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Long-Term Whole-Body Vibration on Knee Extensor Function: A Randomized Clinical Trial

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SUMMARY

Introduction. The whole-body vibration platform (WBV) has shown positive effects on muscle aspects of strength and power due to the tonic vibration reflex. However, there is still disagreement about the parameters to be used.

Objective. To investigate the effect of two WBV frequencies (30 and 45 Hz) on maximum isometric and resistance torques of the knee extensors, and power in two jumping modalities, Squat Jump (SJ) and Counter-Movement Jump (CMJ).

Methods. Randomized clinical trial, composed of 40 healthy young adults of both sexes, aged between 18 and 30 years, not practicing systematic physical activities and randomized into three interventions according to the frequency of WBV: 30 Hz (F30), 45 Hz (F45) and sham (SG). The outcomes evaluated were the maximum isometric torque and quadriceps resistance measured by a traction dynamometer, and the quadriceps power obtained in two jumping modalities: squat and countermovement jump. The WBV intervention lasted 12 weeks, 2x weekly. After a familiarization session the outcomes were measured before and after the interventions. For statistical analysis the percentage of change between pre and post measures was used (Delta percentage).

Results. No statistical differences were observed in the percentage deltas for any of the outcomes evaluated.

Conclusions. WBV, regardless of the frequency adopted, did not influence the aspects of muscle function.

Study registration. Registro Brasileiro de Ensaios Clínicos (ReBEC) with the number RBR-4rrn7cf.

KEY WORDS
Vibration; muscle strength; skeletal muscle; knee joint; quadriceps muscle.

INTRODUCTION

Optimizing aspects of muscle function is widely recognized as an effective way to prevent diseases and improve quality of life through physiological adaptations. High-intensity strength training aims to increase muscle strength, while low-intensity strength training promotes endurance (1, 2).

Neuromuscular adaptations and an increase in muscle cross-sectional area are the main outcomes of strength training, achieved by improving motor unit synchronization and increasing the number of sarcomeres in parallel, respectively. To recruit high-threshold muscle fibers, strength training typically involves a volume of 4 to 12 repetitions at 60% to 80% of the maximum load, determined by a one-repetition maximum test (3-5).

Endurance is defined as the ability of muscles to contract over a given time. Low-intensity strength training involves continuous repetitions of submaximal loads to improve endurance, with minimal homeostatic variation. Strength endurance training increases motor unit firing at the neural level and promotes mitochondrial biogenesis and capillary density, leading to improved oxygen consumption and delayed fatigue during prolonged exercise (4, 6).

Muscle power is defined as the product of force and velocity, representing the amount of work performed per unit of time.

Vertical jump performance is a key indicator of lower limb muscle power, and it is optimized by the Stretch-Shortening Cycle since it involves eccentric contraction followed by concentric contraction, leading to an increase in power (7, 8). Various training methods are available to improve strength, endurance, and power. Studies suggest that whole-body vibration (WBV) can increase strength and power by activating muscle spindles through the tonic vibration reflex and promoting the synchronized recruitment of high-threshold motor units (9-11). However, the neuromuscular effects and practical applications of WBV in strength and power training are still under investigation, with controversial effects and potential risks of injury (12-16).

The present study aims to investigate the effect of two WBV frequencies (30 and 45 Hz) on maximum isometric and resistance torques of the knee extensors, and power in two jumping modalities, Squat Jump (SJ) and Counter-Movement Jump (CMJ).

MATERIALS AND METHODS

Ethics of the study and volunteer recruitment

This study was a blind (participant), parallel, randomized, placebo-controlled clinical trial, following the guidelines of the Consolidated Standards of Reporting Trials (CONSORT) and approved by the Ethics Committee on Research Involving Human Beings of a Higher Learning Institution under number 5.269.114 – Date of approval: March 02, 2022. All participants were informed about the objectives and procedures of the research and signed the informed consent form in duplicate, one copy for themselves and the other for the researcher.

Volunteers were recruited in a non-probabilistic and consecutive manner from young adults aged between 18 and 30 years, who did not engage in systematic physical activities, of both genders. The study was promoted through digital media and personal approaches in the proximity of the University where the research was conducted. Volunteers with neurological and cognitive problems, cardiorespiratory diseases, and a history of joint or muscle injuries in the last six months were excluded from the study. The exclusion criterion for data analysis was the withdrawal of the volunteer's authorization to participate in the study.

