance of 28 cm and to perform SE (semi-flexion of the knee from 10° to 90°). The flexing to 90° was measured for each volunteer using a universal goniometer before starting the exercise series, and a barrier was placed in the gluteal region to limit the degree of knee flexion; therefore, all the volunteers flexed their knees to an angle of 90° [2].

The vibratory stimulus was performed using a commercial model of vibration platform (FitVibe, GymnAUniPhy NV, Bilzen, Belgium), which produces vertical sinusoidal vibrations in both legs while the platform moves predominantly in the vertical direction [13]. The parameters of vibration were 45 Hz with varied peak-to-peak displacement of vibration (2–4 mm). The particular vibration parameters (frequency: 45 Hz; amplitude: 2/4 mm) were selected based on the work of Cochrane et al. [11]. These parameters have been shown to have the same values as the acceleration over 5 min of continuous vibratory stimulus and to raise muscle temperature by 1.5 °C, which significantly increases countermovement jump height (9.3%) and power (4.4%) [11]. Moreover, studies from our group have demonstrated improvement in high-intensity and short-duration performance, according to the proposed protocol [1]. There was no vibratory stimulus in the condition of SE without WBV. However, the individuals remained on the vibration platform without the apparatus operating.

To control the time of each SE, each volunteer flexed the knee to an angle of 90° for 3 s and then flexed to an angle of 10° for 3 s and repeated these movements over a period of 5 min [1]. The timing of the SE was set using a digital metronome. Because each exercise cycle required 6 s and each change in position (up/down down/up) required 1 s, the total time of each exercise cycle was 8 s. Therefore, 37 repetitions were performed in 5 min. The participants were also instructed on body mechanics (i.e., the correct position of their feet on the platform and the positions of their spine, arms and head).

**Measurement of the acceleration of the vibrating platform**

To measure acceleration on the horizontal and vertical axes, 2 accelerometers were fixed at a distance of 14 cm from the center of platform vibration. The signal was amplified electronically and was stored. This signal was obtained at a frequency of 1000 Hz and was sent for computer analysis. Each accelerometer was calibrated using 2 calibration points and applying zero and gravity, Earth’s gravity being 1 G (9.81 m/s²). To obtain the true acceleration values of the platform, the values of Earth’s gravity were subtracted along the vertical axis from the total signal received so that the acceleration of the platform would begin at 0 m/s². The data were transferred to a computer using the Mega-win software program, and the mean and maximum acceleration of each sample on each axis were analyzed using the Matlab software program. Each frequency used was measured over 60 s. In the pilot study, inter-examiner reliability was found to be high, with a coefficient of variation of 1.05% [2].

**Evaluation of post-activation potentiation**

The occurrence of a PAP has been consistently shown when performance is measured both involuntarily, through the use of electrical stimulation, and voluntarily, through the use of physical performance tests [3]. In the present study, PAP was evaluated voluntarily using physical performance tests (concentric muscle torque of flexors and extensors of the knee using an isokinetic dynamometer as well as the power and height of a vertical jump test) that require physical strength and power exercises.

**Evaluation of concentric muscle torque of knee flexors and extensors**

The concentric muscle torque of the knee flexor and extensor were evaluating using the isokinetic dynamometer Biodex System 4 Pro® (Biodex Medical Systems Inc., Shirley, NY, USA), with the individual taking the seated posture, trunk upright, hips and knees flexed at 90°. The thighs, hips and trunk were fixed by strips, and the upper limbs were crossed in front of the trunk. Afterwards, the lower limb to be evaluated (dominant limb) was positioned at 90° of knee flexion (checked individually by goniometry of the knee), and the resistance lever was positioned on the distal third of the leg measured (on the bottom edge of the lateral malleolus).

The volunteers were instructed to perform flexion-extension (90°–30° of flexion, where 0° corresponds to full extension) of the dominant knee at a speed of 60°/s for 3 consecutive uninterrupted contractions [3,25,35]. Volunteers were provided standardized verbal feedback. The peak torque (defined as the highest torque value measured in a repetition, regardless of the range of motion where it occurred) was evaluated.

**Vertical jump test**

During the vertical jump test, jumping mat pressure (Jump System 1.0, Cefise, Brazil), which corresponds to a pair of pressure sensors coupled to the plantar surface of the forefoot and barefoot of the individuals, was used to measure relative power and height of jump.

