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EFFECTS OF NEUROMUSCULAR RESPONSES DURING WHOLE BODY VIBRATION EXERCISE WITH DIFFERENT KNEE ANGLES

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ABSTRACT: The purpose of this study was to compare the effects of whole body vibration (WBV) exercise using different knee angles on three-dimensional acceleration received in the lumbar region and neuromuscular activation of 8 muscles that were selected in order to determine their implications for rehabilitation. Thirty physically active women (mean ± SD; 21.7 ± 1.67 years) were randomized in three groups. The first group performed on the platform with 15, 45 and 90º knee flexions, the second group with 45, 90, 15º, and the third group with 90, 15, 45º. The WBV frequency was 12.6 Hz. The acceleration was recorded by a tri-axial accelerometer (Biopac) attached on the skin at L3 level and the electromyography (EMG) was recorded by surface active electrodes (Biopac) on the extensors and flexors of the knee and lower trunk. The lateral acceleration was 3 times greater ($p< 0.05$) at the vertical line in 3 angles of flexion, and the vertical line was 2 times greater ($p< 0.05$). Maximum accelerations: lateral (11-13 g) and vertical line (6-7 g) had increased when reducing the knee-flexion angles. In conclusion, WBV using the Galileo platform transmits more lateral neuromuscular and mechanical stimuli than vertical stimuli. A smaller degree of knee flexion transmits a greater mechanical stimulus, and a higher flexion of the knees implies an increase of muscular activity in the vastus internus muscle. These findings open the possibility of different applications.

KEY WORDS: vibration, electromyography, posture, rehabilitation

INTRODUCTION

Whole body vibration is based on oscillating waves causing mechanical stimulation that increases the effect of the gravitational load on the skeleton, joints and neuromuscular system [3].

The mechanism responsible for the vibration benefits is not entirely clear. However, it is fair to say that WBV stimulates the sensory receptors localized in muscle or tendon activating mainly the muscle spindles [22]. The activation of these muscles facilitates the activation of α-motoneurons via α-afferent and α-efferent pathways [21], leading to tonic vibration reflex (TVR) [7] increasing the motor unit activation [18]. Currently, there are many vibration platforms on the market and they basically differ in terms of their frequency range, amplitude and type of vibration stimulation. The effects of using WBV with separate types of platforms on training [14], osteoporosis [9], muscle strength [26], equilibrium and falls [6], etc. have been studied. However, the findings are not unanimous as benefits were not present in all the studies [5,27]. The diversity of results may be due to the fact that the optimal dose for improving each value remains unknown, as does the most efficient posture for each training session and the specific population [1]. Furthermore, many unanswered questions concerning aspects of great relevance in WBV training remain: 1) oscillation frequency; 2) amplitude of movement; 3) exposure time; 4) resting time; and 5) body posture, whereby the joint flexion angle is of key importance [1]. Most prevalent in professional and scientific settings are vertical and tilting vibration platforms. Only a few studies describe the influence of the degree of knee flexion on a vertical vibratory platform, which significantly modulates the transmissibility of mechanical stimuli through the body [23]. However, too little is known about the subject of tilting platforms.

The purpose of this study was to provide researchers and rehabilitation professionals with information concerning the implication of varying the degree of knee flexion, when exposed to WBV on a tilting platform at frequencies below 12.6 Hz. Particularly, the neuromuscular response of eight selected muscles and the three-dimensional acceleration at the lumbar level (L3) were studied so as to expand our knowledge of the most suitable dose response. We hypothesized that changes in the degree of knee flexion on a tilting vibration platform affect or modulate the mechanical and neuromuscular stimuli.

MATERIALS AND METHODS

Participants. An invitation to participate in the study was sent to students of the Faculty of Sports Sciences at the University of Extremadura (Cáceres, Spain). Forty-five students decided to participate. Of those, fifteen were excluded as they did not fulfil the study inclusion criteria, which were:

1. Being a non-smoker.
2. Abstaining from drinking alcoholic beverages.
3. No clinical history of metabolic or biomechanical diseases.
4. Age 18-25 years.
5. Exercising at least 3 h per week.
6. Sign an informed consent form.

The final study sample comprised 30 people. The committee on biomedical ethics of the University of Extremadura (Spain) approved the study.

Data collection

All measurements were made by the same investigator in the morning between 9:30 a.m. and 12 noon. The study used active electrodes (TDS150B, Biopac, USA) that were placed according to a previously used protocol [19] on the following muscles of the trunk and dominant leg: rectus abdominis (RA); obliquus transversus (OT); erector spinae (EC); quadratus lumborum (QL); anterior rectus femoris (RF); vastus externus (VE); vastus internus (VI) and biceps femoris (BF).

