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Impact of Whole-Body Vibration Training Versus Fitness Training on Muscle Strength and Muscle Mass in Older Men: A 1-Year Randomized Controlled Trial

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Background. This randomized controlled study investigated the effects of 1-year whole-body vibration (WBV) training on isometric and explosive muscle strength and muscle mass in community-dwelling men older than 60 years.

Methods. Muscle characteristics of the WBV group ($n = 31$, 67.3 ± 0.7 years) were compared with those of a fitness (FIT) group ($n = 30$, 67.4 ± 0.8 years) and a control (CON) group ($n = 36$, 68.6 ± 0.9 years). Isometric strength of the knee extensors was measured using an isokinetic dynamometer, explosive muscle strength was assessed using a counter movement jump, and muscle mass of the upper leg was determined by computed tomography.

Results. Isometric muscle strength, explosive muscle strength, and muscle mass increased significantly in the WBV group (9.8%, 10.9%, and 3.4%, respectively) and in the FIT group (13.1%, 9.8%, and 3.8%, respectively) with the training effects not significantly different between the groups. No significant changes in any parameter were found in the CON group.

Conclusion. WBV training is as efficient as a fitness program to increase isometric and explosive knee extension strength and muscle mass of the upper leg in community-dwelling older men. These findings suggest that WBV training has potential to prevent or reverse the age-related loss in skeletal muscle mass, referred to as sarcopenia.

AGING is associated with a decline in muscle mass and muscle strength, referred to as sarcopenia (1). Sarcopenia is accompanied by decreased mobility, loss of independence, increased fall risk, and diminished quality of life (2–4). Additionally, sarcopenia may contribute to several age-related chronic disorders (e.g., osteoporosis, type 2 diabetes, insulin resistance, arthritis) and is considered to be a major public health concern in older individuals (2). Loss and atrophy of individual muscle fibers, decreased synthesis of muscle proteins, and reduced mitochondrial function constitute the primary physiological mechanisms that underlie sarcopenia (2,5–7). The prevalence of sarcopenia, estimated to be as high as 30% for persons older than 60 years (3), will increase further as the proportion of older persons continues to grow. In this regard, there is an urgent need for efficient and feasible interventions to prevent or reverse sarcopenia. Progressive resistance training appears to be effective to slow down the effects of aging on muscle (8,9). The increases in muscle strength and muscle mass are the results of high mechanical loading (with loads up to 70% and 90% of one repetition maximum) (10,11). However, a significant proportion of elderly persons may be unable or unwilling to comply with high-intensity exercise regimens.

Whole-body vibration (WBV) training might be an alternative to conventional resistance training. During WBV, the individual stands on a platform that generates vertical sinusoidal vibrations. These mechanical stimuli are transmitted to the body where they stimulate the primary endings of the muscle spindles, which in turn activate α-motor neurons resulting in muscle contractions, comparable to the tonic vibration reflex (12,13). Compared to conventional resistance training, long-term WBV training results in identical gains in muscle strength and jump performance in untrained young men and women as well as in postmenopausal women (14–16). In older men, the effects of WBV training have not yet been reported, nor have there been studies on the long-term effects of WBV on muscle mass. It has been hypothesized that the WBV-induced strength increase is mainly due to neural adaptations following the massive stimulation of propriospinal reflex pathways, whereas morphological changes (hypertrophy) would be rather limited (14,16). It has been shown that vibratory stimulation applied directly to the achilles tendon of rats attenuated an enlargement of slow- and fast-twitch fibers (17). In untrained young women, we previously reported a minor increase in total fat-free mass after 24 weeks of WBV training, measured by underwater weighing (18).

The aim of the current randomized controlled trial was to measure the changes in muscle strength and muscle mass in men between 60 and 80 years after 1 year of WBV training.

