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Research article

Effects of whole-body vibration training on bone-free lean body mass and muscle strength in young adults

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Abstract
Resistance training with whole-body vibration (WBV) is becoming increasingly popular as an alternative to conventional resistance training or as supplementary training. Despite its growing popularity, the specific effects of WBV training on muscle morphology, strength, and endurance are not well understood, particularly in young adults. The aim of this study was to determine the effects of WBV training on bone-free lean body mass (BFLBM), and maximal muscle strength and endurance in healthy, untrained, young individuals. Eighteen healthy men and women (21–39 years) were randomly assigned to either a body-weight exercise with WBV (VT) group or a control exercise group without WBV (CON). Participants performed eight exercises per 40-min session on a vibration platform (VT group, frequency = 30–40 Hz; amplitude = 2 mm) twice weekly for 12 weeks. Anthropometry, total and regional BFLBM (trunks, legs, and arms) measured by dual-energy X-ray absorptiometry, and muscle strength and endurance measured by maximal isometric lumbar extension strength, maximal isokinetic knee extension and flexion strength, and the number of sit-ups performed were recorded and compared. Two-way repeated-measures ANOVA revealed no significant changes between the groups in any of the measured variables. We conclude that 12 weeks of body weight vibration exercise compared to body weight exercise alone does not provide meaningful changes to BFLBM or muscle performance in healthy young adults.

Key words: vibration, exercise, lean body mass, young, untrained.

Introduction

Resistance training improves muscle strength and power, local muscular endurance, and hypertrophy (Ratamess et al., 2009). Recently, resistance training combined with whole-body vibration (WBV) has been widely introduced to beauty clinics, fitness clubs, and professional sports teams, and has become popular among both untrained individuals and athletes as either alternative to conventional resistance training or as supplementary training. Although numerous studies have demonstrated that WBV training enhances muscle strength and power (Marin et al., 2010a; 2010b), when restricted to studies that compared the effects of WBV training on muscle strength and power with the identical training regimens without WBV in young individuals, the efficacy of WBV is less clear. Out of five studies conducted, only Delecluse et al. (2003) found that WBV training led to significant increases in the outcome of measures of muscle strength and power, whereas the other studies did not find any significant differences in these outcome measures compared with the identical training without WBV (Carson et al., 2010; de Ruiter et al., 2003; Kvorning et al., 2006; Ronnestad, 2004). WBV training has also been reported to increase muscle fatigue (Rittweger et al., 2003). As fatigue is speculated to be necessary a prerequisite for the enhancement of muscle endurance (Ratamess et al., 2009), it is also unclear whether WBV training has the potential to increase local muscular endurance performance.

Several studies have suggested that WBV training may affect not only muscle strength, power, and endurance, but may also influence the morphological characteristics of skeletal muscle (Bogaerts et al., 2007; Fjeldstad et al., 2009; Roelants et al., 2004; von Stengel et al., 2010). For example, WBV training for 8–12 months in individuals over 60 years of age increased muscle mass compared to baseline values (Bogaerts et al., 2007; Fjeldstad et al., 2009; von Stengel et al., 2010). In a recent animal study using rats, WBV training at a frequency of 45 Hz for 8 weeks increased the cross-sectional area of both type I and II fibers in soleus muscles (Xie et al., 2008). In young individuals, however, the effects of WBV on muscle morphology are less clear. In a study that examined the effects of 24 weeks of WBV training in previously untrained young adults (mean age, 21.3 years), WBV training resulted in no significant reductions in body weight, total body fat, or subcutaneous fat, but a 2.2% increase was observed in fat-free body mass (Roelants et al., 2004). Although this represents the only report to suggest that WBV training stimulates morphological changes in the muscles of young adults, an identical exercise group in the absence of WBV was not included. Therefore, further evaluation of the effects of WBV training in young adults is warranted.

The aim of the present study was to investigate the effects of 12-week WBV training combined with WBV on bone-free lean body mass (BFLBM), and maximal muscle strength and endurance in healthy young adults. We hypothesized that vibration training would alter the morphological characteristics of muscles, and lead to greater improvements of BFLBM, muscle strength, and muscle endurance than the identical training without WBV. The primary outcome of the study was the effect on regional BFLBM, and the secondary outcome was the effect on maximal muscle strength and endurance.

