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Whole-body vibration training increases muscle strength and mass in older women: a randomized-controlled trial

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To determine whether 10 weeks of whole-body vibration (WBV) training has a significant effect on strength, muscle mass, muscle power, and mobility in older women, 26 subjects were randomly assigned to a WBV training group (*n* = 13; mean age 79 years) and a control (CON) group (*n* = 13; mean age 76 years). Maximal voluntary isometric contraction (MVIC) increased 38.8% in the WBV group, without changes in the CON group. Electromyographic activity of the vastus medialis (VM), the vastus lateralis, and the biceps femoris (BF) did not change in either group. Thigh muscle cross-sectional area increased significantly after training in VM (8.7%) and BF (15.5%). Muscle power at 20%, 40%, and 60% MVIC decreased from pre-test to post-test in the CON group; however, WBV training prevented the decrease in the WBV group. Consequently, mobility, measured by the Timed Up and Go test, increased significantly after training (9.0%) only in the WBV group. Ten weeks of lower limb WBV training in older women produces a significant increase in muscle strength induced by thigh muscle hypertrophy, with no change in muscle power. The adaptations to WBV found in the present study may be of use in counteracting the loss of muscle strength and mobility associated with age-induced sarcopenia.

Aging is associated with a decline in muscle mass, referred to as sarcopenia, which is directly linked to a reduced muscle strength (Evans, 1995). This can induce muscle weakness and reduced ability to produce rapid force, which are considered to be two of the most common risk factors associated with falls and loss of functional independence in older adults (Taaffe & Marcus, 2000). Resistance training (RT) is a preferred intervention to decrease the effects of sarcopenia, as RT has been shown to induce muscle hypertrophy and to enhance strength, power, and function (Hunter et al., 2004). While most of these effects have been demonstrated using traditional RT methods, whole-body vibration (WBV) training has gained considerable attention lately and has been widely used (Jordan et al., 2005). It is hypothesized that the WBV-induced strength gains are mainly due to neural factors, probably related to an increase in the sensitivity of the stretch reflex, which initiates muscle contractions (Rehn et al., 2007), whereas muscular hypertrophy would be rather limited.

Published research on WBV training in older adults is sparse, but available data seem to indicate changes in hormonal profile (Cardinale et al., 2008) and improvements in postural control (Bogaerts et al., 2007b), mobility (Rees et al., 2007), balance (Cheung et al., 2007; Rees et al., 2008b), maximal isometric force of the knee extensors, and vertical jump performance (Roelants et al., 2004), as well as mineral density of lumbar-spine vertebrae (Iwamoto et al., 2005). One study has examined the effect of WBV training on muscle mass in older men, reporting a significant muscle hypertrophy (Bogaerts et al., 2007a, b), but there is no information on older women. Moreover, neural adaptations or changes in radiological muscular density have not been analyzed in the elderly. Muscle attenuation in Hounsfield units is a measure of muscle density dependent on the radiation absorption of contractile proteins, enzymes, myoglobin, hemoglobin, collagen, and fat (Bulcke et al., 1979). An association has been found among reduced attenuation and diminished muscular strength in patients suffering from different pathologies (Goodpaster et al., 2000). This study aimed to measure the changes in muscle tissue, power, and mobility with 10 weeks of WBV in older women. We hypothesized that WBV training would result in significant increases of muscle strength, muscle mass, electromyographic activity, and radiological muscle density. We also hypothesized that these changes would play an important role in improving mobility.

Material and methods

Subjects

Community-dwelling elderly subjects, recruited through advertisement and personal letters from community elderly centers, volunteered to participate in a 10-week training study. Subjects were required to meet the following criteria for inclusion in the study: (1) women and (2) 65–90 years old. Exclusion criteria were diseases or medications known to affect muscle mass or strength and engagement in moderate-intensity exercise programs for more than 2 h/week. People suffering from diabetes, neuromuscular or neurodegenerative diseases, stroke, serious heart sicknesses, or having an implant, bypass, or stent were also excluded (Fig. 1). After participants were carefully informed about the design of the study, they signed a written informed consent before participation. The research was conducted according to the declaration of Helsinki and was approved by the Ethics Committee of the University of León, Spain.

