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Effect of Whole-Body Vibration on the Functional Responses of the Patients with Knee Osteoarthritis by the Electromyographic Profile of the *Vastus Lateralis* Muscles during the Five-Repetition Chair Stand Test: A Randomized Crossover Trial

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Abstract: Knee osteoarthritis (KOA) can cause functional disability. Neuromuscular function is relevant in the development and progression of KOA. It can be evaluated by the analysis of the surface electromyography (sEMG), which has an important role in the understanding of KOA. Whole-body vibration (WBV) is an intervention suggested to treat KOA. The objective of this work was to verify the effectiveness of WBV on the functionality of lower limbs by the electromyographic profile of the vastus lateralis (VL) muscles during the five-repetition chair stand test (5CST) in patients with KOA. This was a two-period crossover trial study (8-week washout). Nineteen patients with KOA were allocated to the group submitted to WBV (WBVG), with peak-to-peak displacement of 2.5 to 7.5 mm, frequency from 5 to 14 Hz, and acceleration peak from 0.12 to 2.95 *g*, or to the control group (0 Hz) (2 days per week for 5 weeks). The 5CST and the sEMG of the VL during 5CST were evaluated before and after the interventions. Results: Significant differences in 5CST were evident only in WBVG ($p = 0.018$), showing a decrease of the execution time. The sEMG profile showed no significative difference. Therefore, only 10 sessions of WBV with comfortable posture can bring about improvement in functionality of KOA patients without alteration of the muscle excitation.

Keywords: knee osteoarthritis; conservative treatment; whole-body vibration; electromyography; physical and rehabilitation medicine

1. Introduction

Knee osteoarthritis (KOA) is the most prevalent type of arthritis that leads to disability in the elderly, mainly due to pain [1–3]. Cartilage degradation with bone remodeling, joint space narrowing, formation of osteophytes, swelling, low muscle strength, joint inflammation, stiffness, and loss of joint function may be present in KOA patients [3,4]. Neuromuscular function is relevant in the development and progression of KOA [5,6] and, as Mills et al. [7] reported, neuromuscular differences in muscle activity and amplitude. Surface electromyography (sEMG) is a noninvasive tool for detection of the electric potential resulting from the transmembrane current of muscle fibers (muscle excitation). It can be used to measure the muscle activity and might provide insight into neuromuscular responses to exercises, aging, and diseases such as KOA [8,9]. Bigham et al. [8] showed an alteration in neuromuscular activation in individuals with KOA (male and female) compared to healthy individuals, suggesting compensation due to knee extensor muscle strength reduction. Most of the interventions included in neuromuscular rehabilitation programs are based on resistance exercises, promoting the improvement of the pain level and function response in patients with KOA [10]. However, many interventions can lead to symptom exacerbation and pain flares in this population [11]. Therefore, feasible interventions that can induce clinical benefits in patients with KOA have been evaluated in recent years, including whole-body vibration (WBV) [12–15]. An umbrella review reported that moderate evidence supports the role of WBV as a viable clinical intervention for managing KOA, although more studies are still warranted [15]. In a crossover investigation, Liphardt et al. [16] verified that WBV can prevent the loss of tibial articular cartilage thickness (determined by magnetic resonance image) after prolonged immobilization in healthy male individuals. Moreover, authors reported that mechanical vibration can lead to adaptations in muscle and bone [16,17]. In rats, according to Musumeci et al. [18], it is possible that the mechanical stimulation in the articular cartilage could release lubricin antibodies that are capable of inhibiting caspase-3 activity, preventing chondrocyte death. In consequence, mechanical stimulation could be a possible therapeutic treatment, as in osteoporosis, and mild physical activity could also be used as a therapeutic treatment for cartilage disease such as osteoarthritis [18]. Although WBV has shown importance in improving various parameters related to the joint [16,18], it is relevant to consider some undesirable findings, such as the deleterious effect of prolonged vibration from off-road motorcycling on the elbow joint [19].

The clinical benefits of WBV are attributed to the vibratory excitation of muscle spindles and increased motor unit synchronization [17,20]. The importance of this intervention lies in the positive effects reported on muscle strength and flexibility and improvements in symptom severity (i.e., pain) in various populations [21–27]. Until now, only one study showed a decrease in pain level (assessed by the visual analogue scale) using sitting posture in an auxiliary chair with both feet placed on the vibrating platform (VP) [13]. Several authors [13,28,29] have suggested that this posture can reduce the load on the knee joint when compared to squat posture.