Methods

Participants

Nineteen untrained healthy men and women (11 females,

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8 males; 21–39 years old) volunteered for this study. Participants were recruited from the students and staff of Keio University using posted advertisements or through introductions from those who had already entered the study. The required sample size was calculated so that a minimum expected difference of 2.5% in fat-free mass could be detected between study groups. With the power set at 0.8 and an alpha level of 0.05, a sample size of 10 subjects in each test group was required. The eligibility criteria for participants were: 20–39 years old, had never experienced long-term WBV training or conventional resistance training, and performed regularly exercised less than 2 days/week upon entry into study. The exclusion criteria were pregnancy, presence of infectious disease, and a history of severe orthopedic abnormality, diabetes, or acute hernia. One candidate was excluded from the study because of a history of severe orthopedic abnormality. This study was approved by the local ethics committee of Keio University, and written informed consent was obtained from all participants. All experimental procedures were performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

Randomization procedure

A randomized controlled trial design was used to investigate the effects of 12-week WBV training on BFLBM, and muscle strength and endurance in healthy young adults. Participants were randomly assigned to either a body-weight exercise with WBV (VT) group or a body-weight exercise without WBV (control, CON) group. The restricted randomization (blocking and stratification) of the participants was performed as follows. First, four matrices (age, 20s or 30s; gender, female or male) were created to stratify the participants. Second, a computer program decided which of the two groups (VT or CON) would be first in each matrix in an attempt to avoid imbalance between the groups. Third, when each participant finished all of the tests before intervention, an allocation sequence was determined one by one. The participants were alternately allocated to either group followed by the matrices, and the allocations were concealed until that time. Both the investigators and the participants recognized the allocation from the beginning of the training program because the vibration device was noisy and oscillated when it operated; however, the evaluator was unaware of the group allocations.

Training programs

Vibrational training (VT) group

For the generation of WBV, a whole platform-oscillating device (Power Plate® Next Generation, Power Plate International, Northbrook, IL, USA) was used. Mean acceleration magnitudes (g) of the WBV platform were measured using a tri-axial accelerometer (CXL25GP3, Crossbow Technology, Inc., Japan), which was attached to the platform in the indentation normally used for cable attachment, and software (U3HV-LJ, LabJack, CO, USA) at a sampling frequency of 1,000 Hz (Table 1). Mean acceleration of the vibration platform was also measured under weight-added conditions because Pel et al. (2009) found that mean acceleration of the vibration platform increased with weight. Plates for weight training (Ivanko Calibrated Bumper Plates, Ivanko, USA) were used to add weight on the WBV platform. All measurements were performed in triplicate, and mean data obtained 16-25 sec after pushing the start button was used for analyses.

Table 1. Mean acceleration (*g*) on the WBV platform.

Additional weight added	Vibration condition			
	0 Hz, 0 mm [control]	30 Hz, 2 mm	35 Hz, 2 mm	40 Hz, 2 mm
0 kg [control]	1.00	1.40	2.10	3.40
+40 kg	1.00	1.40	2.75	3.68
+50 kg	1.00	1.54	2.80	3.92
+60 kg	1.00	1.54	2.91	3.90
+70 kg	1.00	1.56	2.95	4.00

g is the Earth's gravitational field, 9.81 m/s^2.

Figure 1 shows the training exercise program used in this 12-week study. Participants in the VT group (n = 10) were asked to perform eight different exercises on the vibration platform twice weekly for 12 weeks. Participants stood on the pad provided by the manufacturer and wore socks, but no shoes, during the training, with each session lasting approximately 40 min. Four exercises targeted the lower extremities, while four exercises were specific for the trunk and were performed in the semi-prone and supine positions on the vibration platform. Muscle contractions for longer durations (30 sec) result in increases in the cross-sectional area of lower extremity muscles, and 1- to 2-min rest periods have been recommended for novices of WBV training (Ratamess et al., 2009; Schott et al., 1995). Thus, our training program consisted of lower extremity and trunk exercises performed for 30 sec/set on the WBV platform with intermittent rest periods of 60 sec. Each exercise was performed for 3 sets, except for lower extremity exercise 4 and trunk exercise 4 (Figure 1), which were performed for 2 sets on each limb (4 total sets). The participants performed static exercises for the first four weeks followed by dynamic exercises for the remaining eight weeks of the training period (each eccentric-concentric phase was nearly 2 sec). However, trunk exercise 2 was performed statically for the entire 12-week training period. All training sessions were strictly supervised by the investigators.