Design

A randomized-controlled design was used. An extensive medical screening was performed by a physician who checked the inclusion and exclusion criteria. The physician who performed the assessments was blinded to the use of the WBV training; however, neither the patients nor the trainer who conducted the training program were blinded, because it was impossible to do so. Subjects were randomly assigned to one of the two groups after initial evaluation. After randomization, 14 subjects were assigned to the control group (CON) and 15 were assigned to the experimental group (WBV). Two subjects of WBV group dropped out because of health problems not related to the study protocol and one subject of the CON group dropped out of the study because they discharged themselves early from our study, due to non-medical problems. Hence, outcome data were obtained from the remaining 26 subjects (Fig. 1).

Baseline data (pre-test) were collected during two testing sessions separated by 4 days; similar testing sessions were repeated 10 weeks after (post-test) the training/control period. In the first testing session (either pre-test or post-test), the computerized axial tomography and maximal voluntary isometric contraction (MVIC) test were performed. In the second testing session, mobility and maximal power at 20%, 40%, and 60% of MVIC were measured. One week before the pre-test, subjects attended two familiarization sessions within 5 days defined as follows: (1) the first session was an introduction and familiarization to the bilateral movement tested (horizontal leg-press). During this session, each machine was configured for a given subject and the configuration settings were recorded. Subjects then completed several full range-of-motion repetitions with minimal loads. (2) In the second familiarization session, subjects performed several more minimal load contractions and completed practice MVIC and maximal power test. This session dually served to familiarize subjects with both testing procedures and to instruct and encourage subjects to exert maximal voluntary effort.

Intervention

The WBV group exercised for 10 weeks on a vibration platform (Fitvibe, GymnaUniphy NV, Bilzen, Belgium). All of the training sessions were performed between 9:00 and 13:00 hours. The WBV training performed a lower-body-training program consisting of unloaded static and dynamic exercises. The exercises included a half-squat (knee angle between 120° and 130°) and a deep squat (knee angle 90°), a wide-stance squat, and calves (Fig. 2). Training volume and training intensity were low at the beginning but progressed slowly according to the overload principle. The training volume was increased systematically over the 10-week training period by increasing the duration of WBV sessions, the number of series of one exercise, or the number of different exercises (Table 1). The training intensity was increased by increasing the amplitude (2–4 mm) or the frequency (20–40 Hz) of the vibration (Table 1). Each WBV training session was preceded by a 10-min warm-up that included aerobic exercise and stretching. At the end of the session, participants performed a cooling-down period. The subjects of the CON group were requested not to change their lifestyle during the study or to engage in any new type of physical activity.

Muscle cross-sectional area (CSA)

CSA of the dominant-leg vastus medialis (VM), vastus lateralis (VL), and biceps femoris (BF) muscles were obtained by