The knowledge of surface electromyography and the number of applications have increased considerably during the last years. However, most methodological developments have taken place locally, resulting in different methodologies among the different groups of users.

We used in this study the SENIAM recommendations on sensors, electrode placement, signal processing and modelling [11].

Placement of electrodes

Skin preparation (to minimize the effects of skin resistance in the signal):

1) Pluck the area of muscle where the electrodes are to be placed
2) Sand the area with sandpaper appropriate to remove dead skin
3) Clean with alcohol
4) Place the electrodes according to the SENIAM protocol
5) We left 6 minutes before the pickup of information, since this demonstrated a decline of around 30% in the initial values of skin impedance in the first 5 minutes.

Orientation of electrodes

The electrodes were placed taking into account the orientation of muscle fibres, assuming that the orientation of the fibres is linear and that these are arranged in parallel.

Electrode fixation

We used a gel electrolyte as a chemical interface between skin and metal electrode face.

We used rings of double-sided adhesive, regular tape and elastic straps to fixate each electrode, minimizing the risk of separating the electrodes from the skin.

We fixed the cable with elastic straps and tape on the skin.

Following placement of the electrodes in a single evaluation session, the participants underwent two tests in order to measure electric activation and the maximum force in an isometric voluntary contraction both in the RA, OE, EC and CL muscles of the trunk and the RF, VE, VI and BC muscles of the right leg. The maximum isometric test of the trunk muscles consisted of a maximum abdominal and dorsal flexion, each lasting 20 seconds [13]. Although the standardized protocol of Ito et al. [13] was for 20 seconds to measure the maximal isometric trunk strength, we only analysed the window of EMG data from second 2 to 5 to avoid the fatigue effect because our purpose was to measure the EMG at maximal voluntary contraction for the normalization of other measurements.

As for the muscle test, it consisted of a 5-second maximum isometric contraction of the flexors and extensors of the knee at 15º, 45º and 90º, using an isokinetic dynamometer (System 3, Biodex, USA). We analysed the EMG of the 3 intermediate seconds.

After a 5-min rest, the participants were subjected to three 30-s WBV repetitions at a constant 12.6 Hz rate and 4 mm amplitude on the Galileo vibration platform (Galileo 900, Novo Tec, Pforzheim, Germany). Furthermore, before each WBV series started, five seconds of EMG signal were recorded in the same angle.

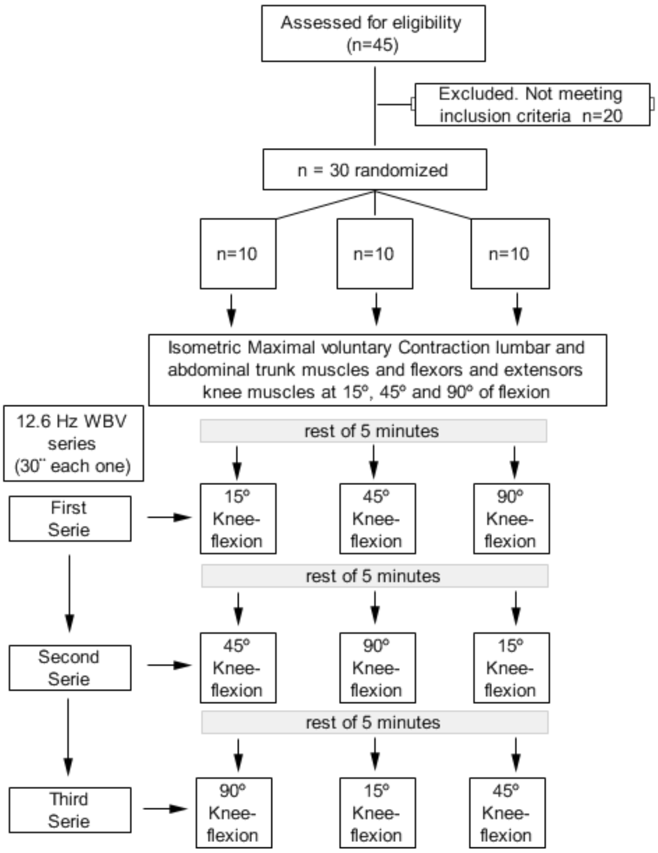

FIG. 1. PARTICIPANTS FLOW DIAGRAM

A 5-min rest was given between repetitions. The study was counterbalanced by randomizing the 30 participants into three groups of 10 individuals; the angle of knee flexion was varied: the first group performed the 15, 45, 90º sequence, the second group the 45, 90, 15º sequence, and the third group the 90, 15, 45º sequence. We used a simple sensor twin axis goniometer (SS20, Biopac, USA) to control the angle of knee flexion and the participants had visual feedback during the performance of the WBV repetitions. Figure 1 shows the whole measurement process.