The adequacy of training intensity was confirmed by a five-point subjective scale for perceived exertion which was evaluated at the end of each session (5: very easy, 4: easy, 3: comfortable, 2: heavy, 1: very heavy), and by a five-point scale administered at the beginning of each session for subjective fatigue caused by the previous training session (5: fully recovered, 4: recovered, 3: slightly tired or almost recovered, 2: tired, stiffness of the muscles, 1: not recovered, very tired, or muscular pain) provided by the Power Plate® Academy program. If a participant rated a three or four on the perceived exertion and a four or five on the subjective health status scale for at least two consecutive weeks, and the investigator judged there to be no physical problems with increasing the load, the vibration frequency was progressively increased for that individual in 5-Hz increments from 30 to 35 and then 35 to 40 Hz. Participants were asked to maintain their daily lifestyles throughout the trial. In addition, participants were occasionally asked whether they experienced any changes in their daily lifestyles, and investigators noted any reported changes.

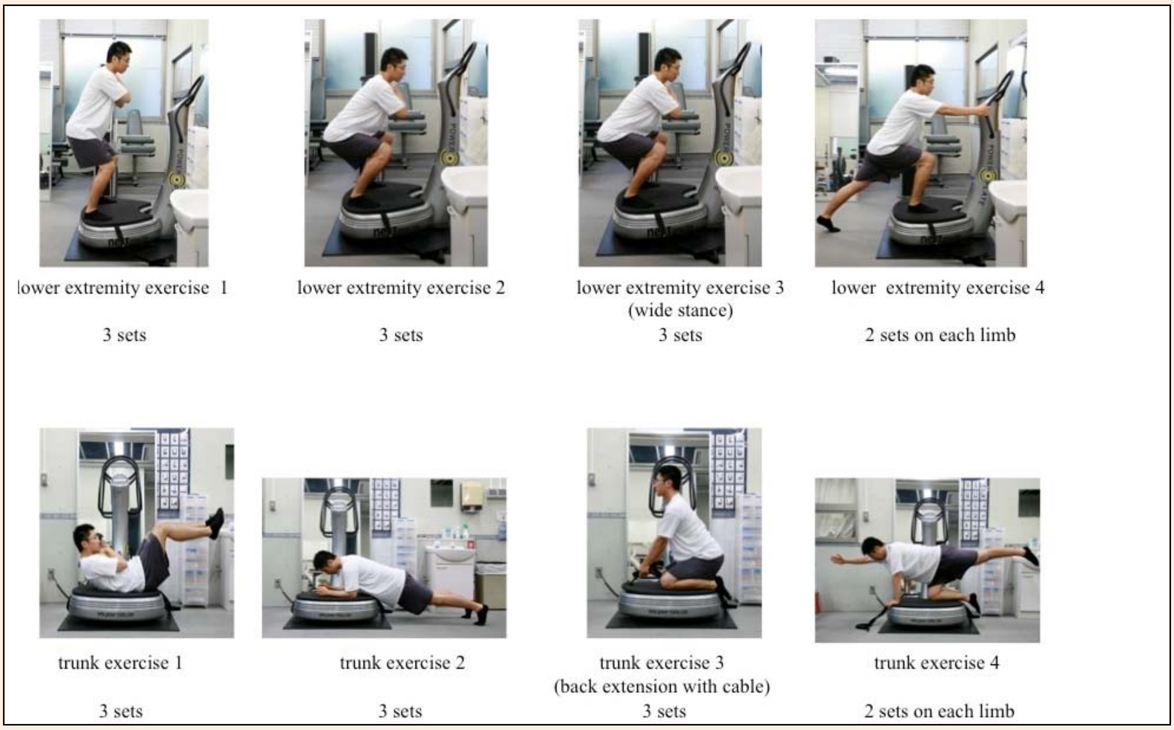

Figure 1. The 8 body-weight exercises of the 12-week training program used in the present study. The top images show the four lower extremity exercises, while the bottom images show the four trunk exercises. The lower extremity and trunk exercises were performed twice weekly for 30 sec/set on the WBV platform with intermittent rest periods of 60 sec. Each exercise was performed for 3 sets, except for lower extremity exercise 4 and trunk exercise 4, which were performed for 2 sets on each limb. In static exercises, the knee and hip joints were in the following positions during the four lower-body exercises: exercise 1, knee angle, 60 degrees knee extension (full extension = 0 degree), and hip angle, 60 degrees hip joint flexion (static position); exercise 2, knee angle, 90 degrees knee extension, and hip angle, 90 degrees hip joint flexion; exercise 3, knee angle, 90 degrees knee flexion, and hip angle, 90 degrees hip joint flexion; and exercise 4, knee angle, 90 degrees knee extension (static position). Only trunk exercise 2 was performed statically throughout the trial. During the dynamic exercises, participants went to the static position, and then returned to the relaxed position. During trunk exercise 3, participants were instructed to lean their upper body backward with their arms straight, and investigators often touched participants' lower back muscles to ascertain the muscles were contracted properly. In dynamic exercises, participants moved their upper body forward to backward.

Control (CON) group

The participants in the CON group (n=8) performed the identical exercises under the same training conditions on the vibration platform as the VT group, but without WBV (Figure 1).

Testing procedures

To evaluate the effects of WBV on muscle strength and endurance, muscle performance tests for the VT and CON groups were conducted before and after the 12-week trial period.

Anthropometry

