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ORIGINAL ARTICLE

Effects of whole-body vibration and resistance training on knee extensors muscular performance

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Abstract Whole-body vibration (WBV) is being promoted as an efficient complement to resistance training. The aim of this study was to investigate the effects of an 8-week program of WBV in combination with resistance training on knee extensors muscular performance. A group of 29 young adults (25 men, 4 women; age 21.8 ± 1.5) performed a WBV plus resistance training program (WBV + RES) or an identical exercise program in absence of vibration (placebo plus resistance training, PL + RES). Participants were evaluated for anthropometry, muscle strength (half-squat three repetition maximum, 3RM), knee extensors isokinetic dynamometry (180° and 60° s^{-1}) and counter-movement jump (CMJ). After the intervention, percent body fat significantly decreased 2.1% only in WBV + RES ($P < 0.001$), while muscle mass significantly increased in both groups ($P < 0.01$): 2.2 and 2.8 kg in PL + RES and WBV + RES, respectively. No significant differences were observed in isokinetic strength or CMJ, and 3RM significantly increased in both groups ($P < 0.001$): 64.2 kg (52% of baseline) in PL + RES, and 46.9 kg (43%) in WBV + RES. The addition of WBV to resistance training during 8 weeks, in recreationally active young adults, did not result in a larger muscular performance improvement compared to an identical exercise program in absence of vibration. Muscle mass also seemed to be equally affected with or without vibration, yet body fat could be exclusively decreased by WBV. Further research is required to clarify whether WBV, as a complement to resistance training, produces additional specific benefits.

Keywords Muscle strength · Whole-body vibration · Resistance training · Knee extensors

Introduction

In recent years, vibrating platforms have become increasingly available and used at sports and rehabilitation institutes. There is an emerging profile of application of vibration as an exercise modality (Rittweger 2010), mainly due to the documented effects of vibration on the neuromuscular and neuroendocrine systems (Cardinale and Wakeling 2005). Whole-body vibration (WBV), i.e. standing in different static positions or exercising on a vibrating platform, is being commercially promoted as an attractive and efficient alternative or complement to resistance training (Nordlund and Thorstensson 2007). Specifically, long-term WBV exercise has been suggested to have positive effects on knee extensors strength and power (Marin and Rhea 2010a, b; Rehn et al. 2007; Luo et al. 2005), and has

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also been recommended as a therapeutic approach for sarcopenia and osteoporosis (Cardinale and Wakeling 2005; Merriman and Jackson 2009; Mikhael et al. 2010).

Despite the increasing scientific interest, there is still no clear consensus on the mechanisms by which vibration may enhance neuromuscular performance, and the results widely vary between studies (Rehn et al. 2007; Cardinale and Rittweger 2006; Luo et al. 2005; Cardinale and Bosco 2003). Irregularities in study design and WBV protocols across the literature contribute to this inconsistency, revealing the need for more uniformity in future trials (Mikhael et al. 2010). In this regard, the inclusion of a control group, and specially the type of activity performed by the control group, are considered of critical relevance when interpreting the results (Nordlund and Thorstensson 2007). As WBV implies that some sort of physical effort is made while on the platform, it is essential that the possible training effects of these exercises be separated from those of WBV as such (Nordlund and Thorstensson 2007).

Whole-body vibration has been suggested to elicit a high degree of muscle activation (Delecluse et al. 2003). We therefore hypothesize that the addition of WBV to resistance training will result in a larger muscular performance increase, compared to an identical exercise program performed in absence of vibration. Previous results are however inconsistent. A systematic review in 2007 observed that four out of five studies with a control group performing the same exercises did not report any difference in performance improvement between groups (Nordlund and Thorstensson 2007).

The aim of this study was to investigate whether the combination of WBV and resistance training during 8 weeks has any additional effect on knee extensors muscular performance compared to an identical exercise program without vibration.