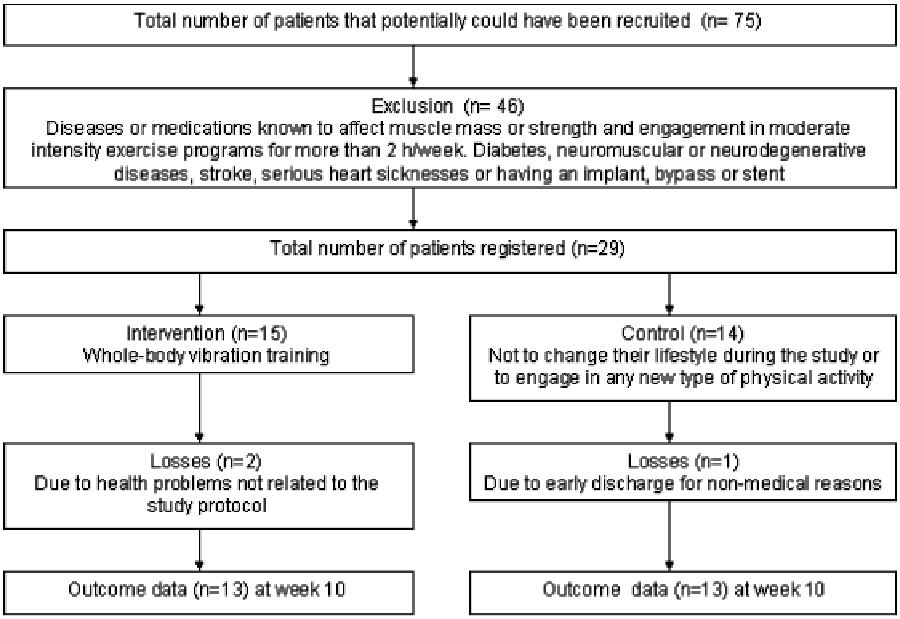

Fig. 1. Flow diagram for randomized subject assignment in this study.

computed tomography (CT) (Tomograph Toshiba Asteion VP, Zoetermeer, the Netherlands). Each subject was examined in the supine position with the thigh muscles relaxed. An axial CT image was obtained at the first third of a line extending from the superior border of the patella to the greater trochanter of the femur. The thickness of the slice was 5 mm. E-film software package (Merge-efilm, Milwaukee, Wisconsin, USA) was used to calculate radiological muscular density.

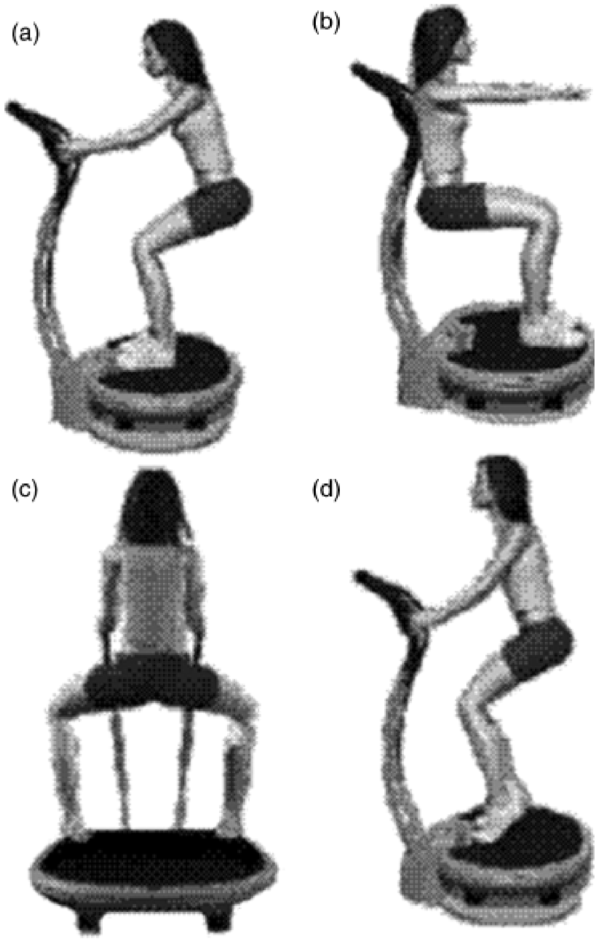

Fig. 2. Position adopted in each exercise: (a) squat, (b) deep squat, (c) wide stance squat, and (d) calves.

Leg-press MVIC test

MVIC of the leg extensors (hip, knee, and ankle extensors) was measured using a horizontal leg-press machine (Telju, Toledo, Spain) with a load-cell attached (Glogus Ergometer, Globus, Codogne, Italy). Subjects were in a sitting position so that the knee and hip angles were 107° and 110°, respectively. They were instructed to exert their maximal strength as fast as possible during a period of 3 s. The best trial of three attempts with regard to maximal peak force was used for the subsequent statistical analysis.