The aim of this investigation is to analyze the short-term effectiveness of WBV on lower-limb functionality through examining the electromyographic activity of the vastus lateralis (VL) [30] muscle during the five-repetition chair stand test (5CST). Therefore, the hypothesis was that the WBV can improve the functional mobility and the neuromuscular response of patients with KOA.

2. Materials and Methods

2.1. Participants

Between March 2013 and July 2017, participants with KOA diagnosed according to the Ahlback criteria [31] were referred by their physicians from the orthopedics department of the local hospital. Inclusion criteria required participants to have a clinical diagnosis of KOA with Ahlback degree 2 or 3, to be age 50 years or above, and to sign an informed consent form [31]. Exclusion criteria comprised other musculoskeletal disorders, joint prosthesis or total knee replacement (TKR), neurological diseases, and uncontrolled hypertension. Participants were instructed to discontinue pain medications during the study period, which was checked before each session. The study was approved by the ethics committee in accordance with the Declaration of Helsinki and the Brazilian clinical trial registry platform (Certificado de Apresentação para Apreciação Ética-CAAE-19826413.8.0000.5259 and RBR-7dfwct).

2.2. Sample Size

The sample size was determined using the formula by Miot [32] for an infinite population. The time to perform the 5CST in individuals with KOA was used as an outcome, considering the standard deviation of 2.4 and mean of 24.3 s [33]; and 16 individuals were established for each group.

2.3. Interventions and Groups

In this two-period crossover trial [34], 19 participants (age 65.42 ± 8.41 years, 3 males and 16 females) were assigned in order of referral by the researcher into two groups in the first period of the intervention: the control group (CON) (n = 10) and the group that received mechanical vibration (WBVG) (n = 9). After that, the groups were switched to the second intervention period. Each intervention period was separated by an 8-week washout to allow for the effective systemic elimination of the mechanical vibrating before initiation of the subsequent treatment based on a previous protocol [35] so that all individuals participated in both groups. Each intervention period lasted 5 weeks (2 days per week with at least 48 h of rest between each session).

Participants were seated in a chair with bare feet placed on a side-alternating VP (Novaplate Fitness Evolution, DAF Produtos Hospitalares Ltd.a, São Paulo, Brazil) with knees flexed (100 to 120°—measured by a goniometer). The hands of participants were positioned on their knees to smooth the transmission of the vibration to the whole body [28,29], as shown in Figure 1a. The vibration protocol of Neto et al. [13] was implemented for this study. Briefly, this involved 10 sessions (two sessions per week for 5 weeks), and participants had to place their feet on demarcated lines on the VP that corresponded to peak-to-peak displacement of 2.5, 5.0, and 7.5 mm (amplitude of 1.25, 2.5, and 3.75 mm) (Figure 1a). The initial vibration frequency was set at 5 Hz and progressively increased by 1 Hz in subsequent sessions, with 14 Hz being the highest frequency attained in session 10. Peak acceleration (a_{Peak}), measured from a three-axial accelerometer attached to the VP using adhesive tape (Vibration Data logger DT-178A, Ruby Electronics, Saratoga, NY, USA), ranged from 0.12 to 2.95 *g* over the 10 sessions. For each session, participants performed 3 min of vibration at the three peak-to-peak displacements, with 1 min of rest between each bout (Figure 1b). During the entire intervention, the participants were accompanied by the investigator to ensure that the feet were kept in contact with the base of the VP, the hands remained facing the knees, and the effect of the mechanical vibration was distributed throughout the body. The participants in the control group performed the same protocol as the WBVG, but the VP was switched off (0 Hz), according to previous studies [13,28,29].