Methods

Participants

A group of 29 young adults (25 men, 4 women; age 21.8 ± 1.5 year; weight 74.8 ± 11.4 kg; height 174.0 ± 6.4 cm) volunteered to participate in the study. The inclusion criteria were: Physical Education college students free of any musculoskeletal problem, and recreationally active but not engaged in organized physical activities. All subjects were informed about the training and test protocol and about the possible risks and benefits of the study. They all gave written informed consent to participate. The study was approved by the Ethical Committee of the University of Granada and was performed in accordance with the Helsinki Declaration.

Study design

We allocated our participants into a placebo plus resistance training group (PL + RES; $n = 15$) and an equivalent WBV plus resistance training group (WBV + RES; $n = 14$). Both groups trained for 8 weeks at a frequency of two times a week, with at least 1 day of rest between sessions. Each training session lasted 35–40 min, including warm-up, exercises, rest periods, and cool-down. After each session, the subjects were asked to report possible side effects or adverse reactions in their personal training diaries. They also completed a Borg scale, a simple method of rating perceived exertion (Dunbar et al. 1992). Before starting the study (pre-test), as well as after 4 and 8 weeks of training (intermediate and post-test, respectively), we evaluated all participants for anthropometric characteristics and contractile properties of the knee extensors.

Training protocol

For both groups, each training session was composed of two main parts: (1) body-loaded static and dynamic knee extensor exercises on the vibrating platform (without vibration in PL + RES group; with vibration in WBV + RES group); followed by (2) moderate to high resistance training half-squat exercises and plyometric jumping-type exercises. All training sessions were performed in groups of 4–6 participants, closely supervised by exercise specialists.

Exercises on vibrating platform

In a standing position on a synchronous (also called vertical) vibrating platform (Fitvibe Excel; N.V. GymnaUniphy, Bilzen, Belgium), holding on the device handle, participants performed several sets of one min exercise with one min rest intervals. The exercise time (60 s) was distributed as follows: 0–10 s isometric half squat, 11–30 s dynamic half squat at a 1:1 cadence, 31–40 s calf raise, 41–60 s one-legged half-squat, alternatively with both legs. At the moment there are no scientific-based, long-term WBV-training programs available. Therefore, we developed an 8-week WBV program with a low training load at the beginning but slowly progressive according to the overload principle. In WBV + RES group, the frequency was increased from 20 to 40 Hz, peak-to-peak displacement from 2.5 to 5 mm, and number of sets from 6 to 10. Participants in PL + RES group performed identical exercises on the vibrating platform without vibration (Table 1). The placebo condition was not blinded for either participants or researchers, as the vibrating platform was not activated. All the participants were asked to wear the same gymnastic shoes during all the sessions to standardize the damping of the vibration due to the footwear.

Table 1 Training program of exercises on the vibrating platform

Group	Week	Frequency (Hz)	Peak-to-peak displacement (mm)	*g*-force[a]	Duration (s)	Rest time (s)	Sets (No.)
WBV + RES	1	20	2.5	2.0	60	60	6
	2	20	5	4.0	60	60	6
	3	25	2.5	3.1	60	60	7
	4	25	5	4.2	60	60	7
	5	30	2.5	6.3	60	60	8
	6	30	5	9.1	60	60	8
	7	35	5	12.3	60	60	9
	8	40	5	16.1	60	60	10
PL + RES	1	0	0	0	60	60	6
	2	0	0	0	60	60	6
	3	0	0	0	60	60	7
	4	0	0	0	60	60	7
	5	0	0	0	60	60	8
	6	0	0	0	60	60	8
	7	0	0	0	60	60	9
	8	0	0	0	60	60	10

[a] Peak acceleration ($2 \times \pi^2 \times \text{frequency}^2 \times$ peak-to-peak displacement) in multiples of Earth's gravity ($1\ \text{g} = 9.81\ \text{m s}^{-2}$) (Rauch et al. 2010)

Resistance training

Immediately after the exercises on the vibrating platform, all participants performed moderate to high resistance training half-squat exercises on a Smith's machine, followed by plyometric jumping-type exercises. The load of the resistance training exercises (dynamic half-squat) was slowly progressive, starting at the 55% of one repetition maximum (1RM) and then was increased to 85% of 1RM (Table 2). 1 RM loads were newly calculated after the first 4 weeks of the training program. After the half-squat exercises, participants performed plyometric exercises: (a) box jumps, landing on a 48 cm flat bench; and/or (b) resisted jumps with 5–10% 1RM. Participants were asked to perform all the exercises at the highest speed. The rest time between repetitions was 2–3 s, and 3 min between sets as well as between different exercises.