Surface electromyographic activity (sEMG)

sEMG of dominant-leg VM, VL, and BF was assessed during the MVIC test. Before the test, each subject was prepped for bipolar surface electrode placement on her dominant leg. Once the skin was shaved and cleaned, one set (two measuring electrodes and a differential one) of surface electrodes (Ag/AgCl, Skintact, Austria) was placed longitudinal to the muscle fibers direction approximately halfway from the motor point area to the distal part of the muscle. An inter-electrode distance of 2 cm was maintained. The reference electrode was placed in a neutral area away from the measuring electrodes. Electrode placement was assured during the study's experimental phase through non-toxic pen markers.

Myoelectric raw signals were detected with the double differential technique. The surface electrodes were connected to a 14-bit AD converter (ME6000 Biomonitor, Mega Electronics, Kuopio, Finland) by pre-amplified cables (Mega Electronics). The total common mode rejection was of 110 dB, and data were low pass filtered (8–500 Hz) and sampled at 2000 Hz before being stored in a memory card (compact flash memory, 256 MB). sEMG data analysis was performed across the use of a specific software (MegaWin V 2.21, Mega Electronics). The three seconds corresponding to the best MVIC attempt were chosen for data analysis across the use of the "Marker Test" provided by the aforementioned software. sEMG raw data were averaged by root mean square in order to obtain maximal amplitude of the sEMG signal.

Table 1. Characteristics of the whole-body vibration (WBV) training program

Period (week)	Volume							Intensity			
	Training frequency (sessions/week)	Number of series per exercise[*]				Duration of each exercise (s)	Duration of session (min:s)	Amplitude (mm)	Frequency (Hz)	Rest (s)	Modality[†]
		a	b	c	d						
1	3	1	1	1		30	7:30	2	20	180	S
2	3	1	1	1	1	30	11:00	2	25	180	S
3	3	2	2	1	1	30	18:00	2	30	180	S
4	3	1	1	2	2	30	18:00	2	30	180	D
5	4	2	2	1	1	45	17:00	2	35	150	D
6	4	1	1	2	2	45	17:00	2	35	150	D
7	4	2	1	2	2	45	20:15	4	35	150	D
8	4	1	2	2	2	45	20:15	4	35	150	D
9	5	2	2	2	2	60	22:00	2	40	120	D
10	5	2	2	2	2	60	22:00	2	40	120	D

[*] Exercises: a, squat (knee angle 120°–130°); b, deep squat (knee angle 90°); c, wide stance squat; d, calves.

[†] Modality: S, static; D, dynamic.

Maximal power test at 20%, 40%, and 60% of MVIC

The horizontal leg-press machine was also used to measure the maximal power output of the leg extensors at three relative loads: 20%, 40%, and 60% of the MVIC. These percentages were based on baseline and post-training MVIC values at the pre- and the post-test session, respectively. Subjects were in a seated position so that the hip angle was 110° and the knee angle was 70°. Then, on verbal command, they were asked to perform a knee and hip extension, as fast as possible, trying to reach a full knee extension against the resistance determined by the loads (kg) chosen on the weight stack. Two attempts for each load were performed, allowing 2 min of rest between consecutive attempts. The maximal power output of each repetition was monitored by linking a rotary encoder (Globus Real Power, Globus) to the footplate.

Mobility: Timed Up and Go (TUG) test

The TUG measures the time a subject needs to stand up from a chair, walk 3 m at a comfortable speed, turn around, walk back, and sit down (Podsiadlo & Richardson, 1991). The subject was allowed to use his/her own walking aids, but no physical assistance could be given by the researcher.