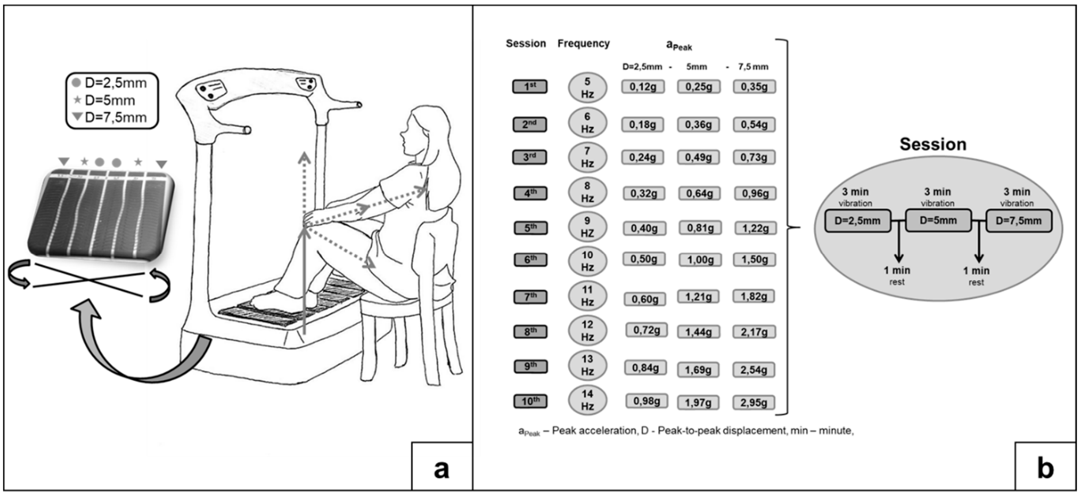

Figure 1. (**a**) The position of participants on the vibrating platform. (**b**) The protocol of the whole-body vibration group (WBVG) intervention.

2.4. *Physical Performance Measures*

2.4.1. Five-Repetition Chair Stand Test

The 5CST was used to evaluate the functional mobility and muscle strength of the lower limbs. Participants were instructed to sit in the middle of the chair with arms crossed over the chest, feet approximately shoulder-width apart and placed on the floor, and back straight. From the sitting position, individuals ascended without the use of the arms to an upright position before sitting down five consecutive times as quickly as possible [36]. Using a digital chronometer (Cronobio SW2018, Brazil), the time to perform the test was recorded. The test was applied at baseline (before the intervention) and immediately after the last intervention in both groups.

2.4.2. Measurement and Surface Electromyography Instrumentation

To record sEMG activity of the VL muscle during the 5CST, skin was shaved and cleaned with 70% alcohol and dead skin was removed before the electrode placement according to the Surface Electromyography for the Noninvasive Assessment of Muscles recommendations [37]. The electrodes were put over the mid-belly of the muscle parallel to the fibers on the right and left VL muscles. The reference electrode was attached to the C7 spinous process. sEMG signals were collected in microvolts (EMG832WF, EMGSystem, São Paulo, Brazil) using passive surface self-adhesive bipolar Ag/AgCl electrodes (Miotec *Equipamentos biomédicos*, Porto Alegre, Brazil). A high-pass filter of 20 Hz and a low-pass filter of 500 Hz were used to minimize interference from movement artifacts of cables and electrodes. To determine the excitation of the VL, an electromyograph with sampling frequency set at 2000 Hz was used. The electromyographic profile of the VL was evaluated during the 5CST (from the initial movement upward to the last upward movement) before and after the protocol (5 weeks), and the root mean square (RMS) (µV) was calculated by the software (Tool Box BR V1.0 by EMG System do Brasil *LTDA*). The analysis was conducted based on the RMS (µV) measure provided by the equipment software. The test was applied at baseline (before the intervention) and immediately after the last intervention.

2.5. Statistical Analysis

R software, version 3.5.0 [38] with the R coin package [39], was utilized to perform the statistical analyses. Results were considered significant when $p < 0.05$. The Wilcoxon signed-rank test for paired samples was used to compare the time (s) of the 5CST and the RMS values (µV) recorded before and after the interventions (CON and WBVG). The Mann–Whitney test was used to compare the time (s) of the 5CST and the RMS values (µV) between groups at baseline and after intervention.

3. Results

In this crossover study, 19 participants were assigned to two groups: CON (n = 10) and WBVG (n = 9). Three CON participants did not return to WBVG after the washout period (8 weeks). The flowchart of the individuals throughout the work is reported in Figure 2. Table 1 shows some anthropometric characteristics of the participants of both groups before the first intervention (baseline). No participant used pain medication during the study period. After performing this protocol, none of the individuals reported adverse effects.