Testing procedure

Testing took place in laboratory conditions in two sessions 48 h apart. Anthropometric measurements and isokinetic dynamometry were administered in the same day, while jumping performance and maximum repetition (RM) were measured in the other session. The order was randomly chosen for each participant. In both testing sessions, prior to muscular assessment, participants completed a dynamic warm-up of 10 min composed of jogging, specific knee extension movements and stretching exercises. For each participant, all testing sessions were administered at the same time of the day and under the same environmental conditions. The subjects were asked to perform all the tests at maximal intensity.

Physical examination

Weight was measured in underwear and without shoes with an electronic scale (SECA 861) to the nearest 0.1 kg, and height was measured barefoot with a telescopic height measuring instrument (SECA 225) to the nearest 0.1 cm. Body mass index was calculated as body weight in kg divided by the square of height in meters. A set of skinfold thickness (biceps, triceps, subscapular, suprailiac, abdominal, thigh, calf) was measured on the right side of the body, with a Holtain caliper to the nearest 0.2 mm, according to Lohman's (1991) anthropometric standardization reference manual. All the anthropometric variables were measured in order, and then the same measurements were repeated once more. The mean of the two measurements was used in the analyses. Durnin and Womersley's (1974) skinfold equation was used to estimate body density, and percent body fat was calculated using Siri's equation (1961). Total muscle mass (kg) was calculated following the equation developed by Lee et al. (2000). All anthropometric measurements were performed by the same certified anthropometrist ISAK level 1.

Table 2 Resistance training program in both groups

	Exercise	Load	Repetitions (No.)
Week 1			
Day 1	Half-squat	55% 1RM	3 × 6
Day 2	Half-squat	55% 1RM	3 × 6
	Box jump		5 × 5
Week 2			
Day 3	Half-squat	65% 1RM	3 × 6
	Box jump		5 × 5
Day 4	Half-squat	65% 1RM	3 × 6
	Resisted jump	10% 1RM	5 × 3
Week 3			
Day 5	Half-squat	70% 1RM	4 × 4
	Box jump		5 × 5
Day 6	Half-squat	70% 1RM	4 × 5
	Resisted jump	10% 1RM	5 × 4
	Box jump		5 × 5
Week 4			
Day 7	Half-squat	75% 1RM	4 × 5
	Box jump		5 × 5
Day 8	Half-squat	75% 1RM	5 × 3
	Resisted jump	10% 1RM	5 × 4
	Box jump		5 × 5
Week 5			
Day 9	Half-squat	75% 1RM	5 × 3
	Resisted jump	5% 1RM	3 × 4
	Box jump		5 × 5
Day 10	Half-squat	75% 1RM	5 × 3
	Box jump		5 × 5
Week 6			
Day 11	Half-squat	75% 1RM	5 × 3
	Resisted jump	5% 1RM	3 × 4
	Resisted jump	10% 1RM	2 × 4
	Box jump		5 × 5
Day 12	Half-squat	80% 1RM	3 × 3
	Resisted jump	5% 1RM	2 × 4
	Resisted jump	10% 1RM	3 × 4
	Box jumps		5 × 5
Week 7			
Day 13	Half-squat	80% 1RM	3 × 2
	Resisted jump	5% 1RM	2 × 3
	Resisted jump	10% 1RM	3 × 2
	Box jump		5 × 5
Day 14	Half-squat	80% 1RM	3 × 2
	Box jump		5 × 5
Week 8			
Day 15	Half-squat	85% 1RM	3 × 2
	Resisted jump	5% 1RM	2 × 3
	Box jump		5 × 5
Day 16	Half-squat	85% 1RM	2 × 2
	Box jump		5 × 5