Methods

Participants were locally recruited, between 60 and 80 years old, and noninstitutionalized. Exclusion criteria were

Table 1. Characteristics of the Whole-Body Vibration Training Program

Period (Week)	Volume Duration of exercise (s)	Intensity: Frequency (Hz)	Intensity: Amplitude (High 5 mm/Low 2.5 mm)	Rest (s)	Modality	Number of Series per Exercise*: a	b	c	d	e	f	g	h
1 → 4	30	35	Low	60	Static[†]	3	1						
5 → 9	45	40	High	60	Dynamic + Static[§]	3	1	1			1	1	
10 → 14	60	40	High	45	Dynamic[‡]	3	3	3	1		1	1	
15 → 19	60	40	High	45	8 s principle[‖]	3	3	3	1		1	1	
20 → 24	60	30	High	30	8 s principle	3	3	3	1		1	1	
Midtests (25 → 26)	30	30–35	Low	30	Dynamic + Static	3	3	3	1		1	1	
25 → 29	30–45	35	High	30	Dynamic	3	3	3	1		1	1	
30 → 34	45–60	35	High	15	Dynamic	3	3	3	2		1	1	1
35 → 39	60	35	High	15	8 s principle	3	3	3	2	1	1	1	1
40 → 44	60	35	High	15	8 s + Dynamic	3	3	3	2	1	1	1	1
Posttests (45 → 47)	60	35–40	High	15	8 s + Dynamic	2	2	2	1	1	1	1	1

Notes: *Exercises: (a) squat, (b) deep squat, (c) wide stance squat, (d) one-legged squat, (e) lunge, (f) toes-stand, (g) toes-stand deep, (h) moving heels.

[†]Static: exercises are performed isometrically.

[‡]Dynamic: slowly going up (2 seconds), slowly going down (2 seconds).

[§]Dynamic + static: the first two series were performed in a dynamic way, the last series in a static way.

[‖]8 seconds principle: four repetitions performed in a dynamic way, 4 seconds static performance, four repetitions in a dynamic way, static performance until the end of the exercise.

(i) diseases or medications known to affect bone metabolism or muscle strength and (ii) engagement in moderate-intensity exercise programs for >2 hours/week. After a medical screening including a graded maximal bicycle test where heart rate was recorded continuously, 220 men ($n = 114$) and women ($n = 106$) were randomly assigned to one of three groups: the WBV group, fitness (FIT) group, or control (CON) group. All participants were enrolled in a 1-year randomized controlled study on the effects of training on health-related parameters. Muscle mass was only measured in a subset of 97 men. The main focus of this article is muscle mass and muscle strength of those 97 participants (WBV: $n = 31$, FIT: $n = 30$, and CON: $n = 36$). For comparison, isometric strength data of the 106 female participants (WBV: $n = 46$, FIT: $n = 30$, and CON: $n = 30$) are described briefly at the end of the Results section.

The study was approved by the University's Human Ethics Committee according to the declaration of Helsinki. All participants gave written informed consent.

Interventions

The WBV and FIT groups trained three times weekly for 1 year, with at least 1 day of rest between the training sessions. All sessions were held at the University Training Center and were closely supervised by qualified health and fitness instructors.

WBV Group

The WBV group exercised for a maximum of 40 minutes on a vibration platform (Powerplate, Amsterdam, The Netherlands): squat, deep squat, wide stance squat, toes-stand, toes-stand deep, one-legged squat, and lunge. Training load increased gradually according to the overload principle (Table 1).

FIT Group

The FIT group performed cardiovascular, resistance, balance, and flexibility exercises for about 1.5 hours in total. The guidelines of the American College of Sports Medicine for exercise prescription in older individuals were used to set up the intensity of the program (19). The cardiovascular program (70%–85% of the heart rate reserve) consisted of walking/running, cycling, or stepping. The resistance program (1–2 sets with a load between 8 and 15 repetition maximum) consisted of exercises for the whole body, including leg press and leg extension (Technogym Systems, Gambetolla, Italy). Balance was trained by standing on one or both legs with the eyes open or closed, on a firm or unstable surface. At the end of each session, the participants performed stretching exercises.

