REVISTA NEUROCIÊNCIAS

Original

# The effect of whole-body vibration training on electromyographic signals in stroke patients

## *O efeito do treinamento de vibração do corpo inteiro nos sinais eletromiográficos em pacientes acometido por AVC*

## *El efecto del entrenamiento vibratorio de todo el cuerpo sobre las señales electromiográficas en pacientes con accidente cerebrovascular*

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## Resumo

**Objetivo.** Foi verificar a influência do treinamento vibratório no sinal eletromiográfico dos músculos retofemoral (RF) e tibial anterior (TA) em pacientes com acidente vascular cerebral (AVC). **Método.** Trata-se de ensaio clínico, com amostra composta por 43 pacientes hemiparéticos com AVC, que foram randomizados em dois grupos: controle (GC, n=19) e intervenção (GI, n=24). Os instrumentos utilizados para avaliação foram o Mini Exame do Estado Mental, a Escala de Avaliação de Fugl-Meyer e a eletromiografia de superfície (EMG) em contração isométrica voluntária máxima (CIVM) dos músculos RF e TA bilateral e simultaneamente. A terapia vibratória de corpo inteiro (TVCI) (plataforma vibratória triplana, frequência de 50 Hz e amplitude de 2 mm) foi utilizada para o tratamento. A aplicação da TVCI foi realizada três vezes por semana durante 8 semanas consecutivas. A análise estatística utilizada foi o teste t independente para comparar as características basais do GC e GI. Foi aplicado o teste de Shapiro-Wilk para verificar a normalidade dos dados e posteriormente o teste de Wilcoxon para comparar os tempos e o teste de Mann-Whitney para comparar os grupos. **Resultados:** Os resultados mostram que a atividade EMG RMSn não se alterou intragrupo nem intergrupo. **Conclusão:** O treinamento vibratório não influenciou o sinal EMG dos músculos RF e TA em pacientes com AVC.
**Unitermos.** plataforma vibratória; reabilitação; acidente vascular cerebral

## Abstract

**Objective.** Was to verify the influence of vibration training on the electromyographic signal of the rectofemoral (RF) and tibialis anterior (TA) muscles in stroke patients. **Method.** This is clinical trial, with 43 hemiparetic stroke patients, who were randomized into two groups: control (CG, n=19) and intervention (IG, n=24). The instruments used for evaluation were the Mini Mental State Examination, the Fugl-Meyer Evaluation Scale, and surface electromyography (EMG) in maximum voluntary isometric contraction (MVIC) of the RF and TA muscles bilaterally and simultaneously. Whole-body vibration therapy (WBV) (tri-plane vibration platform, a frequency of 50 Hz and 2 mm of amplitude) was used for treatment. The application of the WBV was performed three times a week for 8 consecutive weeks. The

statistical analysis used was the independent t test to compare the baseline characteristics of the CG and IG. The Shapiro–Wilk test was applied to verify the normality of the data and subsequently the Wilcoxon test to compare times and the Mann-Whitney test to compare groups. **Results.** The results show that EMG RMSn activity did not change intra-group nor inter-group. **Conclusion.** Vibration training did not influence the EMG signal of the RF and TA muscles in stroke patients.
**Keywords**. vibration platform; rehabilitation; stroke

## Resumen

**Objetivo.** Fue verificar la influencia del entrenamiento vibratorio en la señal electromiográfica de los músculos rectofemoral (RF) y tibial anterior (TA) en pacientes con accidente cerebrovascular. **Método.** Se trata de un ensayo clínico, con 43 pacientes hemiparéticos con ictus, que fueron aleatorizados en dos grupos: control (GC, n=19) e intervención (GI, n=24). Los instrumentos utilizados para la evaluación fueron el Mini Examen del Estado Mental, la Escala de Evaluación de Fugl-Meyer y la electromiografía de superficie (EMG) en máxima contracción isométrica voluntaria (MVIC) de los músculos RF y TA de forma bilateral y simultánea. Para el tratamiento se utilizó terapia de vibración de cuerpo entero (TVCE) (plataforma de vibración triplano, una frecuencia de 50 Hz y 2 mm de amplitud). La aplicación de la TVCE se realizó tres veces por semana durante 8 semanas consecutivas. El análisis estadístico utilizado fue la prueba t independiente para comparar las características basales del GC y el GI. Se aplicó la prueba de Shapiro-Wilk para verificar la normalidad de los datos y posteriormente la prueba de Wilcoxon para comparar tiempos y la prueba de Mann-Whitney para comparar grupos. **Resultados**. Los resultados muestran que la actividad EMG RMSn no cambió intragrupo ni intergrupo. **Conclusión:** El entrenamiento vibratorio no influyó en la señal EMG de los músculos RF y TA en pacientes con ictus.
**Palabras clave.** plataforma vibratória; rehabilitación; ictus