Statistical analysis

The data are presented as means ± standard deviation (SD). All measures were normally distributed, as determined by the Shapiro–Wilks test. Statistical analysis was performed using an analysis of variance (ANOVA) for repeated measures: 2 (group) × 2 (time) for MVIC, and mobility; 2 (group) × 2 (time) × 3 (resistance) for muscle power; 2 (group) × 2 (time) × 3 (muscle) for sEMG, CSA, and muscle radiological density. A Bonferroni correction was used to adjust the P-value in relation to the numbers of contrast that were performed. Differences in the pre-test values between groups were assessed using a t-test. The significance level was set at $P<0.05$ for all the comparisons.

Results

Training experience and dropout

In the WBV group, subjects became familiar with the training program rapidly. There were no reports of adverse side effects. Most subjects enjoyed the vibration loading, and did not consider it to be a difficult workout. The average overall adherence (number of exercise classes attended as a percentage of the total number of classes) to the training program was 94.8%.

The basic characteristics of the remaining 26 subjects who completed the study are given in Table 2. Except for height, no significant differences in age, body mass, or body mass index were detected between the groups at the start of the study.

Muscle CSA

Table 3 provides the mean muscle CSA of three different muscles. At pre-test, CSA did not significantly differ for VM and BF between the CON and the WBV groups; however, VL was higher for the CON group ($P<0.05$). Analyses of CSA revealed a significant group ($F_{1,25}=7.16$, $P<0.05$), time ($F_{1,25}=10.96$, $P<0.01$), and muscle ($F_{2,24}=112.36$, $P<0.001$) main effect. *Post hoc* tests showed a significant increase for VM (8.7%) and BF (15.5%) CSA after 10 weeks of WBV training. In contrast, no changes were detected in the CON group.

Analyses for radiological density of muscle tissue revealed a muscle main factor ($F_{2,25}=44.56$, $P<0.001$) and group × time × muscle interaction ($F_{2,24}=6.26$, $P<0.05$). *Post hoc* test indicated significant differences between BF and every measured muscle ($P<0.001$). During the 10 weeks of WBV training, the mean Hounsfield number increased significantly 5% only for VM in the WBV group (from 46.3 ± 10.2 to 48.6 ± 9.56 HU) ($P<0.05$). No change was found in the CON group.

Table 2. Subject characteristics by group

Group	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
WBV	79.3 ± 7.3	149.2 ± 4.5*	63.7 ± 10.4	28.6 ± 4.0
CON	76.2 ± 8.4	156.6 ± 5.2	72.5 ± 13.6	29.4 ± 4.6

Values are means ± SD for 13 subjects in each group.

*Different from CON group, $P<0.01$.

WBV, whole-body vibration training group; CON, control group.

Table 3. Muscle cross-sectional area (CSA) of different muscles before (PRE) and after (POST) 10 weeks in whole-body vibration (WBV) and control (CON) groups

	WBV		CON	
	PRE	POST	PRE	POST
VM	500.7 ± 177.4	544.7 ± 149.3$^{\&}$	563.4 ± 289.6	591.6 ± 311.9
VL	2607.8 ± 529.0	2667.1 ± 633.8	3149.8 ± 584.2*	3161.8 ± 583.3*
BF	729.5 ± 214.6	843.0 ± 227.8$^{\&}$	707.4 ± 363.6	730.4 ± 339.3

Values are means ± SD in mm^2 for 13 subjects in each group.

*Different from WBV group, same time, at $P<0.05$.

$^{\&}$Different from PRE, same group, at $P<0.05$.

WBV, whole-body vibration training group; CON, control group; VM, vastus medialis; VL, vastus lateralis; BF, biceps femoris.