CON Group

The CON group was repeatedly advised not to change lifestyle or physical activity during the project. The Flemish Physical Activity Computerized Questionnaire (FPACQ) determining lifestyle and activity patterns, showed no significant changes in physical activity level in the CON group during the study ($p = .909$).

Outcome Measurements

Isometric and explosive strength of the quadriceps muscle and muscle mass of the upper leg were evaluated at baseline and after 12 months.

Isometric strength.—Isometric knee extension strength was tested on an isokinetic dynamometer (Biodex; Shirley, NY) (20) on the right side, unless there was a medical problem. The rotational axis of the dynamometer was aligned with the transversal knee-joint axis and connected to the distal end of the tibia using a lever arm. The highest torque (Nm) of two maximal contractions (with a knee joint angle of 120°) was further analyzed.

Explosive strength.—A counter movement jump (21) was performed on a contact mat to evaluate the explosive capacity of the lower limb muscles after a stretch-shortening cycle. We analyzed the average jump height (in centimeters) of three separate jumps.

Muscle mass.—A multislice computed tomography (CT) scan (Siemens Sensation 16; Forcheim, Germany) delivered axial slices of the right upper leg which were analyzed with the program Volume (Siemens). If necessary, corrections were made for artefacts (e.g., varix clips). The midpoint between the medial edge of the greater trochanter and the intercondyloid fossa of the patella was determined, and subsequently a 2 mm-thick axial image (1 mm above and 1 mm below this midpoint) was further analyzed. This procedure was repeated 3 cm above and 3 cm below the midpoint. Muscle tissue area was segmented by using standard Hounsfield Units ranges for skeletal muscle (0–100) (22). We analyzed the summed muscle volume (in cubic centimeters) of the three slices. Corrections were made for bone marrow with similar Hounsfield Units as those of skeletal muscle, as this tissue was also seen as muscle tissue. Test–retest reliability, evaluated by repeated scans within 2 weeks in an extra group of 12 older men, yielded an intraclass correlation coefficient of 0.99. Measurements were performed in the Universitary Hospital and were executed by an expert radiologist.

Statistical Analysis

One-way analysis of variance (ANOVA) was used to test for differences between the groups at baseline. The changes over time in isometric strength, explosive strength, and muscle mass were analyzed by repeated-measures ANOVA. Contrast analysis was used to assess between- and within-group differences. All analyses were executed using Statistica 6.1 (Statsoft, Tulsa, OK). Level of significance was set at $p \leq .05$.

Results

Dropouts and Training Compliance

No adverse side effects of the intervention were reported in the training groups. All dropouts were related to personal reasons ($n = 5$) or health problems ($n = 8$), none of which, according to the physician, related to the training program. The average overall adherence (number of exercise classes attended as a percentage of the total number of classes) to the training program was 87.6% in the WBV group and 87.1% in the FIT group. Only the results of the participants with a minimal compliance rate of 66% are reported. Therefore, two participants of the FIT group were not included in the analysis. Table 2 shows the basic characteristics of the remaining participants (WBV: $n = 25$, FIT: $n = 25$, CON: $n = 32$). No significant baseline differences were detected between the groups in age, body mass, body mass index, maximal oxygen uptake (VO_{2max}), isometric strength, explosive strength, and muscle mass. VO_{2max} was determined by gas analysis during a graded maximal bicycle test.

Outcome Measurements

Isometric strength.—Isometric strength of the men changed significantly over time ($p = .002$), and this change was different for the three groups ($p = .009$). Both the WBV and FIT groups showed significant improvements in muscle strength (9.8% [$p = .005$] and 13.1% [$p < .001$], respectively), whereas no changes were detected in the CON group (–0.6%, $p = .838$) (Figure 1). The changes in both the WBV and FIT groups were different from those in the CON group ($p = .026$ and $p = .004$, respectively). Training effect was not significantly different between the training groups ($p = .467$).