Randomization and blinding

The volunteers were assigned to one of three intervention conditions based on the frequency imposed by the WBV as follows: sham (SG), frequency 30 Hz (F30), frequency 45 Hz (F45) (explained in detail in the next item). The distribution between intervention frequencies was matched by sex. The randomization process was carried out by a researcher not involved in any other stage of the study, and a list was generated electronically using GraphPad QuickCalcs software. The recruitment process is shown in **figure 1**.

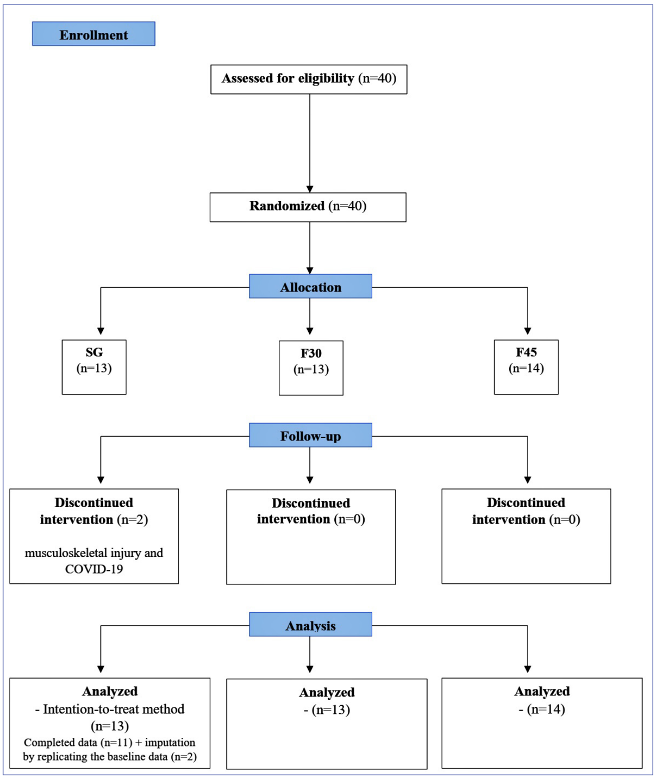

Figure 1. Study flowchart for distribution of volunteers into interventions according to vibration platform frequency.

SG: Sham; F30: frequency 30 Hz; F45: frequency 45 Hz.

Interventions

Determination of maximal squat volume - Exhaustion Squat Test (EST)

The EST was conducted during the familiarization visit to measure the volume of squats during the interventions. For this test, participants were instructed to perform squats until exhaustion within an amplitude range of 180° to 120° of hip flexion, as delimited by fixed bars. The pace of execution was standardized using a metronome for all participants, and the test intensity was targeted to correspond to the Borg 6 to 20 scale rating of "Slightly Tiring", which is equivalent to numerical ratings of 13 and 14 scale rating (17). The time until test interruption and the number of repetitions performed were recorded.

If participants failed to reach the bars that delimited the test amplitude or executed squats outside the rhythm determined by the metronome for three consecutive times, the test was interrupted, and only the data that followed the test protocol correctly were used for analysis.

Whole-Body Vibration (WBV)

The intervention comprised 12 sessions over a 6-week period, with 2 sessions per week. Participants performed a series of squats identical to the baseline evaluation. The WBV parameters for the intervention were an amplitude of 1.5 mm at a frequency of 30 Hz and an amplitude of 2.0 mm at a frequency of 45 Hz. The SG performed the same squatting protocol on the platform, but with the vibration function turned off.

The percentage volume was calculated for each of the 12 sessions based on the maximum number of squats performed by each participant, and the volume was progressively increased weekly. **Figure 2** shows the distribution of the volume over the sessions, expressed as a percentage of the maximum number of squats.

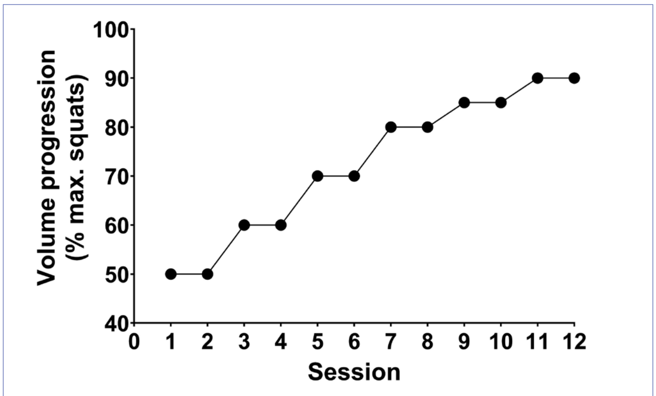

Figure 2. Distribution of squat volume, in each of the sessions, over the intervention period.