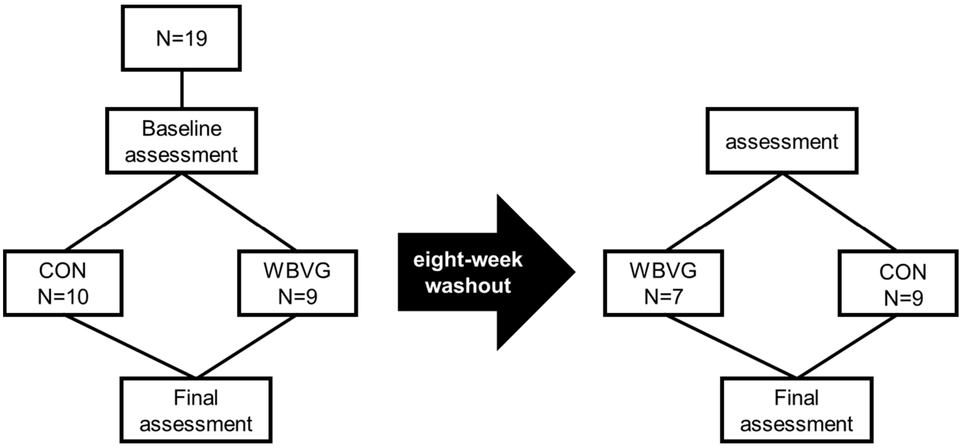

Figure 2. Flowchart with some information about the individuals that participated in the study and the crossover intervention. CON—control group; WBVG—vibration group.

Table 1. Mean (SD) of demographic characteristics of participants at baseline (n = 19).

Variables	CON (n = 10)	WBVG (n = 9)	*p*-Value
Age (years)	66.89 (8.55)	64.1 (8.50)	0.4862
Stature (m)	1.592 (0.08)	1.568 (0.07)	0.4878
Body mass (kg)	84.91 (14.7)	85.21 (16.28)	0.9671
Body mass index (kg.m^{-2})	33.73 (6.92)	34.98 (8.69)	0.9438

CON—control group; WBVG—vibration group. $p < 0.05$.

Considering that the intervention periods were separated by an 8-week washout period to allow for the effective systemic elimination of the mechanical vibration, the analysis was performed per group independent of the intervention period.

No significant differences were found between groups at the beginning regarding time to complete the 5CST ($p = 0.665$) and RMS values (µV) in the right VL muscle ($p = 0.481$) and left VL muscle ($p = 0.800$).

The effects of the interventions are reported in Table 2 and Figure 3. Significant differences in completing 5CST were evident in WBVG, but no significant differences were found in CON. During the 5CST, there was no significant difference in VL excitation (RMS) (µV) between CON and WBVG of right and left VL muscles.

Table 2. Descriptive statistics for the five-repetition chair stand test and right and left vastus lateralis electromyography during the five-repetition chair stand test for CON and WBVG.

			Mean	Range	Standard Deviation	Coefficient of Variation	Standard Error	Minimum	1st Quartile	Median	3rd Quartile	Maximum	*p*-Value
5CST (s)	CON (n = 19)	Before	27.43	36.37	12.41	0.45	3.44	13.97	16.35	22.41	33.94	50.34	0.060
		After	21.63	25.12	7.63	0.35	2.11	13.57	16.50	19.78	23.34	38.69	
	WBVG (n = 16)	Before	27.29	63.69	17.21	0.63	4.77	14.00	16.47	22.28	32.63	77.69	0.018 [&]
		After	21.72	32.57	9.49	0.43	2.73	12.53	15.25	17.82	26.38	45.10	
VLR RMS (μV)	CON (n = 19)	Before	23.49	34.96	14.38	0.61	3.99	7.57	11.30	19.22	40.84	42.53	0.352
		After	35.36	77.33	22.05	0.62	6.11	3.76	17.63	42.54	45.6	81.09	
	WBVG (n = 16)	Before	32.85	75.73	22.07	0.67	6.12	4.34	14.56	33.67	42.73	80.07	0.599
		After	33.03	65.88	21.65	0.65	6.25	8.43	15.00	33.01	43.91	74.31	
VLL RMS (μV)	CON (n = 19)	Before	24.99	24.83	6.16	0.24	1.71	9.96	22.68	26.21	26.93	34.79	0.095
		After	32.28	75.20	18.24	0.56	5.06	3.39	25.97	27.29	31.93	78.59	
	WBVG (n = 16)	Before	24.77	65.82	16.73	0.67	4.64	5.47	12.45	25.82	27.72	71.29	0.454
		After	25.64	27.05	8.60	0.33	2.48	10.59	21.42	27.64	31.81	37.64	

5CST—five-repetition chair stand test; VLR—vastus lateralis right; VLL—vastus lateralis left; CON—control group; WBVG—vibration group; RMS—root mean square. [&] $p < 0.05$.