Subjects were instructed to jump as high as possible in 3 vertical jumps with a 10-s interval between jumps. The jumps began from a squat position with knees at 100° of flexion [16], hands resting on the ilioc crest (in an attempt to remove impulsion resulting from arm oscillations) and spaced foot to 18 cm. Afterwards, the height of jump and power output were calculated using the formulas shown below [34]:

**Height of jump**: \( \frac{1}{8}gt^2 \)

where \( g \) is the acceleration of gravity (9.81 m/s²), and \( t \) is the hang time in the air.

**Power output**: \( 60.7 \times (\text{height of jump} + 45.3 \times (\text{body mass}) – 2055) \)

The highest values of relative power and height of jump were considered for analysis.

**Intraclass Correlation Coefficient**

Prior to the start of the study, the intra-examiner reliability was calculated for the following variables: concentric muscle torque of knee flexors and extensors (dominant limb), relative power and height of vertical jump. For this purpose, 10 volunteers were subjected to a pilot study on 2 separate days with an interval of at least 24 h between testing. The intraclass correlation coefficients (ICC) were 0.983 (95% CI 0.917–0.957), 0.960 (95% CI 0.813–0.992) and 0.974 (95% CI 0.878–0.995) for concentric muscle torque of knee flexors and extensors (dominant limb), relative power and height of vertical jump, respectively.

**Statistical analysis**

The SPSS® (IBM®, Chicago, IL, USA) version 18.0 software program was used for statistical analysis. The data were expressed as the mean and standard deviation. The significance level was defined as p ≤ 0.05. First, the Shapiro-Wilk test was used to verify...
the normality of the data. Subsequently, the differences between the conditions were tested using 3×2 repeated measures ANOVA. Post-hoc Tukey test was used to investigate the differences between conditions. To check the size of differences between pre- and post training, it was analyzed the magnitude of effect [14]. The analysis of magnitude of effect is an additional measure to the traditional statistical test of the null hypothesis, which aims to verify the clinical significance of the effect found, not limited to dichotomizing results into significant or not significant [18]. Thus, with the magnitude of the effect analysis, it is possible to identify whether the observed differences were small, moderate or high [14].

### Results

All participants completed all the experimental procedures of all interventions. The data obtained in tests of physical performance prior to the experimental conditions showed no difference from the baseline data (Table 1).

The conditions with WBV potentiated Peak Torque compared with the condition without WBV during concentric knee flexion on isokinetic dynamometer (p: 0.04, effect size: 0.645, power: 0.617) (Fig. 2b), without difference for knee extension (p: 0.509, effect size: 0.201, power: 0.128) (Fig. 2a). However, these results were not further potentiated by augmenting the vibratory stimulus.

The data from the jump tests after the experimental conditions (Squat exercise + WBV) showed a significant increase in relative power (p=0.014, effect size: 0.756, power: 0.855, Fig. 3a) and in height of jump (p=0.027, effect size: 0.700 power: 0.729, Fig. 3b) compared with Squat without WBV. Moreover, delta data analyses [delta (Δ=Post−Pretest)] also demonstrated a significant increase in relative power [Δ: without WBV = −0.30% (p: 0.486), WBV 2 mm = +2.12% (p: 0.006), WBV 4 mm = +2.19% (p: 0.008)], Fig. 3c and height of jump (Δ: without WBV = −0.4% (p: 0.201), WBV 2 mm = +4% (p: 0.018), WBV 4 mm = +4.24% (p: 0.017), Fig. 3d) in the WBV conditions compared with the SE without WBV. However, increasing the peak-to-peak displacement of the vibratory stimulus did not further potentiate the results.

For each dependent variable (peak torque of knee extensors and knee flexors, power output and height of jump), the statistical power of the study was calculated for comparisons among the groups. The magnitude of the effect was high for both power output (Cohen’s f=0.855) and height of jump (Cohen’s f=0.729), indicating that the study had statistical power greater than 70% for these variables, while the magnitude of the effect was moderately high for peak torque of knee flexors (Cohen’s f=0.645), indicating that the study had a statistical power greater than 60% for this variable.

### Discussion

The main findings of the present study were that adding WBV potentiated the concentric torque of knee flexors measured using an isokinetic dynamometer and the power output during vertical jumps. However, increasing the peak-to-peak displacement of the vibratory stimulus did not further potentiate the results.