Table 2. Participant Characteristics of the Control (CON), Fitness (FIT), and Whole-Body Vibration (WBV) Groups (Mean ± Standard Error)

Characteristic	CON ($N = 32$)	FIT ($N = 25$)	WBV ($N = 25$)	p Value*
Age, y	68.6 ± 1.0	67.6 ± 0.9	66.9 ± 0.7	.37
Body mass, kg	80.6 ± 1.5	84.2 ± 2.1	79.9 ± 2.0	.23
Body mass index, kg/m^2	26.9 ± 0.5	28.0 ± 0.7	27.0 ± 0.7	.44
VO_{2max}, ml/min/kg	24.3 ± 0.8	23.1 ± 0.9	24.8 ± 1.0	.43
Isometric strength, Nm	165.2 ± 7.3	164.3 ± 7.4	161.3 ± 6.8	.90
Explosive strength, cm	16.2 ± 0.9	16.9 ± 1.1	16.5 ± 0.7	.71
Thigh muscle mass, cm^3	121.1 ± 2.3	124.7 ± 2.7	121.4 ± 2.9	.57

Notes: VO_{2max} = Maximal oxygen uptake, determined by gas analysis during a graded maximal bicycle test.

*Results of one-way analysis of variance.

Explosive strength.—Jump performance of the men changed significantly over time ($p < .001$), and this change was different for the three groups ($p = .031$). Contrast analysis showed a significant improvement in explosive strength in the WBV group (10.9%, $p < .001$) and FIT group (9.8%, $p < .001$) but no significant changes in the CON group (1.8%, $p = .499$) (Figure 2). Training effect was not significantly different between the training groups ($p = .808$); both the WBV and FIT groups were significantly different from the CON group ($p = .017$ and $p = .030$, respectively).

Muscle mass.—Muscle mass of the men changed significantly over time ($p < .001$), and this change was different for the three groups ($p < .001$), with a significant increase in the WBV (3.4%, $p < .001$) and FIT (3.8%, $p < .001$) groups but no changes in the CON group (–0.7%, $p = .180$) (Figure 3). Training effect was similar in the WBV and FIT groups ($p = .465$); both groups differed significantly from the CON group ($p < .001$ and $p < .001$, respectively).

Isometric strength of the women increased significantly over time ($p < .001$), and this change was different for the three groups ($p = .03$). The WBV and FIT groups improved significantly (12.3%, $p < .001$ and 10.6%, $p = .005$, respectively), whereas no changes were detected for the CON group (2.2%, $p = .468$). Training effect was not significantly different between the training groups ($p = 714$). Only the changes in the WBV group were significantly different from the changes in the CON group ($p = .01$). The relative change over time in isometric strength was comparable for men and women of the WBV group ($p = .609$), FIT group ($p = .194$), and CON group ($p = .643$).

Discussion

To our knowledge, this is the first randomized controlled trial investigating the effects of 1-year WBV training on