1RM one repetition maximum

Isokinetic dynamometry

Isokinetic strength tests were performed unilateral on the right side using a Gymnex Iso-2 dynamometer (EASY-TECH s.r.l., Italy), calibrated following the manufacturer's instructions before data collection. The knee extensor muscles were tested concentrically at 180° and 60° s^{-1}. The upper leg, the hips, and the shoulders were stabilized with safety belts. The rotational axis of the dynamometer was aligned with the right lateral femoral condyle. The force pad was placed 3–4 cm superior to the medial malleolus. The knee extension was initiated at a joint angle of 90° and ended at 170°. The subject was instructed to submaximally flex and extend the knee five times, and then to complete three maximal repetitions. One minute rest was allowed between submaximal and maximal trials, and 5 min between 180° and 60° s^{-1}. The peak torque was determined as the single repetition with the highest muscular force output (Nm). Strong verbal encouragement was given during the test, and the same trained researcher conducted all the isokinetic testings. The intraclass correlation coefficient (ICC) for test–retest reliability for this test has been found to be >0.90 (Sole et al. 2007).

Muscle strength

Three repetition maximum (3RM) was tested in half-squat exercise. The tests were performed on Smith's machine in which the barbell was attached to both ends, with linear bearings on two vertical bars allowing only vertical movements. To assure similar knee angle (~90°) for all the participants, the subjects' squat depth was individually marked at the pre-test depth of the buttock on a list. Thus, the subject had to reach his individual depth (touch his list with the buttock) in the post-test to get his lift accepted. The shoulders of the subjects were in contact with the bar, whereas the trunk was kept as straight as possible.

The first load selected was 20 kg (barbell load) and next the resistance was gradually increased by 10–2.5 kg until two consecutive failures in lifting the load three times. The rest period between each attempt was 3 min. Participants were instructed on proper breathing and lifting form. The coefficient of variation for test–retest reliability for a similar test has been found to be <2% (Paulsen et al. 2003).

Jumping performance

A vertical counter-movement jump (CMJ) was used to assess lower-body explosive strength (also called power) after stretch shortening of the muscles (Bosco et al. 1983). To avoid immeasurable work, horizontal and lateral displacements were minimized, and the hands were kept on the hips throughout the jump. During CMJ, the angular dis-

Table 3 Training effects on body composition within each group

	PL + RES ($n = 10$)				WBV + RES ($n = 13$)			
	Pre-	Interm-	Post-	Within-groups *P* value	Pre-	Interm-	Post-	Within-groups *P* value
Weight (kg)	74.7 (8.9)	75.8 (8.3)	75.5 (8.2)	**0.024**	74.9 (12.9)	75.2 (13.0)	75.0 (13.5)	0.743
BMI (kg m^{-2})	25.4 (2.6)	25.5 (2.3)	25.7 (2.3)	0.650	24.4 (2.9)	24.2 (2.7)	24.4 (3.1)	0.680
Body fat (%)	20.5 (5.0)	19.5 (6.0)	19.2 (6.1)	0.116	22.4 (5.4)	20.5 (5.4)	20.3 (5.8)	**<0.001**
Muscle mass (kg)	63.6 (9.7)	66.4 (9.9)	65.8 (9.5)	**<0.001**	62.2 (8.4)	64.7 (10.2)	65.0 (9.8)	**0.003**

Data are presented as mean (SD). The effects of the intervention were first analyzed within-groups by means of ANOVA for repeated measures [1 (group) × 3 (time)]. Bold values are statistically significant

BMI body mass index

placement of the knees was standardized so that the subjects were required to bend their knees to approximately 90°. The test was performed on an infrared light mat (ERGO JUMP Plus-BOSCO SYSTEM; Byomedic, SCP, Barcelona, Spain), recording the flight time in milliseconds. The best of three trials was recorded to determine the test score. The obtained flight time (t) is further used to determine the increase in the centre of gravity (h), i.e., $h = gt^2/8$, where $g = 9.81$ m s^{-2}. CMJ test–retest reliability has been noted as a Cronbach's alpha coefficient of 0.98 and a coefficient of variation of 2.4% (Markovic et al. 2004).