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## INTRODUCTION

Whole body vibration (WBV) is a neuromuscular exercise modality that is gaining prominence both in physical training centers as a therapeutic modality for rehabilitation and in research[1]. WBV is an intervention involving a vibrating platform and the mechanical oscillation of force alternating between acceleration and displacement. The most common types of alternation are lateral (oscillatory) and vertical (linear). These stimuli are transmitted to the body and are captured by sensory receptors. The stimuli cause a complex neurophysiological spinal and supraspinatus reaction called tonic vibration reflex. This reflex is responsible for muscle activation and increased functional performance[2,3].

Studies point to promising results of this therapy for patients affected by stroke. It has been shown to improve motor function, increase blood perfusion[4], and potentiate muscle activation[5,6]. However, these mechanisms are still not clearly elucidated, and there are strong recommendations for more research to better understand and substantiate the mechanism of biomechanical and physiological changes in the effect of vibration on stroke patients[7].

According to the World Health Organization, stroke is an important public health problem in Brazil. It is a leading cause of death in the country and has a strong impact on the functional capacity of survivors[8]. Therefore, we propose implementing WBV in the rehabilitation of stroke patients and the use of surface electromyography (EMG) as a method of assessing the effects of WBV on this population[9,10].

EMG is a technique that allows the recording and analysis of electrical signals produced in muscle cells. It can be used to quantify the relationship between the strength of electromyographic signals, the level of muscle activation, the moment of muscle activation, and the fatigue signal[9]. It was observed an increase in muscle activity of 5%–50% of the maximum voluntary isometric contraction (MVIC) of six lower limb muscles in healthy adults during WBV[11]. It was observed significant increase in muscle activity of the vastus lateralis (VL) and gastrocnemius, of about 10%–20% of the MVIC in post-stroke patients[12].

Similar responses were observed in the electromyographic activity of the muscles vastus lateralis muscle and gastrocnemius of the paretic and non-paretic limbs with frequency between 20 to 55Hz and peak 0.96 to 1.61g[12]. However, the electromyographic responses of the tibialis anterior (TA) and rectus femoris (RF) muscles have been poorly investigated. Therefore, the objective of this study was to verify the effect of vibration training on the electromyographic signals of the RF and TA muscles in stroke patients. The study hypotheses were as follows: (1) the EMG activity of the RF and TA muscles can increase significantly after 8 weeks of vibration training; (2) vibration training with a frequency of 50Hz and an amplitude of 2mm can modify the electromyographic signals of the RF and TA muscles; and (3) vibration training can have more relevant effects on the paretic side.

## METHOD

### Study design

This is a randomized, parallel clinical trial with statistical analysis and blinding of the evaluators. The study was approved by the Ethics Committee in Research of the Universidade do Vale do Sapucaí (UNIVÁS) in Pouso Alegre, Minas Gerais, Brazil (protocol number 1499/10) and answered all the provisions contained in Resolution 466/12 of the National Health Council. All participants gave informed consent and were told about the objectives, research procedures, and the minimum risk, such as muscle fatigue. They were clearly told their participation was voluntary and that they could withdraw from the study at any time without prejudice to the researchers. The study was registered as a Brazilian clinical trial with the number RBR-34v9px. It was carried out from August 2013 to July 2015 at the human motricity laboratory at UNIVÁS.