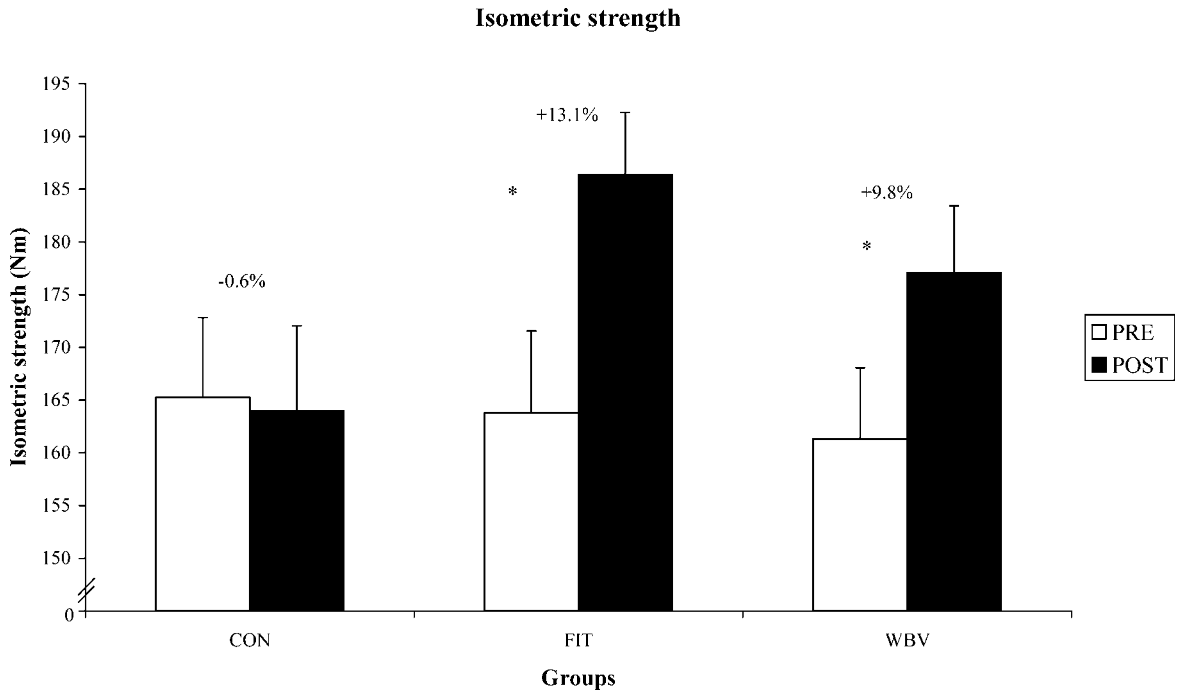

Figure 1. Isometric knee extension strength in the control (CON), fitness (FIT), and whole-body vibration (WBV) groups at baseline (PRE) and at 1 year (POST). Results of repeated-measures analysis of variance are presented as means ± standard errors. *Significant pre–post difference within group ($p < .05$).

muscle performance and muscle mass in community-dwelling men older than 60 years. In line with results previously reported in older women (15), our current findings confirm a WBV-induced increase in isometric and explosive muscle strength in men. Additionally, our study indicates that this improvement is not solely due to neurological adaptations, but also to an increase in muscle mass.

Isometric muscle strength increased by about 10% in the WBV group participants. The relative improvement was comparable for men and women, indicating that both sexes