The accelerometer (TSD109F, Tri-Axial 5G, Biopac, USA) was placed at the lumbar level on a skin area at the L3 vertebral level.

The electromyographic signal was gathered at 1000 Hz, and then analysed with the (software) program AcqKnowledge 3.7.3 (Biopac, USA).

Checking the EMG signal

After connecting the electrodes (including grounding) to the amplifier, start the PC-signal monitor and zoom in the raw EMG trace of each channel to allow a detailed inspection. We asked the participant to completely relax (the participant lay down on a therapy bench). The EMG baseline inspection focuses on these three major factors:

1) Baseline noise. Calculate the EMG mean amplitude of the raw rectified EMG for 5 seconds should be minor at 2.5 μV in all measures.

2) Baseline offset. We performance the mean value of the raw EMG is shifted near from the true zero line.

3) Baseline shifts. The baseline before/after contractions had to constantly remain at the zero line.

Filter

SENIAM and ISEK recommended amplifier band-pass settings from 10 Hz high pass up to at least 500 Hz low pass, but in order to minimize the baseline shifts that typically appear from wire movement artefacts within the muscle tissue (as in our case), it is recommended to apply a high-pass filter upper 10 Hz. Although to reduce noise that the baseline you can use a filter to 20 Hz, in our study the signal EMG was filtered with a high-pass filter at 15 Hz – we used a vibration artefact of 12.5 Hz because with this frequency we eliminated the most noise of artefacts at baseline.

EMGrms

The electromyographic signal was calculated and expressed as a function of time, 100 ms windows around every data point, based on the square root of the average power of the electromyographic signal (EMGrms). EMGrms was normalized by MVC and expressed as percentage of EMGrms without WBV in the same angle.

A descriptive study was made, as was a comparison of the data obtained by electromyography of the separate muscles during the 3 angulations of knee-flexion extensions. An analysis of the variance (ANOVA) using repeated measurements with the statistical (software) program SPSS 15.0 (Chicago, Illinois) was done. For all tests the significance level was set at $p<0.05$.

RESULTS

Three-dimensional accelerometry. All the women that were studied were within normal parameters in terms of weight, height and muscular strength (Table 1), and also reported normal strength and electric activity in their isometric muscular contractions with 15, 45 and 90º knee flexions.

The accelerations during WBV at the L3 level varied depending on the knee-flexion angle. The results of the median recorded accelerations at the lumbar level reflect their decrease with increasing knee flexion angle (Figure 2).

TABLE 2. SAMPLE CHARACTERISTICS (N=30)

Characteristics	Mean ± SD
Age (years)	21.77 ± 1.65
Weight (kg)	59.30 ± 5.67
Height (m)	1.64 ± 5.40
Body mass index (kg · m⁻²)	22.03 ± 1.99