**Sample**

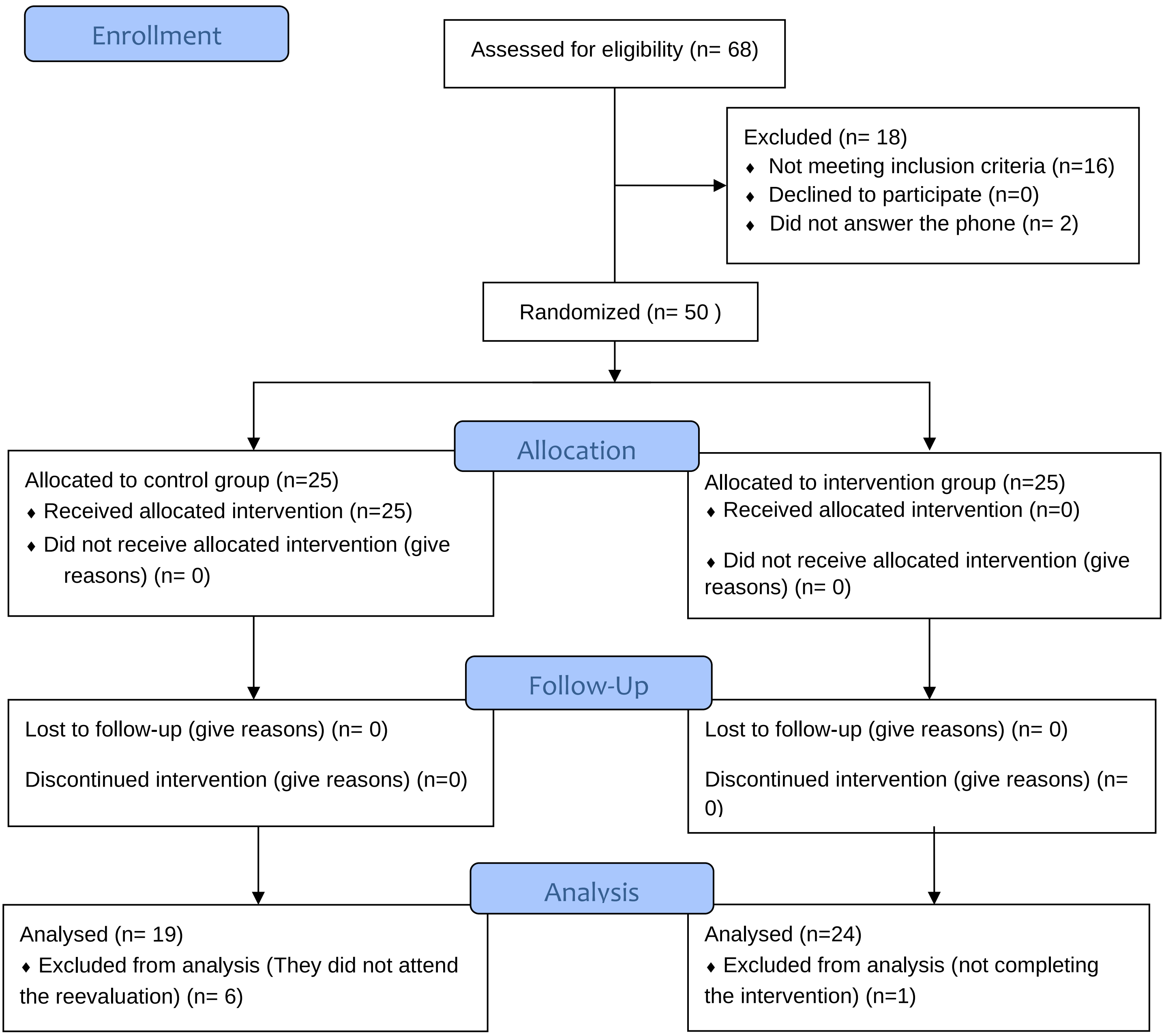
The individuals were recruited from a waiting list at the physiotherapy outpatient clinic and the Neurology Department at the Hospital Clínicas Samuel Libânio, Pouso Alegre, Minas Gerais, Brazil. The following inclusion criteria were used: sequelae of hemiparesis due to stroke; clinically diagnosed by stroke, more than 3 months of injury; both genders; age over 20; mental competence assessed using the Mini Mental State Examination (MMSE) [13]; and reduction of motor function assessed using the Fugl-Meyer Assessment (FMA) of sensorimotor function scale[14,15]; have agreed to participate in the research and signed the free and informed consent form. Excluded from the study were individuals who presented with sequelae of hemiparesis due to another central lesion (head trauma, multiple sclerosis, encephalitis, parkinson, cerebellar lesions and amyotrophic lateral sclerosis), double hemiparesis, use of botulinum toxin in the muscle evaluated in the past 6 months, being on medication to control spasticity, or having dermatitis or a wound in the evaluated muscle, fractures in the lower limbs, deep vein thrombosis, pacemaker use and ulcers on the soles of the feet due to diabetic neuropathy