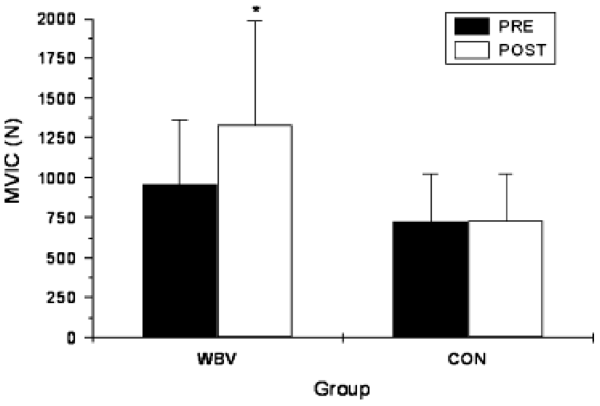

Fig. 3. Maximal voluntary isometric contraction (MVIC). Mean and SD before (PRE) and after (POST) 10 weeks in the whole-body vibration (WBV) and the control (CON) group. *Significantly different from PRE, same group, $P < 0.05$.

Table 4. Surface electromyographic activity (sEMG) of vastus medialis (VM), vastus lateralis (VL), and biceps femoris (BF) before (PRE) and after (POST) 10 weeks in whole-body vibration (WBV) and control (CON) groups

	WBV		CON	
	PRE	POST	PRE	POST
VM	117.4 ± 58.9	87.7 ± 57.6	116.5 ± 47.1	112.2 ± 77.5
VL	149.0 ± 38.9	129.9 ± 40.4	160.1 ± 71.7	143.3 ± 71.7
BF*	122.8 ± 80.3	100.5 ± 80.3	58.3 ± 54.7	56.9 ± 27.3

Values are means ± SD in μV for 13 subjects in each group.
*Different between groups, at $P < 0.05$.
WBV, whole-body vibration training group; CON, control group; VM, vastus medialis; VL, vastus lateralis; BF, biceps femoris.

MVIC test

There was no significant difference in MVIC between groups at the pre-test. A significant time main effect ($F_{1,25} = 39.16$, $P < 0.001$) and a significant interaction ($F_{1,25} = 12.36$, $P < 0.05$) were observed (Fig. 3). MVIC increased significantly from pre-test to post-test only in the WBV group (38.8 ± 18.3%) (Fig. 3).

The results of the ANOVA for sEMG revealed only a significant muscle main effect ($F_{2,24} = 11.4$, $P < 0.01$) and a group × muscle ($F_{2,25} = 4.74$, $P < 0.05$) interaction (Table 4). *Post hoc* test also detected differences in BF between groups ($P < 0.05$).

Maximal muscle power at 20%, 40%, and 60% MVIC

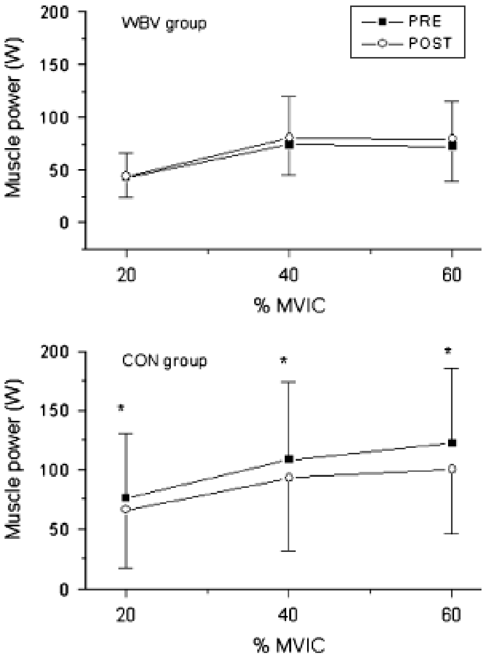

Fig. 4. Maximal power at 20%, 40%, and 60% of maximal voluntary isometric contraction (MVIC) before (PRE) and after 10 weeks (POST). WBV, whole-body vibration group; CON, control group. *Post-test values are significantly lower than the pre-test value at $P < 0.05$.