The height and body mass of all participants were measured. Measurements of waist and hip circumferences followed the American College of Sports Medicine Guidelines for Exercise Testing and Prescription (Whaley et al., 2006). With participants wearing light clothes and standing upright and relaxed, horizontal measures were taken at the level of the umbilicus and the maximal circumference of the hip for the measurements of waist and hip circumference, respectively. Thigh circumference was measured 20 cm from the top of the patella. The same evaluator measured the waist, hip, and thigh circumferences of all participants.

Bone-free lean body mass

One whole-body dual-energy X-ray absorptiometry (DXA) (PRODIGY® Advance, GE Healthcare Yokogawa Systems, Tokyo) scan using enCORE 2006 software version 10.5 was performed by the same licensed X-ray operator at Keio University Hospital. Standard scan mode was used for the whole-body scans. Total and regional BFLBM (arms, trunk, and legs) were measured by DXA. Calibration procedures were performed daily prior to each scan. For the DXA measurements, the CV% for the BFLBM was 1.4%. The primary outcome was BFLBM for both the total body and regional analyses.

Maximal muscle strength and endurance tests

Unfortunately, no universally acknowledged test exists for measuring trunk extension strength. In the present study, maximal isometric lumbar extension strength was measured with an isometric lumbar extension machine (MedX, Orlando, FL, USA) using testing positions that were standardized following the manufacturer's guidelines. The reliability of the maximal isometric lumbar extension strength test was high (r=0.78 to 0.95, 7 testing positions) (Graves et al., 1990). After the participant was seated in the lumbar extension machine, the pelvis was stabilized, and a counterweight was adjusted while the participant rested against the upper back pad (the angle of full extension was 0 degrees) to neutralize gravitational force on the head, torso, and upper extremities. Lumbar extension strength was then measured in the sitting position through a 72-degree arc of lumbar motion (at 72, 60, 48, 36, 24, 12, and 0 degrees of trunk flexion). An interfaced IBM computer automatically integrated the area under the curve obtained from the strength of seven angles (termed the strength index [SI] by the manufacturer), and the obtained SI values were used for further analyses.

Maximal isokinetic knee extension and flexion were measured using a Kin-Com® KC500H device (Chatteex, Hixson, USA). After gravity correction was performed in accordance with the manufacturer's guidelines, in a sitting position (hip flexion, 85 degrees), the maximal concentric and eccentric isokinetic knee extension strength at knee angles of 80 to 10 degrees and a velocity of 60 deg/sec for 8-10 trials were measured, and the best score was recorded. The identical procedure was then repeated in the maximal concentric and eccentric isokinetic knee flexion strength tests at knee angles of 10 to 80 degrees and a velocity of 60 deg/sec (hip flexion, 0 degrees). All maximal strength tests were normalized to body mass.