Four researchers were involved in this study. Researcher 1 served as the outpatient secretary, contacting the participants by telephone and performing simple allocation. Researcher 2 carried out the initial evaluation using a sociodemographic questionnaire (age, sex, side affected, dominant side, and type of stroke–ischemic or hemorrhagic), clinical evaluation, measurement of sensory motor function (FMA), mental competence (MEM), muscle electrical activity (EMG), and a final assessment (EMG). Researcher 3 applied the entire intervention protocol for 8 weeks. Researcher 4 performed the statistical analysis of the results.

Sixty-eight participants were contacted, and of those only 50 met the inclusion criteria. Individual randomization of participants was carried out and allocation was confidential. Participants were allocated into two groups, an intervention group (IG; n=25) and a control group (CG; n=25). Seven participants were excluded from the research because they did not attend the re-evaluation and gave up the intervention (Figure 1). The IG and CG were followed for eight weeks of intervention, it was not possible to carry out the follow-up after the intervention.

The sample calculation was performed with five patients for the IG (96.26±4.34) and five for the CG (79.12±10.31) post-intervention for the RF variable. An alpha of 0.05 and power of 0.95 were adopted, and six individuals were determined for both groups.

Figura 1. CONSORT 2010 Flow Diagram.



## Procedure

*Randomization process*

Researcher 1 created a randomization list sequentially numbered by the computer and stored in a sealed envelope. The researcher subsequently carried out a random draw allocating participant to the CG and the IG (Figure 1).

*Assessment tools*

Participants were assessed using the following instruments. Sensorimotor function was evaluated using the Brazilian version of the FMA. The Brazilian version of the MMSE and surface EMG (EMG System of the Brazil Ltda.®) were also employed.

To determine the level of motor impairment, the Brazilian version of the FMA was used because it has high inter- and intra-examiner agreement and reliability (CI=0.99 and 0.98, respectively)[15]. This scale is a quantitative evaluation system that addresses six aspects of a patient—range of motion, pain, sensitivity, motor function of the upper and lower extremities and balance, coordination, and speed—totaling 226 points. Each item is presented with an ordinal scale of three points: 0 - cannot be performed, 1 - partially performed, and 2 - completely performed. In the present study, only motor function was applied, with a maximum score of 100 points for normal function (66 points for the upper extremity and 34 for the lower extremity). From this score (100), the level of impairment was determined; a score of less than 50 indicates severe motor impairment; 50–84 indicates marked motor impairment; 85–95 indicates moderate impairment; and 96–99 indicates mild impairment[14,15].

The Brazilian MMSE was used to assess cognitive ability. The MMSE consists of five dimensions that evaluate orientation; episodic memory; immediate and late; calculation/working memory; visuospatial ability and language. The maximum score is 30 with cutoffs of 18 and 25 according to the absence or presence of formal schooling, respectively[13]. The study showed the test–retest reliability of the Portuguese version to be adequate[16].

EMG was used to assess the muscle electrical activity of the RF and TA muscles in MVIC[9]. EMG showed satisfactory reliability in assessing the electrical activity of the muscles[17].