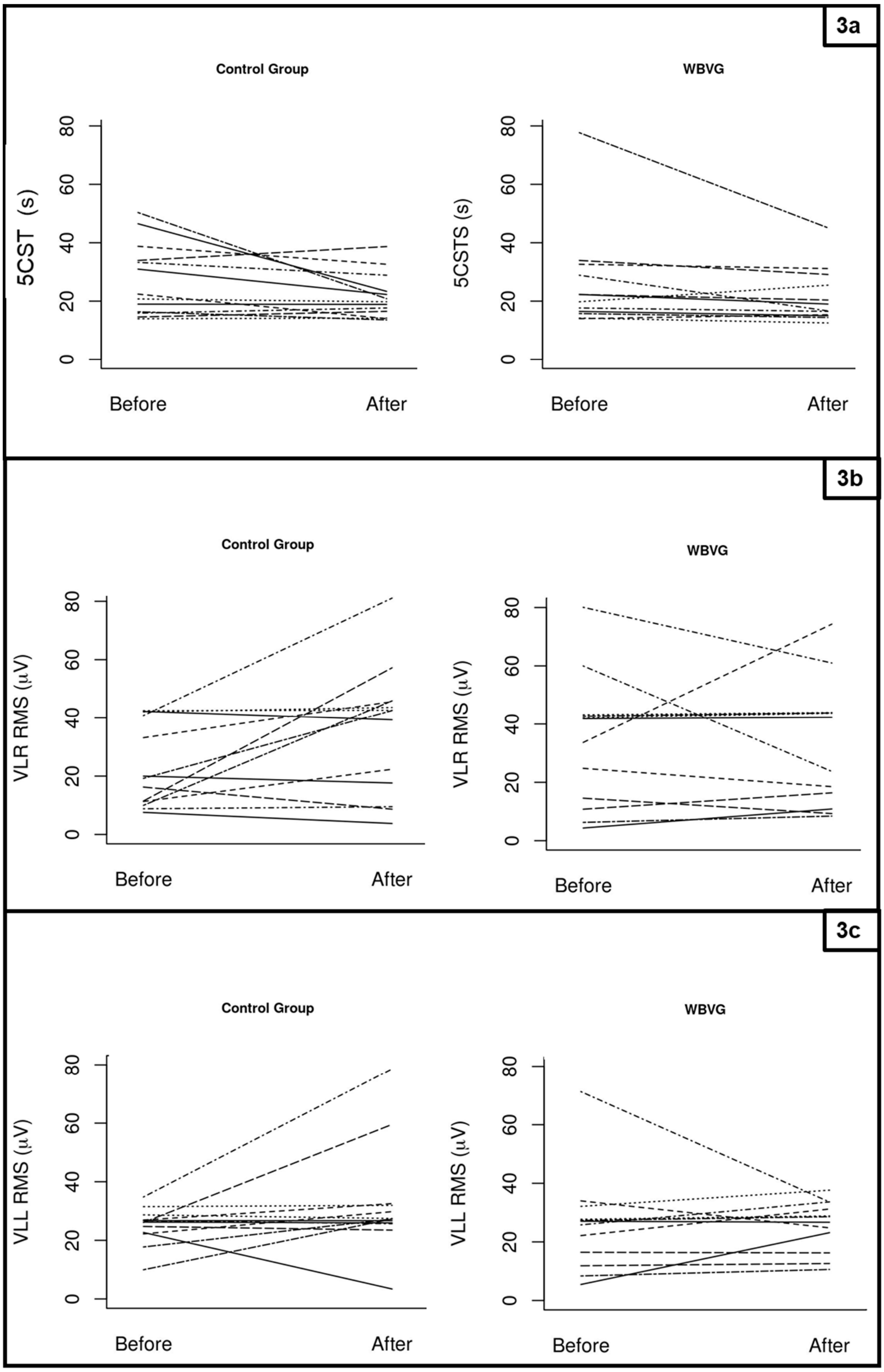

Figure 3. Outcome measures before and after intervention: (**a**) execution time of five-repetition chair stand test, (**b**) electromyographic activity of the vastus lateralis right, and (**c**) electromyographic activity of the vastus lateralis left. Legend: 5CST—five-repetition chair stand test; VLR—vastus lateralis right; VLL—vastus lateralis left; control group (n = 19); WBVG—vibration group (n = 16); RMS—root mean square. $p < 0.05$.

The time required to perform the 5CST was reduced after intervention in both groups, but the differences were only significant in the WBVG. Although there were no significant differences between performance times of the test in both groups, it is interesting to note that there was a clear opposite tendency regarding RMS values (μV) in both VL muscles, with RMS values (μV) lowering in the WBVG and increasing in the CON group.