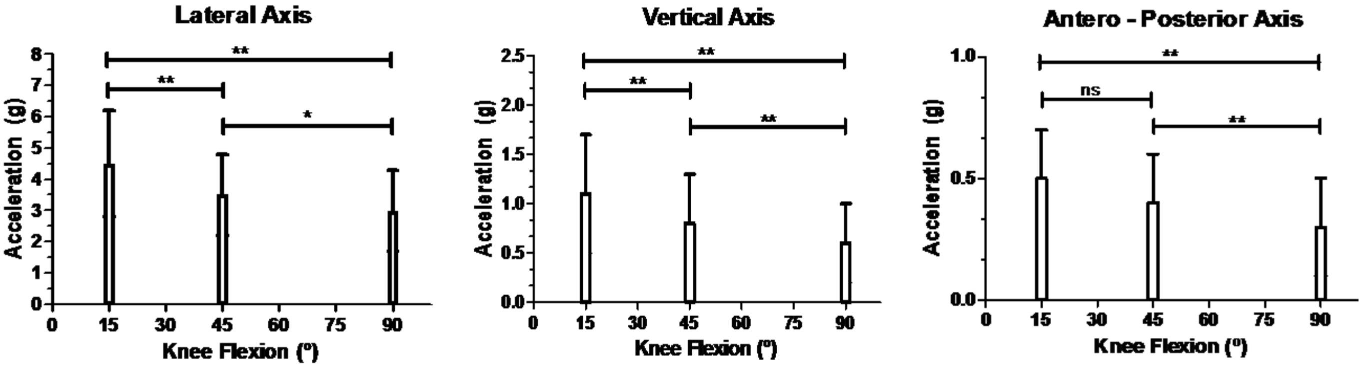

FIG. 2. MEDIAN ACCELERATIONS AT THE LUMBAR LEVEL IN DIFFERENT KNEE FLEXION ANGLES

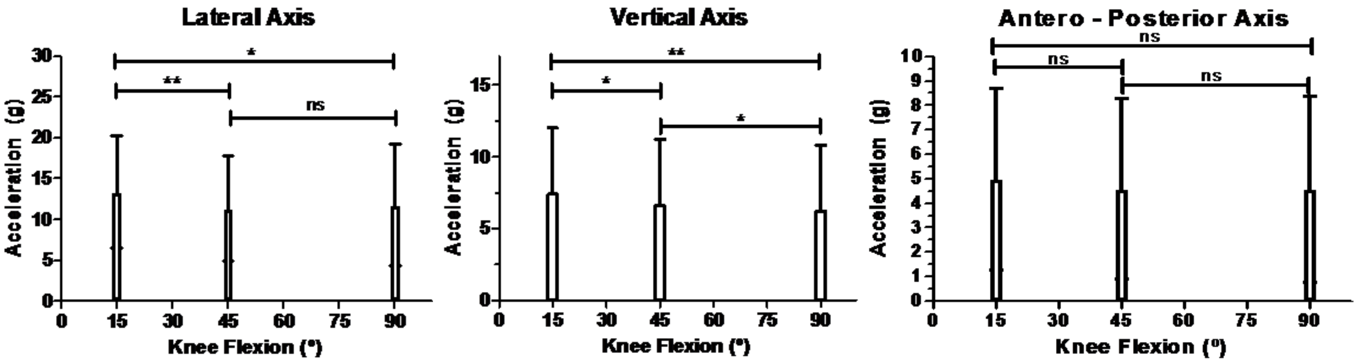

FIG. 3. MAXIMUM ACCELERATION AT THE LUMBAR LEVEL IN DIFFERENT KNEE FLEXION ANGLES

The median acceleration in the lateral axis was three times greater ($p<0.001$) than in the vertical axis, and the acceleration in the vertical axis was twice that ($p<0.001$) of the anteroposterior axis.

As for maximum acceleration, lateral acceleration was always greater than vertical acceleration at 15º, 45º and 90º, whereby vertical acceleration was ($p<0.001$) greater than anteroposterior acceleration at 15º, 45º and 90º. There were no significant differences in the anteroposterior axis according to the degree of knee flexion, in the vertical axis there were significant differences for all the knee-flexion degrees in the lateral axis, and only when comparing 45º with 90º were there no significant differences (Figure 3).

Neuromuscular response

The electric activity of the abdominal rectal muscle during WBV is significantly less for 15º than for 45 and 90º (Figure 4). The activity of the rectus femoris anterior during WBV was kept constant during the 3° of knee flexion relative to no WBV condition (Figure 5). The activity of the vastus internus muscle at 90º was greater than at 15º and 45º. However, the remaining evaluated leg muscles show similar electric activity in the three positions.

DISCUSSION

The most important finding of this study is that a tilting vibration platform transmits more lateral than vertical accelerations at the lumbar level, whereby this acceleration is sufficient in order to be compatible with the bone anabolism in the neck of the femur. It has also been confirmed that with increasing knee flexion on this type of platform, major activation of the VI muscle occurs.

In a study performed with a vertical platform [23], more vertical than lateral accelerations were determined at the lumbar level, while with our lateral platform, more lateral than vertical accelerations were determined. The site where more micro-impacts are received differs, depending on which platform is used. On vertical platforms, micro-impacts occur mostly in the lumbar spinal region, while on lateral platforms, these occur mostly in the femoral heads, which explains why following vertical vibration exercise, an increase in the bone mineral density at the level of the vertebral column (spine) [24] occurs, and following vibration exercise on lateral platforms, increased mineral density in the neck of the femur occurs [9]. Hence, both types of platforms may supplement one another in terms of certain effects.