*Electromyographic evaluation procedures*

Electromyographic signals were collected using a four-channel device (EMG System do Brasil Ltda.®), model EMG-800C, including pre-amplified active bipolar electrodes with a 20x gain, a 20–500 Hz analog bandpass filter, and a common mode rejection ratio >100 dB. Electromyographic signals were collected with a sampling frequency of 2 KHz and were digitized using a 16-bit A/D converter. Disposable silver/silver chloride (Ag/AgCl) circular electrodes with a 10-mm diameter (MediTrace®) were placed at 20-mm intervals.

First, electromyographic signals were collected bilaterally and simultaneously from the TA and RF muscles during WBV[18-21]. To establish the WBV reference values, the volunteers stood in the orthostatic position on a rubber mat with the feet apart, knees flexed to 30°, and hips flexed to 10°, while placing the hands on a flat surface for support. A goniometer was placed on the knees to maintain the 30° flexion. The participants were requested to perform a sustained isometric contraction (by applying maximal strength against the ground surface) for 5 s. The participants performed three 5-s MVIC series with 1-min rest intervals between the series, while following the examiner's verbal requests for maximum contraction.

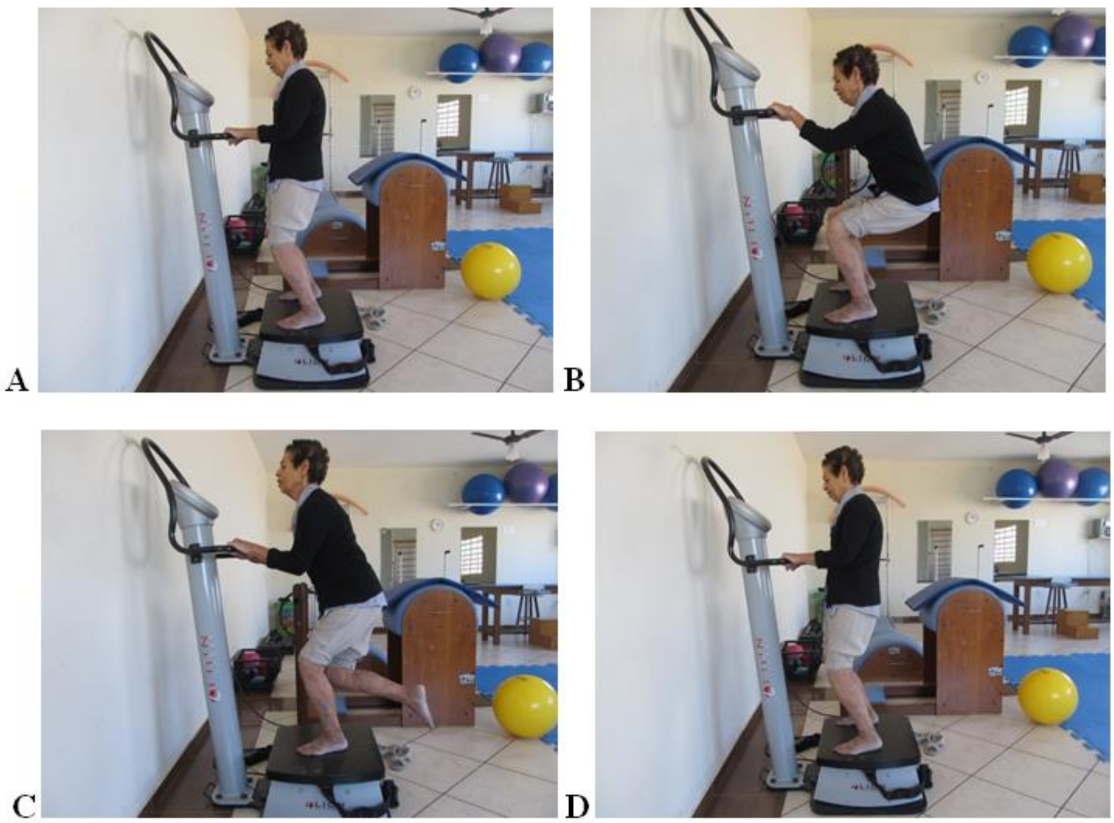
To analysis, the skin was cleansed using a piece of cotton and 70% alcohol, and trichotomy was performed before the active electrodes were placed along the direction of the muscle fibers (TA and RF). To place the TA electrodes, the participants sat on a table with the knees half-flexed and were requested to perform dorsiflexion with ankle inversion; in that position, the electrode was placed at a position one-third below the fibula, with a 2-cm distance between the electrodes. In the case of the RF, the participants sat on a table with the knees slightly flexed and the upper part of the trunk slightly stretched; in that position, the electrode was placed at the midpoint of a line extending from the anterior–superior iliac spine to the patellar upper margin. The reference electrode was placed on the right ankle[22].