After intervention, no significant differences were found between groups (n = 16) considering the 5CST ($p = 0.716$) and RMS values (μV) in the right VL muscle ($p = 0.607$) and left VL muscle ($p = 0.128$).

4. Discussion

This investigation analyzed the effectiveness of a 5-week, nonpharmacological intervention (WBV) on lower-limb functionality and electromyographic activity during the 5CST. Although the electromyographic profiles of the VL of both lower limbs did not change ($p > 0.05$), 5CST completion time improved after 5 weeks of WBVG.

In the current study, subjects sat on an auxiliary chair with knees flexed and bare feet on the base of the VP, aiming to decrease the knee load impact. Previous research observed a decrease of pain level using the same position in patients with KOA [13], and this could justify the improvement in functionality of the lower limbs evaluated by the 5CST, as shown in the current study. Fransen et al. [40] suggested that any type of short-term physical activity program carried out repeatedly and monitored can improve physical function and quality of life and reduce the pain related to KOA. Thus, the WBV can be considered a type of regular exercise capable of promoting the improvement of physical capacity in patients with KOA. Other studies present similar results concerning pain level and functional performance using the squat position on the VP. Prior research reported that a single bout of intermittent WBV (10 × one minute of mechanical vibration with one minute rest) of 35 Hz and 4–6 mm significantly improved the time taken to complete the step test after 5 min of performed [41]. In longer-term investigations of WBVG, Avelar et al. [42] observed that KOA patients improved their functional test scores and Western Ontario and McMaster Universities OA Index (WOMAC) values. However, the improvements were not significantly different from the CG that performed squat training without WBVG. Another study involving 8 weeks of WBV training showed a significant increase in muscle strength and knee extension in women with KOA [43]. In a meta-analysis review [44], the authors concluded that 8 to 12 weeks of WBV training could be beneficial in rehabilitation programs, especially for KOA, leading to a decrease of the pain level and the enhancement of physical functions such as walking and balance, suggesting that the WBV is an effective and safe approach for this population.

Despite the reduction in time taken to perform the 5CST, which suggests an improvement of functionality, no significant differences were observed in sEMG RMS (μV) of the VL between pre- and postintervention for CON and WBVG. Similarly, other research found no significant difference in sEMG of KOA subjects that performed squats with or without WBV [45,46]. In contrast, Benedetti et al. [47] reported increased muscle activity in patients with KOA that were treated with localized muscle vibration, which is consistent with previous studies reporting that the vibratory stimulus increases neuromuscular activity [48–50].

Although no consensus is established, as the vibratory stimulus affects the neuromuscular system, it is suggested that the increase in sEMG activity is related to an excitatory response of the muscle spindles in consequence of the stretch reflex mechanism during WBV [48–50]. However, the current findings indicate that the excitatory responses of muscle fibers do not remain after the end of the protocol, since we observed a tendency of the amplitude of the sEMG to decrease in the group submitted to mechanical vibration.

The strength of this study is related to the acquisition of information about the effect of WBV on functional responses evaluated by sEMG in a special protocol in which the individuals with KOA are seated in a comfortable position in an ancillary chair.

This work has limitations that must be considered in the interpretation of the results. There are a myriad of different possibilities in selecting the biomechanical parameters, and to date there is still no optimal WBVG protocol. Moreover, the Ahlback grading, the osteoarthritis laterality, and the body mass index were not indicated as inclusion criteria. Although there are studies considering the analysis of various muscles [7,46], in the design of the current work, considering the clinical conditions of the individuals with KOA, only the response of the VL muscle was investigated. Furthermore, following this idea, no rigorous evaluation of the transmissibility was performed, and the results are presented only as RMS values (μV). It is relevant to point out, not as a specific limitation but as a relevant approach, that this study used a protocol with low vibration frequencies and with the participants with KOA seated in an ancillary chair in front of the VP with their feet on the base of the VP. These conditions could have had an influence on the findings described.

5. Conclusions

In the protocol of the 10 sessions of WBV with comfortable posture, patients with KOA presented functional responses with a decrease in the time taken to perform the 5CST (WBV group $p < 0.05$), although no significant differences were found between the groups. This suggests that further investigation is needed to better understand the effect of WBV on functionality using the 5CST in individuals with KOA. However, these individuals did not present any alteration in muscle excitation. As a result, it is relevant to highlight the clinical evidence of the findings of the current study.

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