Statistical analysis

One-way analysis of the variance (ANOVA) was used to compare baseline characteristics between groups. As some training effect could be plausibly expected in both groups, the effects of the intervention were analyzed first within-groups by means of ANOVA for repeated measures [1 (group) × 3 (time)]. When a significant effect was observed in both groups, we compared the magnitude of the change between groups by using one-way analysis of covariance (ANCOVA): post–pre difference was used as dependent variable, group as fixed factor, and adjusted for baseline level of the variable. All analyses were executed using the Statistical Package for the Social Sciences (version 18.0; SPSS Inc, Chicago, IL, USA). Significance level was set on $P < 0.05$.

Results

Compliance and drop-out

Neither participants nor exercise supervisors did report any difficulty or incident to get familiarized with the movements, sequence and loads of the exercises, neither on the vibrating platform nor in the subsequent resistance exercises. During the 8 weeks of the study, six participants dropped out, four men and two women: five in PL + RES group and one in WBV + RES. All these drop-outs were related to an incompatibility of the test/training program and other commitments (e.g. work, studies, etc.) of the participants. All remaining participants performed at least 14 training sessions (from a total of 16), as some subjects missed one or two sessions during the 8 weeks. These participants ($n = 23$) completed all pre-, intermediate and post-measurements, and were therefore included in the analyses. No significant differences between groups were detected in any parameter at baseline, although 3RM was close to be different between groups: 123.6 ± 23.0 in PL + RES and 108.2 ± 14.6 in WBV + RES ($P = 0.064$).

Body composition

After the 8-week program, body weight significantly increased in PL + RES group by 0.8 kg ($P = 0.024$), while percent body fat significantly decreased 2.1% in WBV + RES group ($P < 0.001$) (Table 3). A significant increase in muscle mass was observed in both groups ($P < 0.01$), with total increments of 2.2 and 2.8 kg in PL + RES and WBV + RES groups, respectively (Table 3). Further analysis revealed that these muscle mass increments were not significantly different between groups ($P = 0.562$).

Muscular performance

No significant pre-post differences were observed in any group for isokinetic strength (either 180° or 60° s^{-1}) (Fig. 1) or CMJ (Fig. 2). Performance in 3RM significantly increased in both groups (Fig. 3): the training protocol resulted in increments of 64.2 kg (52% of baseline) in PL + RES group and 46.9 kg (43%) in WBV + RES (in both cases $P < 0.001$). Although close to be significant, the analysis revealed that these increments were not statistically different between groups ($P = 0.054$).

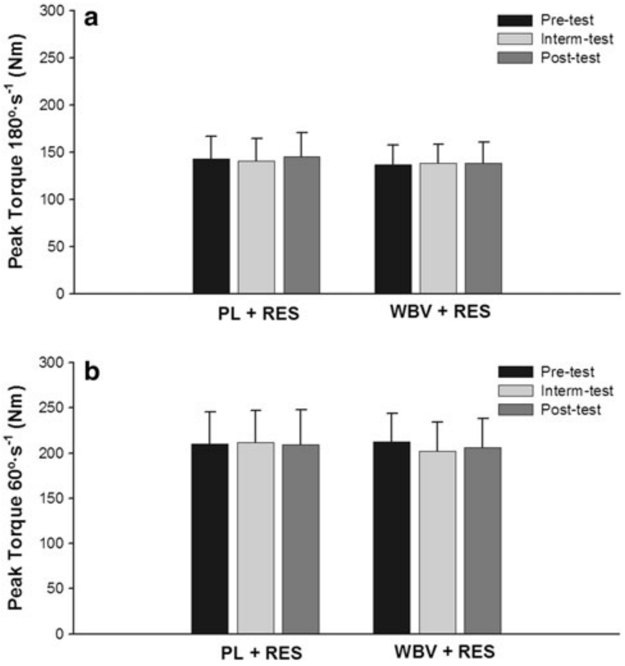

Fig. 1 Mean and SD of peak torque before (pre-test), during (interm-test) and after (post-test) the training program. **a** 180° s^{-1}. **b** 60° s^{-1}