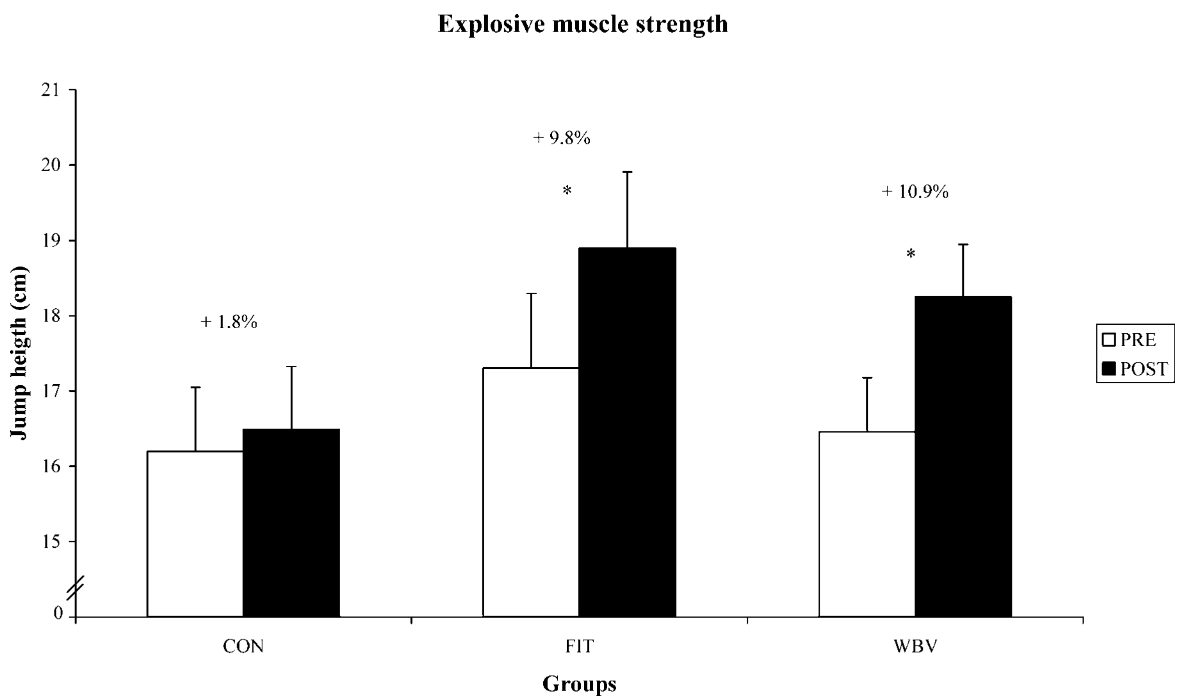

Figure 2. Explosive muscle strength in the control (CON), fitness (FIT), and whole-body vibration (WBV) groups at baseline (PRE) and at 1 year (POST). Results of repeated-measures analysis of variance are presented as means ± standard errors. *Significant pre–post difference within group ($p < .05$).

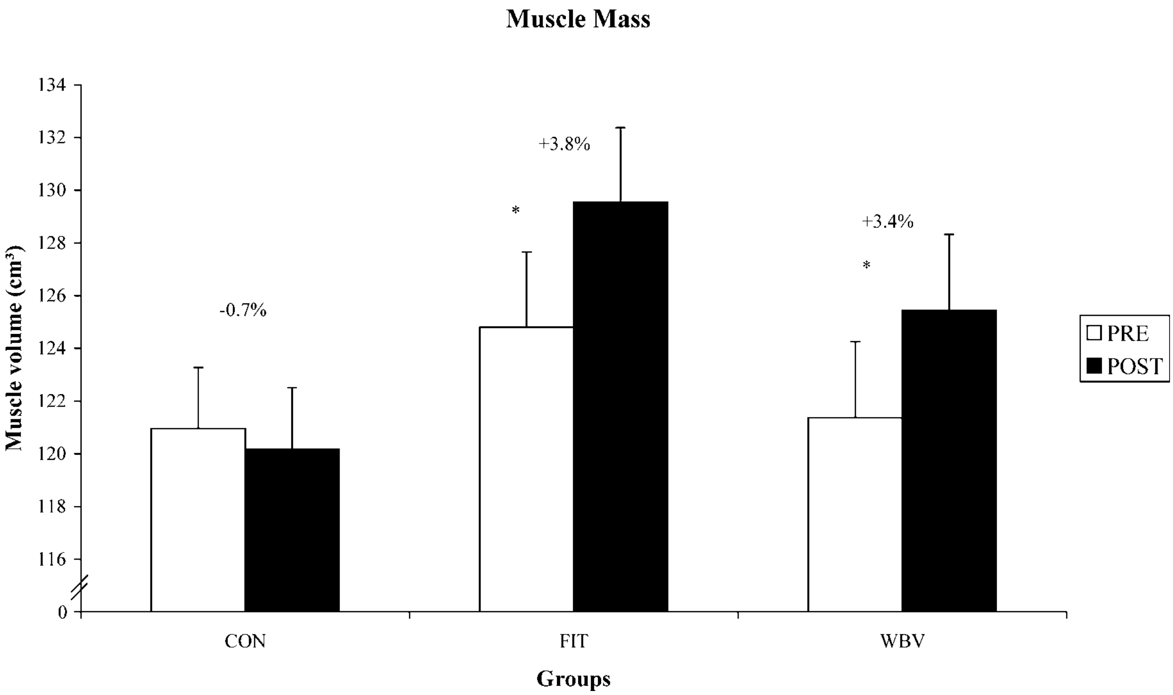

Figure 3. Muscle mass in the control (CON), fitness (FIT), and whole-body vibration (WBV) groups at baseline (PRE) and at 1 year (POST). Results of repeated-measures analysis of variance are presented as means ± standard errors. *Significant pre–post difference within group ($p < .05$).