Abdominal muscle endurance was determined by the total number of sit-ups performed in 30 sec. We applied the sit-up test used in the New Japan Fitness Test formulated by the Japanese Ministry of Education, Culture, Sports, Science and Technology, which is nearly identical to that used in the Eurofit Fitness Testing Battery, with the exception of arm position. As the reliability of the sit-up test in the Eurofit Fitness Testing Battery was reported to be r = 0.83 (Tsigilis et al., 2002), and the correlation between the number of sit-ups and maximal isokinetic strength is also relatively high (r = 0.79) (Yamamoto, 2004), the results of sit-up testing are considered suitable for demonstrating training effects on abdominal muscle endurance and strength. Briefly, the participant was positioned on the mat with knees bent at 90-degree angles, feet flat on the floor and held down by an investigator, and arms folded in front of the chest. On the command 'Go', the participant raised their upper body so that his or her elbows touched his or her thigh, and then returned to the floor. The back was required to return to the floor before proceeding to the next sit-up. All tests described in this section were conducted at least three days after the last training session to minimize acute effects.

Statistical analyses

Normality assumptions were performed using the Kolmogorov-Smirnov test, and equal variance assumptions were performed using the Levene test. For baseline comparisons in age, body mass, BFLBM, muscle strength and endurance, and the attendance of the participants, the unpaired-t test was used if normality was assumed. If not, the Mann-Whitney U test was conducted. If normality and equal variance were assumed, longitudinal changes in all outcomes were compared within the groups using a two-way ANOVA (group-by-time) with repeated measurements. The Statistical Package for the Social Sciences version 17.0 for Macintosh (SPSS, Inc., Tokyo, Japan) was used for the statistical analyses. The level of significance was set at $p < 0.05$. All values are presented as the mean ± standard deviation (SD).

Results

Participant baseline characteristics, attendance, and training safety

Table 2 summarizes the study participants' baseline characteristics. The flow of participants through the trial is shown in Figure 2. The mean participant attendance of the training sessions was 88.1 ± 13.9% in the VT group and 92.1 ± 5.3% in the CON group [t (1, 16) = 0.437, p = 0.67].

Table 2. The characteristics of the participants. All values are presented as the mean (± SD).

	VT n = 10 F: 5, M: 5	CON n = 8 F: 5, M: 3	Unpaired-t test t	df	p
Age (years)	26.8 (4.5)	28.1 (6.2)	.54	16	.60
Height (m)	1.65 (.10)	1.63 (.03)	-.63	16	.54
Body mass (kg)	57.9 (9.7)	52.6 (5.1)	-1.49	16	.18
BFLBM (kg)	42.5 (9.0)	39.3 (5.6)	-1.08	16	.30

BFLBM, bone free lean body mass, CON, control group; VT, vibration training group; df, degrees of freedom.

We monitored the participants' transition through the three vibration frequencies (30, 35, to 40 Hz) during the 12-week study period, which were based on perceived exertion and residual fatigue. On average, the vibration frequency increased from 30 to 35 Hz in the 10th (5-13th) training session, and from 35 to 40 Hz in the 18th (12-20th) training session.

No adverse effects during the course of the study were reported, except that four participants (2 males and 2 females) experienced itching in either their feet or ears when they performed exercises in the standing and supine positions on the vibration platform.

Anthropometry and BFLBM

The pre- and post-12-week training values for the anthropometric measurements and BFLBM are summarized in Table 3. Notably, no significant group-by-time interactions were observed in any of the outcome measurements. However, significant time effects were observed in the BFLBM of the trunk region. We also did not observe significant changes in the BFLBM for the specific body regions within either of the groups.

Maximal muscle strength and endurance

To evaluate the effects of WBV on maximal muscle strength and endurance, muscle performance tests for the VT and CON groups were conducted before and after the 12-week trial period (Table 4). No significant differences between the two groups at baseline were observed.