To ensure external load control, if volunteers failed to reach the amplitude limits set for squats or perform them out of rhythm with the metronome three times consecutively, the prescribed volume of squats for the following week would remain the same as the current week.

Outcomes

The study assessed the quadriceps maximum isometric torque, quadriceps resistance torque, and quadriceps power.

Maximal isometric quadriceps strength test

The volunteer sat in a chair, with the trunk inclined backwards by 10° and the upper limbs resting at the edges of the chair, so that the hip flexion angle was kept around 100°. The volunteer was instructed not to make compensatory movements during the execution. He was instructed to apply as much force as possible to extend the knee for 5 s at a fixed 45° angle.

Evaluation of the maximum isometric force was done using an inextensible chain connected to a load cell (E-lastic model 200 kg, W-sporte SE, Brazil) that was fixed to the frame of the chair. The other end of the chain was hooked to an anklet worn by the volunteer. The test was performed twice and there was a 60 s interval between repetitions. Considering that the length of the volunteer's leg was always invariable, the lever arm was always determined by the center of the distance between the knee joint to the point where the load cell chain attaches to the ankle support.

Quadriceps strength endurance test

The volunteer remained in the seated position in the chair, as previously described. In the endurance test, each volunteer performed four series of knee flexion-extension movements, starting at 90° of knee flexion, moving to 40° and returning to 90°, performing as many repetitions as possible until muscle fatigue. The rest interval between each series was 45 s, and there were beacon lines to delimit the range of motion between 90° and 40°. The fatigue point was considered by the volunteer's own perception or when he did not reach the mark corresponding to the 40° angle for three consecutive repetitions. At the end of each series, the perceived exertion level (PSE) was collected using the Borg scale from 6 to 20 (17). The number of repetitions and the duration of each series were recorded.

The load imposed during the strength endurance test was determined using a latex tube exerciser present in the elastic kit, which could be red (weak intensity) or blue (strong intensity). One end of the elastic tube was hooked to the load cell, which in turn was attached to the chair frame, and the other end was hooked to an anklet worn by the volunteer. In the familiarization test, all participants started wearing the red rubber band. If the participant, with the red rubber band, reached 250 repetitions or more in the first series along with a PSE lower than 13 (a bit tiring), the load was switched to the blue rubber band and with it the participant would perform the remaining evaluations. The muscle strength needed to overcome the elastic resistance of the exerciser was quantified by the load cell in each extension movement. The values of mean and maximum force, recorded in kgf, and the number of repetitions of the extension moment were obtained by a smartphone application of the elastic system.

The strength data from both the maximal isometric test and the strength endurance test were converted to torque. Once the force was obtained and the distance between the volunteer's knee and the ankle support was measured, the torque was obtained by the following equation:

$T = F \times D$

where T = torque; F = force; D = distance.

Jumping parameters

The jumping parameter evaluated was the power of the lower extremities. In the SJ there is no countermovement, which is the acceleration of the center of mass in a downward direction prior to the act of jumping and, therefore, the concentric action of the agonists is predominant. On the contrary, in the CMJ there is the presence of countermovement that lengthens the agonist muscle, activates the stretching and shortening cycle, and mobilizes elastic energy from the stretching of the musculotendinous unit that, added to the concentric agonist work, enhances the jump performance of the jump (18).

To determine the power, jump height and flight time, for both types of jumps, the volunteers jumped over the JumpTest® contact mat (Hidrofit LTDA, Belo Horizonte, Brazil) with dimensions of 50 × 66 cm. The contact mat was connected to a laptop computer (Itautec Infoway, Intel® Core i3 370M 2.40 GHz, 8.00 GB RAM) in which Multisprintfull® (Hidrofit, Belo Horizonte, Brazil) software was installed, which processed the data in real time. This mat is made up of two conductive surfaces that respond to small pressures by closing the system. After the subject's feet lose contact with the mat during the jump, the system is opened, and a chronometer in the software is started and kept timing until the subject regains contact with the mat, closes the system again, and stops timing. Considering the flight time, obtained by the stopwatch, the jump height is calculated as (19, 20):

$h = g \times t^2 \times 8^{-1}$

where: h = jump height; g = acceleration of gravity (9.81 m $\times$ s^{-2}); t = flight time (s).