respond similarly to vibration stimuli. The gains in isometric strength were similar to those induced by an equal number of fitness training sessions. In a previous study in older women, we reported slightly higher increases in isometric strength after 6 months of WBV and FIT training (15% and 18.4%, respectively) (15). In the FIT group of the present study, the gain in muscle strength was also slightly lower than expected from other studies using high resistance and/or explosive strength training (23,24). However, training intensity of the present resistance training program was designed according to the recommendations of the American College of Sports Medicine to improve, not to maximize strength (19).

It has been hypothesized that vibration training may improve muscle strength by facilitating neural control following tonic vibration reflex muscle activation (i.e., increase in motor unit synchronization, co-contraction of the synergist muscle, increased inhibition of the antagonist muscles, and increased ability of motor units to fire briefly at very high rates) (24–26). However, the extent to which WBV might induce muscle hypertrophy remained to be clarified (17,18). To our knowledge, this is the first study providing direct evidence for a WBV-induced increase in muscle mass. This increase was similar in magnitude (3%–4%) than the one observed in the FIT group. A coefficient of determination of 0.27 ($r = 0.52$) between the gains in muscle strength and the gains in muscle mass suggests that, next to neural adaptations, also hypertrophic adaptations contribute to the functional improvements after long-term WBV.

The gain in explosive strength in this study is in line with previous reports (14–16,27), and may indicate that WBV specifically trains fast-twitch fibers, although it remains unclear if there is a difference in hypertrophic response between slow- and fast-twitch fibers. Whereas high-frequency electrical stimulation has been shown to elicit a preferential recruitment of fast-twitch fibers (28–30), recent studies with electrostimulation resistance training and frequency-controlled muscle vibration suggest that slow-twitch fibers are also activated and develop hypertrophy (31,32). Because aging is associated with a preferential loss in size and number of fast-twitch fibers (33), future (biopsy) studies could examine the WBV-induced changes at the level of the individual muscle fibers.

Our findings may have important clinical implications. WBV does not only improve muscle function but, because of its hypertrophic effect, may potentially improve health outcome by reducing and/or reversing the age-related process of sarcopenia and its related disorders. Maintaining muscle strength and muscle mass may be critically important for elderly persons to perform daily activities and to remain independent (34). In this regard, the present results suggest that WBV training may potentially be useful as a low-impact training method to enhance muscle mass and muscle strength of the lower limb muscles in older individuals. In contrast with conventional resistance training, WBV training minimizes the need for conscious exertion and stress on the musculoskeletal, respiratory, and cardiovascular systems. In the context of this study, the compliance of the WBV program was excellent. The vibration sessions were experienced as pleasant and both socially and physically rewarding. After the study, most participants wanted to continue to participate, suggesting that WBV might be feasible over longer time periods, in apparently healthy older individuals.

The hypertrophy due to WBV might also be beneficial for other populations with atrophy. For instance, it is well known that long-term exposure to microgravity induces skeletal muscle atrophy in astronauts (35,36). In this respect, it has recently been shown that frequency-controlled muscle vibration during 55 days of bed rest results in a preservation of muscle strength and an increase in myofiber size (32). Vibration training may also have implications for patients in various clinical settings, including patients with neuromuscular diseases or those in rehabilitation.

Conclusion

The present study supports the use of WBV as an efficient training stimulus to enhance isometric and explosive muscle strength, and muscle mass, in community-dwelling men older than 60 years. WBV training deserves further research in instutionalized elderly persons in whom the control of sarcopenia is even more critical for health and independence.

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