Similar to the anthropometric measurements and BFLBM, no significant group-by-time interactions were observed in any of the evaluated muscle strength or muscle endurance tests. However, a significant time effect

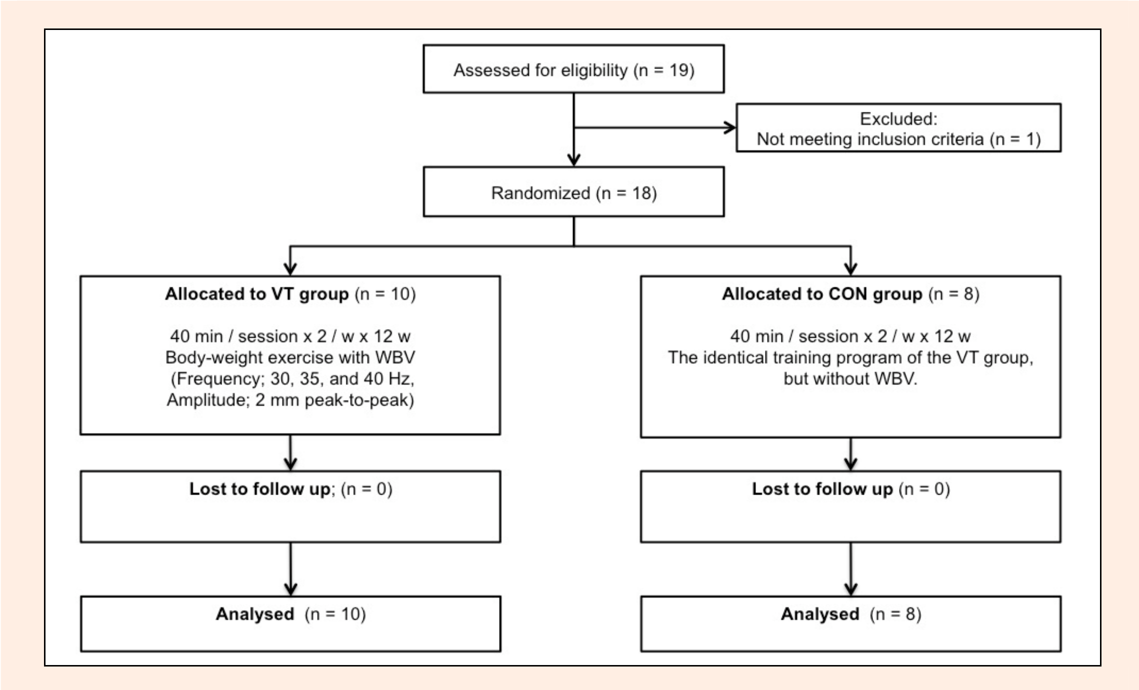

Figure 2. **The flow of participants through the trial. VT, vibration training; CON, control; WBV, whole-body vibration.**

was observed in both maximal isokinetic concentric knee flexion strength (p = 0.001) and maximal isometric lumbar extension strength (p = 0.001). In addition, a significant time effect was observed in the sit-up test (p < 0.001).

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Discussion

In the present study, we examined the effects of body-weight exercise in combination with WBV on BFLBM and maximal muscle strength and endurance in healthy young adults. Compared to the identical training regimen without WBV, we found that 12 weeks of body-weight vibration exercises targeting the trunk and lower extremities did not result in meaningful increases in BFLBM or muscle performance.

Table 3. **Anthropometric variables and bone-free lean body mass before and after a 12-week WBV training program. All values are presented as the mean (± SD).**