The above is of great relevance for specific groups, e.g. postmenopausal women [9], older people [17], or patients with neuromuscular disorders, including Alzheimer [29], Parkinson's disease [15] or multiple sclerosis [16], since decreased mineral bone density is common among these populations. Nowadays, in order to maintain and/or improve bone mass, pharmaceutical drugs are generally the preferred choice [4], or if allowed by the pathology, low-impact activities, e.g. walking on hard surfaces, jogging, multiple jumping, step aerobics, etc. [20]. However, these types of exercise may cause serious risk of falls and lesions in these populations. However, in all the studies reviewed on body vibration in patients with neuromuscular pathology [2,8,10,25,28], not a single case involving lesions due to such usage was found.

On the other hand, it was observed that the neuromuscular response (NR) of the evaluated muscles at the lower pace may be affected by the degree of knee flexion over the platform. Moreover, it appears that in addition to the degree of knee flexion, the type of vibration (vertical or lateral) affects the NR of the evaluated muscles.

People with neuromuscular disorders have a significant amount of falls [12]. In lateral falls the VI muscle plays an important role. This study determined that a significant increase in the percentage of neuromuscular activation occurs in the VI muscle. When increasing the degree of knee flexion, a similar neuromuscular activation trend was observed on both platforms [22]. People with neuromuscular disorders show a strength deficit in the lower-body muscles, so exercising those muscles may prove highly beneficial [12].

In the reviewed studies concerning WBV in patients with neuromuscular pathology, no explanation was given as to the criterion that was followed for selecting the posture (degree of knee flexion) to be used on the vibration machine [2,8,10,25,28], when it was seen that this decisively affects NR .