*Experimental protocol*

The entire procedure was carried out in five stages: 1) evaluation using the FMA and MMSE scales and a questionnaire to gather demographic data for sample selection; 2) randomization for the groups (IG and CG); 3) evaluation of the EMG surface of the two groups (IG and CG); 4) application of the intervention protocol with WBV therapy associated with neuromotor physiotherapy for the IG and for the CG treatment with neuromotor physiotherapy; and 5) reassessment of the EMG surface for both groups. The IG received the WBV therapy on the tri-plane vibration platform (Lion® brand), being fixed at a frequency of 50 Hz and 2 mm of amplitude. Individuals were instructed to maintain activities in neuromotor physiotherapy three times a week. The application of the WBV was performed three times a week for 8 consecutive weeks. The procedure was divided into two phases, a first phase equivalent to 4 weeks and a second phase equivalent to another 4 weeks.

In the first phase, four 60-s sets of full body vibration were applied, with a 60-s rest between each series. In the first series (60 s), the subjects were instructed to remain in a static standing position with foot support and hands supported by the vibration device, keeping their feet apart with their knees semi-flexed at 30°. In the second series, the same position was used, but with the knees flexed at 90°. In the third series, the same position was used as in the first but with unipodal support of the affected limb with the knee semi-flexed at 30°. The fourth series was performed the same way as the first series, without modifications (Figure 2). In the resting posture, the participants remained on the vibrating platform, maintaining the static standing position with their knees extended. The second stage was conducted the same way as the first but with double the number of series, that is, eight series. All participants were positioned barefoot on the vibrating platform with support for the upper limbs, and a mark was put on the vibrating platform for foot placement[23]. To measure the angle of the knees, a 35-cm open plastic goniometer with two rulers containing a 0°–360° transfer system was used. The center of the goniometer was positioned on the knee joint axis; one of the rulers (fixed part) aligned with the femur segment and the other ruler (mobile part) was positioned on the tibial segment[24].

Figure 2. Intervention protocol for the IG with the whole-body vibration platform, 4 series of 60 seconds were performed according to the image above. A: Individuals orthostatic posture with bipodal support and hands supported on the vibration device, keeping the feet apart with the knees semi-flexed at 30°. B: Same posture as A, but with the knees flexed at 90°. C: Same position as A, but with unipodal support on affected limb with knee semi-flexed at 30°. D: Identical positioning as A, without modification.



The CG performed neuromotor physiotherapy three times a week for 8 consecutive weeks. Neuromotor physiotherapy consisted of stretching exercises, training functional activities for the upper and lower limbs, and aerobic exercises on an exercise bike totaling 1h of intervention.

*Processing of the EMG signal*

To analyze the activity of the investigated muscles, the root mean square of the EMG signal amplitude was calculated. All the signals were processed using MATLAB software routines (MathWorks Inc, Natick, MA). The EMG signal length was 5s, but the first and last seconds were disregarded; therefore, a period of 3s was analyzed. This was used to establish the reference value, the maximal root mean square, of each analyzed signal before and after the intervention to achieve reliable measurements. The reference value was divided by the greatest value of all the analyzed signals and then multiplied by 100.