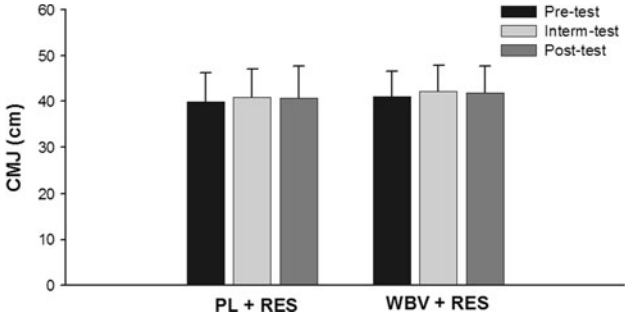

Fig. 2 Mean and SD of counter-movement jump (CMJ) before (pre-test), during (interm-test) and after (post-test) the training program

Perceived exertion

The perception of exertion reported by the participants significantly increased during the 8 weeks in both groups: from 10.3 ± 2.2 in the first week to 14.1 ± 2.5 in the last week in PL + RES group ($P < 0.001$); and from 11.1 ± 1.3 to 14.3 ± 1.6 in WBV + RES group ($P = 0.001$) (data not shown). No significant differences were noted between groups in each week.

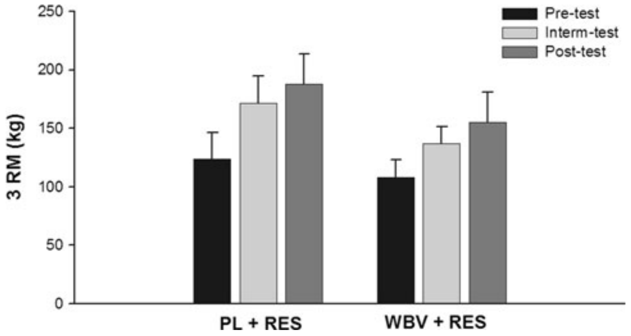

Fig. 3 Mean and SD of three repetition maximum (3RM) before (pre-test), during (interm-test) and after (post-test) the training program. The training protocol resulted in significant increments in both groups (P values < 0.001). The magnitude of the change was not significantly different between groups

Discussion

This study was designed to test whether the combination of WBV and resistance training has any additional effect on knee extensors muscular performance compared to an identical exercise program without vibration. The results indicate that 8 weeks of combined WBV and resistance training increased muscle strength (as measured by half-squat 3RM) at the same extent than in the absence of vibrations. Our findings also indicate that none of the training conditions improved isokinetic strength or power (CMJ).

Despite the increasing scientific interest, the results of WBV interventions on muscular performance differ between studies. Two recent systematic reviews highlighted that gender, age, training status, and exercise protocol are moderators of the response to vibration exercise for strength and power development (Marin and Rhea 2010a, b). The type of vibrating platform also seems to affect the training results. For chronic adaptations, like those investigated in our study, synchronous (vertical) platforms have been suggested to elicit a larger treatment effect than alternating (oscillating) platforms (Marin and Rhea 2010a, b). Vibration frequencies between 35 and 40 Hz and peak-to-peak displacements from 8 to 10 mm have shown to be the most effective for long-term strength and power adaptations (Marin and Rhea 2010a, b). The lack of improvement in isokinetic strength and CMJ in our study may be related with the fact that frequencies at 35–40 Hz were only used during the last 2 weeks of the intervention, and the displacements generated by our vibrating platform were 2.5 and 5 mm.