					ANOVA					
		VT	CON		Group		Time		Group-by-Time	
		n = 10	n = 8	df	F	p	F	p	F	p
Body mass (kg)	pre	57.9 (9.7)	52.6 (5.1)							
	post	58.4 (9.7)	52.2 (4.6)	1,16	2.36	.14	.05	.82	2.84	.11
Total BFLBM (kg)	pre	42.5 (9.0)	39.3 (5.6)							
	post	43.0 (9.0)	39.4 (5.6)	1,16	1.30	.27	2.42	.14	1.45	.25
Trunk BFLBM (kg)	pre	19.9 (3.5)	18.3 (2.2)							
	post	20.6 (3.7)	18.7 (2.4)	1,16	1.43	.25	8.67	.01	.35	.56
Leg BFLBM (kg)	pre	14.8 (3.3)	13.3 (2.5)							
	post	14.7 (3.2)	13.1 (2.2)	1,16	1.34	.26	1.96	.18	.70	.41
Arm BFLBM (kg)	pre	4.7 (.8)	4.4 (1.3)							
	post	4.7 (.8)	4.4 (1.3)	1,16	1.32	.28	3.49	.10	1.32	.28
Waist circumference (cm)	pre	74.3 (6.8)	71.4 (5.1)							
	post	72.4 (7.8)	69.3 (3.9)	1,16	.99	.34	3.26	.09	.09	.79
Hip circumference (cm)	pre	92.8 (6.1)	91.3 (4.1)							
	post	90.6 (6.3)	91.0 (4.6)	1,16	.03	.87	1.69	.21	.90	.36
Right thigh circumference (cm)	pre	50.3 (3.1)	47.3 (2.6)							
	post	50.5 (3.7)	47.8 (2.2)	1,16	3.75	.07	1.65	.22	.07	.80

CON, control group; VT, Vibration training group; BFLBM, Bone-free lean body mass.

Table 4. The effects of 12-week whole body vibration training on muscle strength and endurance. All values were presented as mean (± SD).

		VT	CON	unpaired-t test (baseline)			ANOVA					
							Group		Time		Group-by-Time	
		n = 10	n = 8	df	t	p	F	p	F	p	F	p
Maximal isometric lumbar extension strength (SI/kg)												
	pre	149.6 (54.6)	135.0 (45.3)	1,16	-.61	.55	.13	.72	18.29	.001	.79	.39
	post	169.8 (68.7)	165.8 (46.3)									
Maximal isokinetic knee extension-con- (Nm/kg)												
	pre	1.92 (.48)	1.53 (.80)	1,16	1.28	.22	1.95	.18	2.53	.13	.15	.70
	post	2.13 (.50)	1.66 (.96)									
Maximal isokinetic knee extension-ecc- (Nm/kg)												
	pre	2.34 (.79)	2.05 (.86)	1,16	.75	.46	.82	.38	2.65	.12	.37	.55
	post	2.59 (.85)	2.17 (1.00)									
Maximal isokinetic knee flexion - con- (Nm/kg)												
	pre	1.00 (.25)	.78 (.38)	1,16	1.54	.14	2.49	.13	16.85	.001	.04	.84
	post	1.22 (.31)	.97 (.40)									
Maximal isokinetic knee flexion- ecc- (Nm/kg)												
	pre	1.29 (.22)	1.02 (.34)	1,16	2.02	.06	4.61	.05	3.56	.08	.09	.77
	post	1.43 (.31)	1.12 (.38)									
Number of sit-ups (time)												
	pre	18.1 (4.5)	17.6 (4.3)	1,16	-.23	.82	.18	.67	39.56	.001	1.80	.20
	post	20.8 (5.2)	19.4 (4.7)									

CON, control group; VT, Vibration training group; con: concentric contraction; ecc: eccentric contraction; SI: strength index.

Although untrained individuals are most likely to benefit from WBV training, those with lower fitness levels can significantly increase muscle strength and cross-sectional area in quadriceps by body-weight training alone (Rehn et al., 2007; Schott et al., 1995). Therefore, the lack of additional effects as a result of WBV might be attributable to the low fitness level or differences in baseline maximal muscle strength of the study participants. Concerning participant fitness level, when the baseline data of the sit-up test were compared with the average data stratified by age and gender in the New Japan Fitness Test, the fitness level of both women (15.4 ± 3.0 sit-ups) and men (21.3 ± 3.6 sit-ups) was lower than the average of Japanese women (19.4 ± 5.5 sit-ups) and men (27.4 ± 5.5 sit-ups) in their twenties (Sports and Youth Bureau, Ministry of Education, Culture, Sports, Science and Technology, 2009). In addition, we also observed a trend of reduced baseline muscle strength and endurance in the CON group compared to that of the VT group (Table 4). Therefore, it is possible that even if WBV increased training intensities, the relative training intensities were nearly identical for each group due to the lower baseline strength of the CON group. Thus, the improvements in the trunk BFLBM, maximal muscle strength, and muscle endurance resulting from body-weight training alone may have masked or limited the additional effects of WBV because of the low fitness levels and baseline maximal muscle strength differences of the VT and CON groups.