## Statistical analysis

Descriptive statistics were used to characterize the sample relative to the clinical and demographic variables. An independent t test was used to compare the baseline characteristics of the GC and the GI. A Shapiro–Wilk test was performed to determine the normality of the data. In addition, a Wilcoxon test was used for within-group comparison, and a Mann–Whitney test was used for between-group comparison. All analyses were executed using the SPSS package (version 20.0). The probability level for statistical significance in all tests was set at $p<0.05$.

## RESULTS

Forty-three individuals completed the entire intervention protocol, with a sample loss of seven participants due to missing the intervention. Table 1 shows the clinical characteristics of the remaining sample. There was no statistical difference regarding age, level of cognition, and motor dysfunction.

Table 1 Demographic and clinical characteristics of the study participants.

| Variables | | IG (n=24) | | CG (n=19) | | p value |
|---|---|---|---|---|---|---|
| Age (years), Mean (SD) | | 60.62±12.11 | | 60.35±12.22 | | 0.89 |
| Mini Mental Examination, Mean (SD) | | 22.95±3.64 | | 24.21±3.55 | | 0.88 |
| FMA, Mean (SD) | | 59.33±21.43 | | 68.1±19.77 | | 0.83 |
| | Severe % | 37.5 | | 21.05 | | |
| | Marked % | 54.16 | | 36.84 | | |
| | Moderate % | 8.33 | | 36.84 | | |
| | Light % | 0 | | 5.26 | | |
| Sex, % | | 66.66 | M | 63.15 | M | |
| | | 33.33 | F | 36.84 | F | |
| Affected Side, % | | 62.5 | L | 50 | L | |
| | | 37.5 | R | 50 | R | |
| Dominant Side, % | | 95.83 | R | 100 | R | |
| | | 4.16 | L | 0 | L | |
| Stroke, % | | 95.83 | I | 84.21 | I | |
| | | 4.16 | H | 15.78 | H | |

IG: Intervention Group; CG: Control Group; SD: Standard Deviation H: Hemorrhagic; I: Ischemic; M: Male; F: Female; R: Right; L: Left; FMA: Fugl-Meyer Assessment

## EMG activity of paretic leg RF and TA

Table 2 shows the muscular activity of the RF and TA of the paretic side in a comparison before and after the intervention and between the groups. The EMG activity normalized root mean square (RMSn) did not change after the intervention with the WBV or when compared to the CG. Statistical analysis confirmed these non-significant observations, with p≥0.05 and a low effect size.

Table 2. Mean and standard deviation of the values obtained from electromyographic variables after the intervention of lower limb affected.

| **Variable** | **Randomised (n=50)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Intervention Group (n=24)** | | **p-value intragroup** | **Effect Size intragroup/power** | **Control Group (n=19)** | | **p-value intragroup** | **Effect Size intragroup/power** |
| **RMSn** | **Pre-intervention** | **Post-intervention** | | | **Pre-intervention** | **Post-intervention** | | |
| **RF** | | | | | | | | |
| **mean±SD** | 88.90±10.36 | 85.87±12.00 | 0.54 | 0.26/0.34 | 84.42±12.88 | 83.91±9.63 | 0.84 | 0.04/0.07 |
| **IC 95%** | 84.52–93.28 | 80.80–90.94 | | 0.24 | 78.98–89.86 | 79.84–87.98 | | 0.05 |
| **TA** | | | | | | | | |
| **mean±SD** | 84.55±15.49 | 84.81±17.51 | 0.66 | 0.01/0.05 | 81.19±20.63 | 81.03±19.78 | 0.81 | 0.00/0.05 |
| **IC 95%** | 78.55–91.09 | 77.41-92.21 | | | 72.48–89.91 | 72.68–89.39 | | |
| **P-value intergroup** | 0.19 | 0.26 | | 0.05 | 0.91 | 0.5 | | 0.05 |
| **Effect size intergrupo RF** | | 0.08 | | | | | | |
| **Power RF** | | 0.05 | | | | | | |
| **Effect size intergroup TA** | | 0.20 | | | | | | |
| **Power TA** | | 0.09 | | | | | | |

RMSn: normalized root mean square. RF: rectus femoris. TA: tibialis anterior .