No significant pre-test differences were found between groups in muscle power at different %MVIC (20%, 40%, and 60% MVIC). Analyses of muscle power revealed a significant group × time effect ($F_{1,25} = 9.19$, $P < 0.05$). *Post hoc* comparisons indicated a significant decrease from pre-test to post-test in the CON group ($F_{1,25} = 16.66$, $P < 0.05$). Muscle power demonstrated a significant resistance main effect ($F_{1,25} = 13,67$, $P < 0.05$). Values reached at 20% MVIC were significantly lower than those measured at 40% and 60% MVIC. Muscle power with an external resistance of 20%, 40%, and 60% MVIC decreased from pre-test to post-test only in the CON group (Fig. 4).

Mobility

There were no significant differences between groups at pre-test. A significant interaction effect (group time) was found ($F_{1,25} = 7.42$, $P < 0.01$). As can be seen in Fig. 5, mobility (s) decreased from pre-test to post-test (−9.0%) in the WBV group, whereas there were no significant changes in the CON group. Therefore, WBV training had a significant effect on mobility.

Discussion

To our knowledge, this is the first study investigating the long-term effects of WBV training on CSA, strength, power, and mobility in older women. The major finding was that 10 weeks of lower-limb WBV training enhances knee and hip extensors' muscle strength induced by muscle thigh hypertrophy. Moreover, given that muscle power was unchanged after training, the increase of muscle strength was enough to improve mobility. Considering that WBV

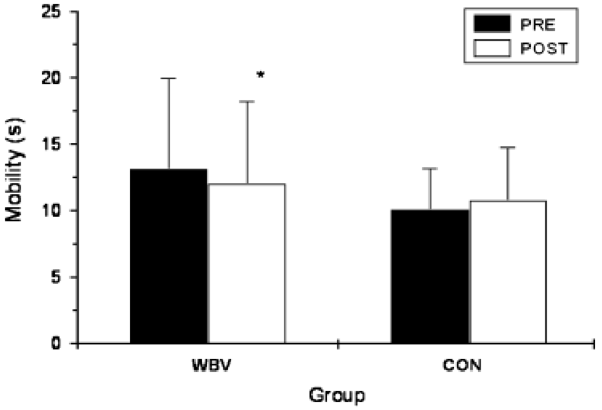

Fig. 5. Timed Up and Go (TUG) test. Mean and SD before (PRE) and after (POST) 10 weeks in the whole-body vibration (WBV) and the control (CON) group. *Post-test values are significantly lower than the pre-test value at $P<0.05$.

training minimizes the need for conscious exertion and stress on the musculo-skeletal, respiratory, and cardiovascular systems (Rittweger et al., 2000; Garatachea et al., 2007), this alternative exercise could be a good strategy to use in older people for preventing sarcopenia.

Although data on the effects of strength training in older individuals initially suggested that strength gains were primarily due to neurological adaptations (Moritani & deVries, 1980), it is now understood that heavy-resistance strength training can induce skeletal muscle hypertrophy in the elderly (Ivey et al., 2000). The present findings confirm a WBV-induced increase in CSA, but whereas increments of only 3.4% on thigh CSA have been previously reported in men (Bogaerts et al., 2007a), women in the present research showed increments of 8.7% for VM and 15.5% for BF after the training period. The significant increase in CSA could be explained, at least in part, by the eccentric nature of the WBV stimulus, given that eccentric overload has been proposed to elicit early adaptations in skeletal muscle size (Norrbrand et al., 2008). In this sense, WBV exercise consists in opposing the movement elicited by vibration, and so the eccentric component of WBV stimulus is rather marked. Some responses induced by WBV have been previously attributed in part to this eccentric component (Rittweger et al., 2001; Garatachea et al., 2007). Neural adaptations could also have been involved in strength improvement, and there is a recent report that unilateral arm strength training enhances contralateral peak force and rate of force development (Adamson et al., 2008). The possibility of reduced co-activation of antagonist by WBV needs to be explored.