Compared to resistance weight training alone, we found that 12 weeks of training coupled with WBV did not lead to significant additional effects on total BFLBM, maximal muscle strength, or muscle endurance. Our results are inconsistent with the study by Roelants et al. (2004), who found that WBV training increased fat free mass by 2.2% and maximal knee extension strength by 24.4%, and the study by Delecluse et al. (2003), who found that WBV training increased maximal knee extension strength by 16.6%. However, our results are supported by those of de Ruiter et al. (2003), who found that WBV training did not increase maximal muscle strength or power. As more than half of skeletal muscle mass exists in the lower extremities (Janssen et al., 2000), the total volume of training for lower extremities might have effects on increases of not only maximal knee extension muscle strength and power, but also on total BFLBM. The total duration of exercise for the lower extremities per session in our study (6.5 min) was shorter than the duration of Delecluse et al. (2003) and Roelants et al. (2004) (progressively increased from 1-18 min, with no rest period), but was nearly identical to that of de Ruiter et al. (2003) (5-8 min). Therefore, the lower total exercise and WBV exposure times per session may have been an insufficient load and amount of stimulation to affect the total BFLBM and maximal knee extension/flexion muscle strength.

Although numerous exercise programs using vibration platforms have been previously evaluated, little is known about the vibration frequencies and amplitudes that are optimal for WBV training in the supine and prone positions on vibration platforms. As it has been suggested that joints or items such as shoes and pads dampen the vibration magnitude (Rittweger, 2010), our study group participants performed exercises in prone and supine positions to ensure close proximity of the trunk muscles to the WBV source. We applied WBV at frequencies ranging from 30–40 Hz and amplitude of 2 mm, because nearly all participants experienced discomfort in their head and chest regions when exercises were performed in the supine position at a frequency of 50 Hz or amplitude of 4 mm. All participants in the VT group initially performed exercises on the vibration platform at a frequency of 30 Hz, and subsequently transitioned to higher frequencies based on their reported levels of exertion and recovery. Although the timing of the vibration frequency transition was slightly different among the participants, all participants reached 40 Hz by the end of the study. Based on the participants' subjective reports, a 4-5 week training period (or 8-10 training sessions) might be required to become accustomed to a higher vibration frequency.

Several limitations of this study should be considered when interpreting and generalizing the findings presented here. First, the study was a restricted randomized control trial stratified by gender and age. As the ratio of men and women differed between the groups, this gender unbalance might have affected the results. Second, the present study was underpowered due to the small sample size and the failure to detect differences in maximal muscle strength, and endurance outcomes may reflect this limitation. Third, although participants were asked to maintain their normal dietary intake and physical activity throughout the trial, these variables were not strictly controlled. However, as only a few participants reported slightly increased dietary intake, changes in daily lifestyle and eating habits were not considered to have significantly affected the study outcomes. Fourth, the present study lacked a non-exercise control group that did not perform body-weight training. Finally, the participants were asked for their subjective health condition and perceived exertion at the beginning and end of each training session. Based on their answers, the vibration frequency was progressively increased on an individual basis throughout the training period; thus, the number of training sessions at each vibration frequency was different for each participant. Subsequent investigations are needed to objectively determine the length of time needed for individuals to adapt to WBV as a load and the optimal progressive loading in WBV training.

Conclusion

In conclusion, our results suggest that 12 weeks of body-weight exercise combined with WBV compared to body-weight exercise alone might not provide meaningful changes in the BFLBM or maximal muscle strength and endurance in young healthy adults.

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Key points

- A randomized controlled trial was conducted to investigate the effects of body-weight exercise combined with whole-body vibration on bone-free lean body mass and maximal muscle strength and endurance in healthy young individuals.
- Body-weight exercises for lower extremities and trunk muscles were performed twice weekly for 12 weeks.
- Participants in the exercise with whole-body vibration group increased the vibration frequency from 30, 35, to 40 Hz at a constant amplitude of 2 mm during the trial.
- A 12-week body-weight exercise program with whole-body vibration did not significantly increase bone-free lean body mass in healthy young individuals, and no additional increases in maximal muscle strength and endurance were observed.

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