## DISCUSSION

The main finding in the present study reveals that WBV training did not influence the electromyographic signals in the RF and TA muscles. This finding confirms that the EMG

RMS of the VL and RF also did not change after vibration treatment[25,26]. However, the functional performance of athletes and stroke patients has been shown to improve after vibration treatment[27]. Vibration treatment can be justified by the improvement in neuromuscular efficiency leading to a reduction in EMG activity due to the increase in muscle resistance[26]. Resistance training for a long period may increase strength concentration associated with reduced electromyographic activity[26,28]. At the beginning of the training program, biological adaptation occurs, that is, improvement in the neural efficiency of the supraspinal center, descending tract, spinal circuit and motor plate connections, and neuromuscular junctions[28-30].

In the protocol proposed in the present study, there was a change only in the number of series. The intervention took place over a period of 8 weeks, aiming at resistance training. Studies suggest that WBV training can result in neuromuscular adaptations like the effects produced by resistance training, the result of altering the connectivity between corticospinal cells and spinal motoneurons[31-33].

The sample studied in the present study comprised patients with a central lesion resulting in muscle weakness. This weakness results from physiological changes in the motor neuron (loss of the motor unit and changes in the order of recruitment and rate of firing of the motor units); changes in peripheral nerve conduction; and changes in muscle (changes in the morphology, contractile properties of motor units, and mechanical properties)[34,35]. Changes in muscle properties include atrophy of type II fibers and an increase in the proportion of type I fiber with a consequent loss of motor function. Progressive resistance training is an effective form of intervention to improve strength and gait performance[36].

Another justification for vibration treatment is the co-activation of the agonist and antagonist muscles during WBV associated with the isometric squat. This could mask any further increases in the electromyographic activity of agonist muscles due to the balance between excitatory and (Ia afferent) and inhibitory inputs (activation of Golgi tendon organs, skin mechanoreceptors, and receptors)[37,38]. It must be considered that in the aforementioned studies the electromyographic signals were collected during the vibration training and in the present study after the vibration training.

Another point to be analyzed relates to the frequency used in the intervention protocol, 50Hz, which was not able to modify the electromyographic signal. Some researchers have observed that vibration is able to induce increased EMG activity due to the synchronization of motor units, which may be dependent on the frequency of vibration[39-41]. I was used a frequency of 20 Hz–55 Hz, with 55 Hz producing little muscle activation of the lateral gastrocnemius as opposed to the vastus lateralis[37]. It is suggested that the increased frequency of vibration leads to a reduction in EMG activity due to the presynaptic inhibition caused by the constant vibration stimulus. Some studies that highlight the frequency of 30Hz found a greater effect on the electromyographic signal in patients with central injuries and in athletes[42-44]. Researchers report that frequency below 20 Hz can cause a resonance effect on the body, being not indicated in these cases[45,46].

Contrary to the findings of the present study, others have found an increase in the EMG activity of several lower limb muscles[43,47-49]. This may be the result of the collection performed during training different from that in the present study, where data collection was performed before and after the intervention. The RMS is very susceptible to interference from the external environment and therefore data normalization is necessary[9].

Regarding the effect of vibration on the CG and the effect of intergroup and intragroup intervention on the paretic and non-paretic lower limb, there was no statistical difference, and the electromyographic values were similar on both sides after the vibration training. In contrast, it was found a significant increase in electromyographic activity in both limbs for the vastus lateralis and gastrocnemius muscles during different exercises in chronic stroke patients during vibration training[43]. Similar answers were also found in a study for the TA muscles and biceps femoris during WBV[47] and in a study after the intervention[49].

Some limitations should be pointed out, such as the need to change protocols such as frequency variation, use of isotonic exercise, long-term re-evaluation to estimate the best protocol for the rehabilitation of stroke patients, and a follow-up to verify the permanence of the results.

## CONCLUSION

It is concluded that vibration training did not influence the EMG signal of the RF and TA muscles in stroke patients.

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