In the SJ, the volunteer, already on the contact mat, performed a maximum jump from a static semi-lying position in which the knee was bent at approximately 90°, with the trunk as straight as possible and the hands positioned at the waist where they should remain for the entire excursion of the jump (18). Two maximum jumps were requested with a two-minute interval between them, and the highest value was considered for analysis. Subsequently, in the JMC, the evaluated began the jump from the standing position with the knees extended and the hands at the waist. When starting the jump they should first flex the knee to about 90° and then jump as high as possible without taking the hands off the waist (18). They were also asked to perform two maximal jumps with a two-minute interval between them and the highest value was considered for the analysis. The Multisprintfull® software calculated the power of each jump, expressed in watts (W), using the following equation:

$power = m \times g \times (h/t)$

where: power = muscle mechanical power, obtained by the contact mat for each jump; m = body mass in kilograms; g = acceleration of gravity (9.81 m $\times$ s^{-2}); h = jump height (m); t = flight time in seconds.

The power was normalized by the mass of the volunteer and then expressed by the unit W× kg^{-1}.

Methodological procedures

Initially, volunteers were informed about the research objectives and procedures and subsequently gave their consent to participate in the research.

The evaluations occurred on three occasions in time: 1) familiarization, 2) pre-intervention; 3) post-intervention. A schematic description of the methodological procedures can be seen in **figure 3**.

Familiarization

After the registration of the sample characterization variables such as age (years), body mass (kg), and height (m), the volunteers were familiarized with the evaluative procedures of isometric maximum strength and quadriceps strength resistance and jumps in SJ and CMJ modalities, to minimize the learning effect. The volunteers also performed the EST, as previously described. The familiarization data was not computed for the statistical analyses.

Pre-intervention

The volunteers were re-evaluated, in relation to the measures corresponding to the study's endpoints, in the same way as practiced at familiarization, between 72 h and 168 h.

Post-intervention

The volunteers were re-evaluated, in relation to the measures corresponding to the study outcomes, between 24 h and 168 h after the end of the intervention.

Figure 3. Schematic representation of methodological procedures over time.

Data processing

The data were treated by calculating the percentage change between the pre- and post-intervention occasions by the equation:

Delta percentage = (post-intervention value / pre-intervention value) -1 × 100

Statistical analysis

SPSS 20 software was used for statistical analysis. The significance level adopted was 5% ($\alpha = 0.05$).

The factor used in the analyses exploring the effects of the vibration platform on the study results was frequency (sham; 30 Hz; 45 Hz). The outcome variables in the comparisons were percentage deltas of torque measurements (resistance torque, maximum isometric torque) and of the power in the two jumping modalities (SJ and CMJ). Comparisons were made using the Generalized Linear Model Test (GzLM), which is based on maximum likelihood and uses Wald's chi-square test (Wald χ^2) to identify the effect of the variable in the generalized linear model. Sidak's test was used as a *post-hoc* test.

RESULTS

Sample characterization data can be viewed in **table I**. No significant differences were observed for any of the characterization variables between the interventions (age / χ^2 [1,2] = 2.214 and p = 0.331; body mass / χ^2 [1,2] = 0.520 and p = 0.771; height / χ^2 [1,2] = 0.810 and p = 0.667).

No statistical differences were observed in the percentage deltas for any of the outcomes evaluated (resistance torque / χ^2 [1,2] = 1.115 and p = 0.572; maximal isometric torque / χ^2 [1,2] = 2.191 and p = 0.334; power in SJ / χ^2 [1,2] = 0.424 and p = 0.809; power in CMJ / χ^2 [1,2] = 0.284 and p = 0.0.867). The descriptive statistics for each outcome before and post-intervention, and the percentage delta values according to the intervention can be seen in **table II**.

DISCUSSION

The current study emphasized the effect of two different WBV frequencies on maximal isometric and resistance torque, and muscle power. The results pointed out that the WBV intervention for 6 weeks did not present a significant difference in the outcomes.