During the concentric knee flexion on the isokinetic dynamometer, a significant increase in the Peak Torque during WBV was...
observed compared with the same exercise without WBV. This study is the first to demonstrate the potentiation of peak concentric torque of knee flexors. Siu et al. [35] demonstrated that change of eccentric flexor torque after vibration in 26 Hz (106.75 ms⁻²) of vibration frequency tended to be greater but did not reach the statistically significant level when compared with that in controls. The authors speculated that the greater vibration amplitude might have been responsible for the characteristic difference. Moreover, this increased muscle torque could favor sports modalities that require fast activation of the flexor muscles of the knees, such as cycling. Data from our group [1] strengthens this hypothesis because an increase in high-intensity physical performance was observed only in the condition in which the volunteers were subjected to WBV prior to the Wingate test. Because this study also demonstrated the muscle temperature, blood lactate levels and electromyographic activity of the vastus lateralis muscle did not increase, the data suggest an effect of PAP [1].

In contrast to the responses from the torque of knee flexors, adding WBV did not potentiate the concentric muscular torque of knee extensors. Similar results were observed in the study conducted by Jordan et al. [23] in which the authors also found no performance improvement in the muscle strength of knee extensors after vibration stimulus. Accordingly, it was hypothesized that the lack of improvement in extensor torque of the knee may be a result of the possible fatigue induced by SE. These exercises enhance the activity of knee extensors in both the eccentric (flexion to 90°) and concentric (flexion to 10°) phases and thus, block the occurrence of a PAP mechanism. Other studies in the literature also demonstrated no effect of WBV on knee extensor torque during voluntary muscle activation [16,23,25,32]. However, studies investigating the effect of vibratory stimulation on involuntary responses during muscle activation [10,23] observed an increase in the involuntary peak muscle force (neuronal excitation) of approximately 12.4% after the SE associated with WBV.

The data regarding the power and performance of lower limb muscles from this study are consistent with current literature, which shows that the addition of vibration to SE improves the power output and height of vertical jumps. These results
reinforce the idea that vibration is an alternative method for training for and pre-competition routines of sports such as volleyball, basketball, gymnastics and others.

Similar data were obtained in the study of Cormie et al. [16], who found a 0.7% increase in vertical height of jump after adding vibration. The effectiveness of the protocol proposed in the present study was greater because there was a greater increase (approximately 4%) in vertical height of jump after vibration compared with without vibration. However, despite the difference in the protocols of the study of Cormie et al. [16] and the present study, other variables may have influenced the results, such as the fitness level of subjects and the standardization of the jump.

As previously mentioned, a possible physiological mechanism for increasing the power performance of lower limbs could be PAP [36]. Thus, a muscle contraction prior to the performance test would induce the release of calcium ions from the sarcoplasmic reticulum. This release occurs because the contraction activates the light chain kinase enzyme that catalyzes the phosphorylation of the myosin regulatory chain to promote a structural change of the head of this protein. This change allows a faster binding of actin and myosin, and, consequently, a more efficient muscle response [36]. We believe that the vibration stimulus prior to the muscular performance test could influence muscle contraction in a similar manner, enhancing the response of calcium release and all subsequent cascade reactions. To substantiate our assumption, some authors have speculated that the vibratory activity imposes an additional overload to the exercises that may trigger the mechanism proposed above [2,8,11,21,22,30,31].

Along with this proposed mechanism of action (PAP), there are other possible hypotheses. The vibratory stimulation may influence central motor command, which can activate specific brain areas that control the subsequent voluntary movement [6]. Additional explanations include increased release of tissue oxygen, rate of metabolic reactions and muscle blood flow as well as psychological effects [4].

The results presented in this study demonstrate the effectiveness of WBV on the power output of the lower limbs and on the muscle torque of knee flexors with no influence on the muscle torque of knee extensor. Thus, these findings support the reports of the current literature, which have demonstrated that PAP has different responses in different physical performance tests [4]. The present study has limitations, and the results should be interpreted within the context of any potential design. Please note that a specific peak-to-peak displacement and frequency were used. The results thus cannot be extrapolated for different parameters of vibration and time intervals between the conditioning activity and the test performance evaluation [33].

Perspectives

Preparatory activity is part of the routine of athletes and coaches during training sessions and before competitions. Among these activities, the addition of vibratory stimulus to SE may be a technique for enhancing physical performance during subsequent muscle activities. Physiological mechanisms have been proposed, including post-activation potentiation. The results of this study suggest that WBV should be considered by coaches and athletes as a preparatory activity prior to training and competitions in certain activities. For activities that require improvement in the concentric torque of knee flexors and the power output of lower limbs (volleyball, basketball, handball, Olympic gymnastics, sprint cycling), WBV can offer a competitive advantage. Note also that the parameters of WBV used in the present study (45 Hz and peak-to-peak displacement 2 mm) appear to be effective because active individuals are the same with this protocol as with vibratory stimulus of greater magnitude. Different parameters of vibratory stimulus (45 Hz, 2–4 mm) produce the same PAP response.

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References