Our results point to a small but statistically significant increase in the radiological density of RF tissue in response to WBV training. This is consistent with previous studies using conventional weight training (Horber et al., 1985; Jones & Rutherford, 1987; Claassen et al., 1989; Sipila & Suominen, 1995). The structural changes behind these increases in radiological density could improve muscle quality and thereby exert a positive effect on performance. Besides, the current findings confirm a WBV-induced increase in MVIC higher than others previously reported for women (Roelants et al., 2004; Verschueren et al., 2004) or men (Bogaerts et al., 2007a). A recent study in older men (Bogaerts et al., 2007a, b) showed that the MVIC was increased in 9.8% after 1 year of WBV training. However, it should be noted that exercise evaluated in the literature was the knee extension, while we used the leg-press. Hip and knee extensors' strength is associated with mobility (Burnfield et al., 2000) and the risk of falls (Puthoff & Nielsen, 2007) and current data concerning hip extensors' strength gains are in agreement with previous investigations (Cheung et al., 2007). But we should note that in a recent published study (Rees et al., 2008a), the strength gains for the knee and hip flexors and extensors were comparable between a group that performed a WBV training and a group that was only exercised but without vibrations after 8 weeks. Our results indicate no increase in sEMG variables during the MVIC as a result of the WBV training program, which is in line with Ferri et al. (2003), who found significant gains in quadriceps and triceps surae CSA without changes in sEMG after 16 weeks of conventional weight training in older adults.

The results obtained suggest that muscle power did not change in the WBV group, but decreased in the CON group, for all the loads tested. This is in line with a previous work (Roelants et al., 2004) that found no changes in muscle power at 40% and 60% MVIC after 24 weeks of WBV training. However, the authors detected significant differences in power output at low resistance levels (1% or 20% of MVIC). Findings by Roelants et al. (2004), which are in line with our results, do not confirm the beneficial effects of WBV training on muscle power (Rehn et al., 2007) in older women. The reasons for this disparity could be the lack of an optimal training program to increase muscle power in older adults (de Vos et al., 2005), and the variability of the vibration-training protocols used (Jordan et al., 2005).

It has been suggested that WBV training had huge potential in a therapeutic context (Cardinale & Rittweger, 2006), where it may enhance muscular performance in patients and older adults who are not able to perform standard exercise programs. Our training protocol induced gains in mobility, and the TUG test time was decreased to a similar extent as that previously reported in community-dwelling older adults (Bruyere et al., 2005). However, other authors did not find significant improvements in TUG test performance in healthy older people (Rees et al. 2007). Kawanabe et al. (2007) found an improvement in walking ability, tested by a 10 m walking time, in a group of older subjects after a 2-month WBV training plus balance (standing on one leg and tandem gait) and muscle (calf, quadriceps, hamstrings, and gluteus medius) strengthening training and walking exercise; however, no significant change was observed in a group that carried out the routine of exercises without WBV training. According to our data, it seems that WBV-induced improvements in muscle mass may lead to gain in mobility in older women. The mobility tested by the TUG test is a kind of a short sprint test. Our results are in accordance with a recent work that demonstrates a link between improvement in muscle mass and enhancement of sprint performance (Perez-Gomez et al., 2008).

WBV training in older women produces a significant increase in muscle strength, which appears to be induced by thigh muscle hypertrophy, but not by increases in neural activity. This improvement in muscle strength was associated with increased mobility, but changes in muscle power were not.

Perspectives

Our findings confirm that WBV training can induce a very effective adaptation, useful for counteracting the loss of muscle strength associated with sarcopenia. Considering the numerous possible combinations of amplitudes and frequencies with the current technology, long-term studies are needed in order to develop the most effective vibration training protocol to prevent or reverse sarcopenia.

Key words: sarcopenia, hypertrophy, neural adaptation, mobility, elderly.

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