Previous studies have shown that the tonic vibration reflex caused by WBV can lead to an increase in recruited muscle fibers. Lai *et al*. (21) concluded that training with WBV associated with squat training for 8 weeks showed muscle strength gains in patients with knee osteoarthritis using 20 Hz frequency and 2 mm displacement amplitude. Delecluse *et al*. (22) report a significant increase in the isometric and dynamic strength of the quadriceps femoris, since the study was conducted in 12 weeks of intervention, with frequencies of 35 Hz to 40 Hz with wave amplitude of 2.5 to 5 mm. However, the present study is consistent with Kvorning and colleagues (9) who reported that WBV alone or associated with weighted squatting showed no significant effect on

Table I. Characterization data of the sample (mean and standard deviation values).

	F45	F30	SG
Age (years)	20.7 ± 0.7	75.9 ± 20.6	1.67 ± 0.11
Body mass (kg)	21.7 ± 2.8	72.1 ± 17.0	1.71 ± 0.11
Height (m)	21.5 ± 1.2	71.6 ± 15.3	1.70 ± 0.08

F45: 45 Hz group; F30: 30 Hz group; SG: sham group - 0 Hz.

Table II. Average values for resistance torque, maximum isometric torque, power in SJ and CMJ for each group during the 2 evaluation moments (PRE- and POST-intervention) and the percentage delta values.

	PRE			POST			Delta (%)		
	F45	F30	SG	F45	F30	SG	F45	F30	SG
Resistance torque (Nm × kg^{-1})	1.10	1.18	1.19	1.12	1.14	1.24	1.18	-4.24	3.52
Maximum isometric torque (Nm × kg^{-1})	2.13	1.87	1.64	2.31	2.19	1.89	13.6	19.9	7.57
Power in SJ (W)	372.3	342.8	332.4	374.1	352.4	343.8	1.73	5.22	5.61
Power in CMJ (W)	378.7	352.2	340.3	386.4	367.3	354.2	2.89	5.73	5.66

F45: 45 Hz group; F30: 30 Hz group; SG: sham group - 0 Hz; PRE: period before the intervention protocol; POST: period after the intervention protocol; SJ: Squat Jump; CMJ: Counter-Movement Jump.

maximal isometric voluntary contraction with a training over 9 weeks with progressive volume of squats, with a frequency variation of 20 and 25 Hz and amplitude of 4 mm being used. The present study evaluated muscle power from SJ and CMJ, a topic indicated as important for research (23), there was no significant difference between the pre and post-intervention tests, despite showing minimal superiority in the values of low frequency (30 Hz) compared to high frequency (45 Hz) in both jumps. On the other hand, Oliveira and colleagues (24) state that long-term WBV training (3 times a week for 4 weeks) contributes to the improvement of muscular capacity in lower limbs of soccer athletes; however, this study used the frequency of 35 Hz and the wave amplitude of 4 mm. Furthermore, the intervention occurred in five series of static squatting with knee joint amplitude at 90° on the vibration platform for 60 seconds. They also evaluated jump height after 4 weeks of follow-up with loss of muscle performance. In agreement, Torvinen and others (25) analyzing the acute effect of vibration (15-30 Hz and 10 mm), 2 and 60 minutes after intervention, observed an increase in performance of maximum knee extension strength and vertical jump height 2 minutes after intervention, and in the post-test at 60 minutes there were no changes in the proposed variables. In contrast, Charlton and colleagues (26), observed an inhibitory effect in the hamstrings in knee flexion in subjects undergoing WBV and squatting. Meanwhile, in the current study, volunteers were reassessed, with respect to the corresponding measures, between 24 h and 168 h after the end of the intervention, as it was not of interest to analyses the effects of the platform on transient physical and muscular performance, but rather analysis of long-term training.

According to a study (27) the ideal relation between load and movement execution speed during muscle power training is a difficult aspect to control. Training should be performed with average loads and maximum execution speed of a given movement. Taking this into account, it is assumed that the current study did not show significant differences between the groups due to the low volume and load of training used, since the squats performed on the platform were performed in a controlled manner, and the intervention time for each participant varied according to the EST.

CONCLUSIONS

We conclude that there WBV, regardless of the frequency adopted, did not influence the aspects of muscle function.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

EKS, JR, KAH, RAB: research project, data collection, writing - original draft, final approval. ARdC, GRFB: research project, data analysis, writing - critical review & editing, final approval.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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