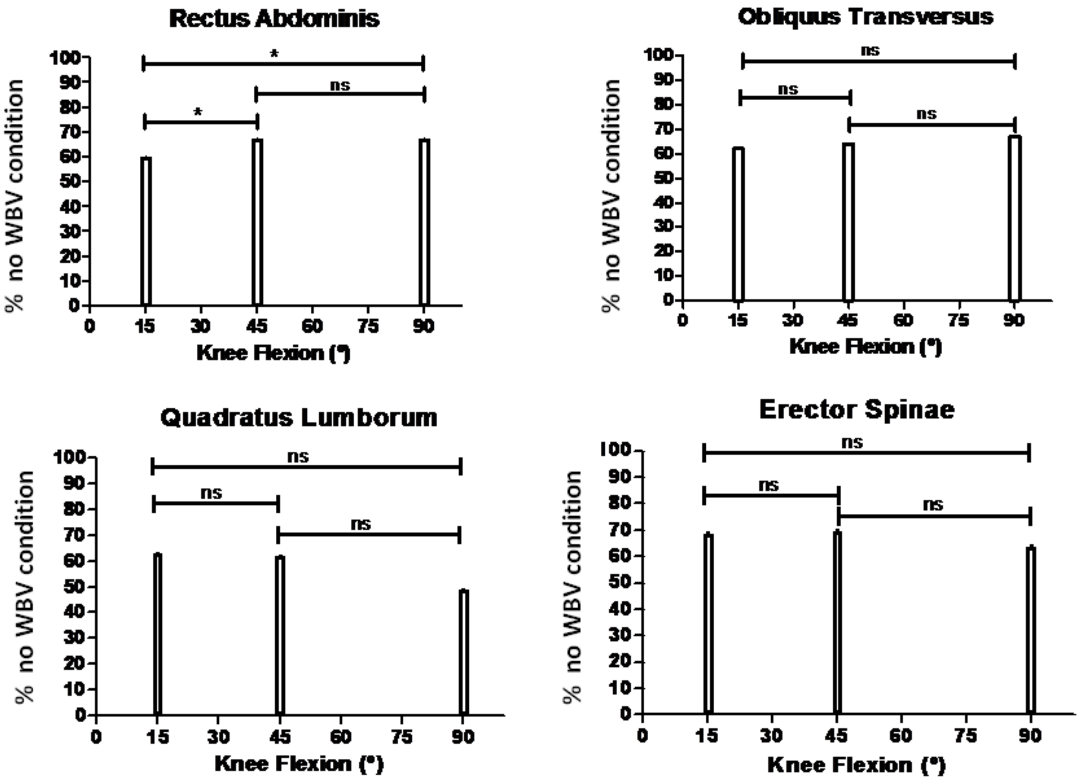

FIG. 4. MAXIMUM ACCELERATION AT THE LUMBAR LEVEL IN DIFFERENT KNEE FLEXION ANGLES

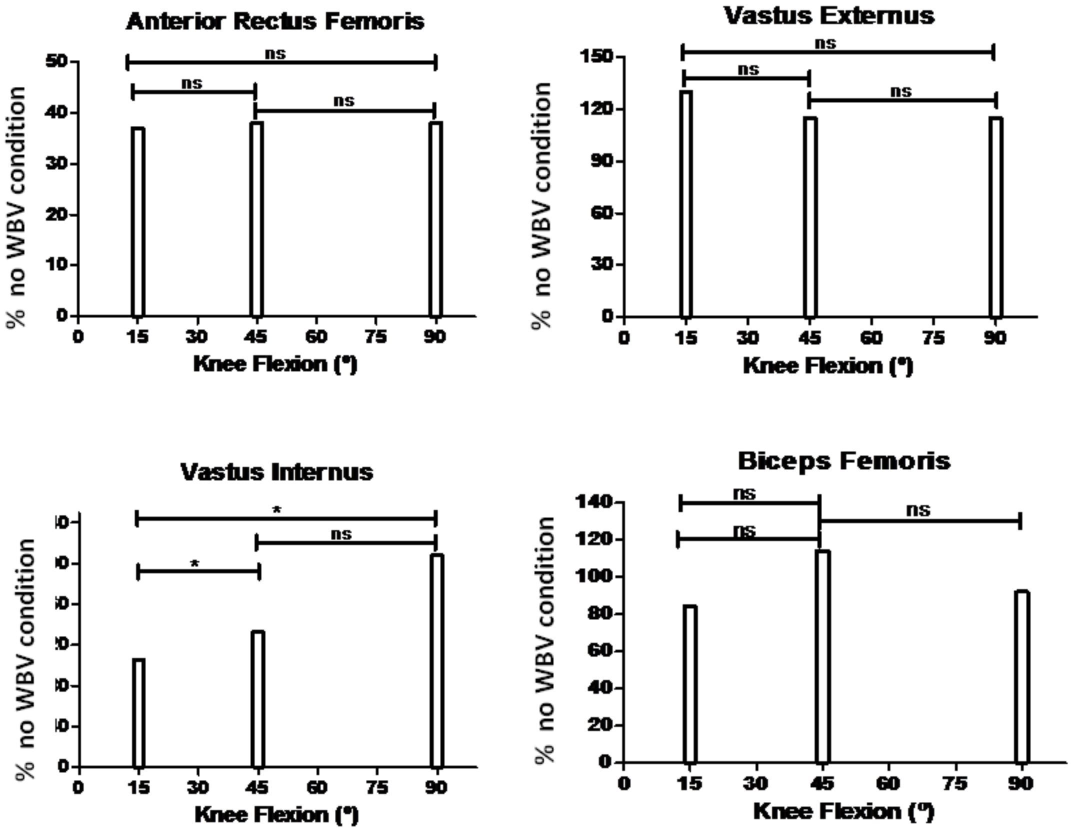

FIG. 5. MAXIMUM ACCELERATION AT THE LUMBAR LEVEL IN DIFFERENT KNEE FLEXION ANGLES

The results obtained in our study provide relevant information to researchers and neuromuscular rehabilitation professionals, when selecting the type of vibration to apply (vertical or lateral), and the degree of knee flexion, and will enable them to better adjust the dose responses of the WBV treatment, both in healthy individuals and individuals with neuromuscular problems.

At the trunk level, it was seen that WBV activates muscles at 60-70% of their maximum voluntary isometric contraction, and it seems that the degree of knee flexion has little influence on the NR of the trunk muscles. However, this does not contradict the beneficial effects of treating lower back pain [23].

Study limitations

This study was performed on young, physically active and healthy individuals. However, applying these findings to other populations, e.g. populations that are less physically active or with neuromuscular pathologies, will require more study. Nevertheless, this study is relevant for one of the determining factors of WBV, i.e.: a) The posture on the platform (degree of knee flexion) and b) the type of platform (vertical or lateral). However, a more thorough determination of the WBV dose response will require future studies using different platforms and additional vibratory-load-determining factors in order to properly advance the professional potentials for this type of vibration-providing device.

CONCLUSIONS

The degree of knee flexion could be used to modulate the load and progression of WBV physical therapy at low frequencies (12.6 Hz) using a tilting vibration platform, especially for preventing falls and osteoporosis. The increase of degree of knee flexion intensifies the neuromuscular response of the vastus internus and rectus abdominus. In addition, more mechanical impact on the hip is expected between 15 and 45 degrees of knee flexion than at a higher degree.

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