In recreationally resistance-trained men, the combination of WBV with conventional resistance training during 5 weeks increased 1RM by ~25–30%, at the same extent with or without vibration (Ronnestad 2004). Only the group with vibration significantly improved CMJ, but there was no significant difference between groups in relative jump height increase (Ronnestad 2004). In our study, both training protocols (WBV and resistance training) were mainly based on half-squat exercises, what could explain the

~50% improvements in 3RM in both groups and the absence of improvement in isokinetic strength (leg-extension exercise). A lack of assessment-exercise specificity may reduce the ability to detect significant changes, especially with small training durations and relatively low number of subjects in each group (Wilcock et al. 2009). The specificity of the type of muscular work performed, together with the use of different energy systems, are major challenges for establishing a gold standard for muscular fitness assessment (Mayhew et al. 1991). The comprehensive evaluation carried out in this study, by means of isokinetic dynamometry, muscle strength and power, tried to cover the main components habitually considered within muscular performance.

In a study with similar aim to ours, three groups of moderately trained young men performed a 9-week program of resistance training, WBV or a simultaneous combination of both (Kvorning et al. 2006). Authors found that maximal isometric voluntary contraction (MVC) equally increased when using resistance training or the combination protocol. Furthermore, the combined protocol did not increase CMJ performance to a larger extent than only resistance training. The training protocol used in this study comprised six sets per session, 30 s vibration sets, 20–25 Hz and 4 mm. The presence (or absence) of vibration was the only difference between combined and resistance training group (Kvorning et al. 2006).

Our participants were Physical Education college students, so they were somehow familiarized with lifting and assessment techniques. However, we did not perform a familiarization phase per se, and that leads to the possibility of neurological adaptations as a result of the intervention. It is widely accepted that gains in muscle strength are due to a combination of neurological and morphological factors. Neurological adaptations, which encompass learning and coordination among others, may make their greatest contribution during the early stages of a training program (Folland and Williams 2007). In non-athletic subjects like those in our study, the potential for neural adaptations may be even higher compared to well-trained athletes (Wilcock et al. 2009). On the other hand, hypertrophic process has also been suggested to commence at the onset of training (Folland and Williams 2007). After 8 weeks of resistance training, increments in 1RM and muscle mass at the levels observed in our participants concur with those reported in previous studies (Tresierras and Balady 2009; Strasser and Schobersberger 2011). The significant decrease in body fat only in the group that included WBV could be associated with the increased energy expenditure that has been observed when adding vibration to resistance training (Da Silva et al. 2007).

The effects on muscle mass and body fat observed in our study require, however, to be interpreted with caution. The use of skinfold-derived equations prevent us to draw robust conclusions, compared to more precise laboratory methods such as DEXA for measuring body composition (Andreoli et al. 2009), or scanning techniques to evaluate muscle cross-sectional area (Folland and Williams 2007). We must also note that participants' dietary and physical activity habits during the study were not registered, which could have influenced the effects on body composition. They were, however, strongly encouraged to maintain their habitual dietary patterns, were not allowed to consume any kind of ergogenic aid or nutritional supplementation, and participation in organized physical activities other than the training program was not permitted.

The terms used in the present report to describe the sinusoidal vibration, the WBV device, the participants' characteristics and the intervention protocol, have been selected in accordance with the recommendation of the International Society of Musculoskeletal and Neuronal Interactions (Rauch et al. 2010). This Society provides useful consensual instructions on how WBV intervention studies should be described to help improve the quality of such reports. As a main concern within these recommendations, we could not test whether the actual frequency and displacement (amplitude) generated by our vibrating platform differed from the values provided by the manufacturer, which is considered by this experts group of particular relevance to interpret the results (Rauch et al. 2010).

In conclusion, the addition of WBV to resistance training during 8 weeks, in recreationally active young adults, did not result in a larger muscular performance improvement compared to an identical exercise program performed in absence of vibration. Muscle mass also seemed to be equally affected with or without vibration, yet body fat could be exclusively decreased by WBV. Further studies involving larger sample sizes and longer interventions are required to clarify whether the use of WBV, as a complement to resistance training, produces additional specific benefits. As stated by other authors (Marin and Rhea 2010b), the combination of vibration exercise and conventional resistance training is very deserving of more research examination.

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Conflict of interest The content of this paper reflects only the authors' views, and they disclose no conflict of interest.

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