EFFECTS OF DIFFERENT AMPLITUDES (HIGH VS. LOW) OF WHOLE-BODY VIBRATION TRAINING IN ACTIVE ADULTS

ESMERALDO MARTÍNEZ-PARDO, SALVADOR ROMERO-ARENAS, AND PEDRO E. ALCARAZ

UCAM Research Center for High Performance Sport, Catholic University of San Antonio, Guadalupe, Murcia, Spain

ABSTRACT

Martínez-Pardo, E, Romero-Arenas, S, and Alcaraz, PE. Effects of different amplitudes (high vs. low) of whole-body vibration training in active adults. *J Strength Cond Res* 27(7): 1798–1806, 2013—The aim of this study was to evaluate the effects of two different amplitudes of whole-body vibrations on the development of strength, mechanical power of the lower limb, and body composition. Thirty-eight recreationally active participants took part in the study. Participants were divided in two experimental groups (low amplitude group [GL] = 2 mm; high amplitude group [GH] = 4 mm) and a control group. The experimental groups performed an incremental vibratory training, 2 days per week during 6 weeks. The frequency of vibration (50 Hz), time of work (60 seconds), and time of rest (60 seconds) were constant for GL and GH groups. All the participants were on the platform in a static semi-squat position. Maximum isokinetic strength, body composition, and performance in vertical jumps (squat and countermovement jumps) were evaluated at the beginning and at the end of the training cycle. A significant increase of isokinetic strength was observed in GL and GH at angular velocities of $60^\circ\cdot s^{-1}$, $180^\circ\cdot s^{-1}$ and $270^\circ\cdot s^{-1}$. Total lean mass was significantly increased in GH (0.9 ± 1.0 kg). There were no significant changes in the total fat mass in any of the groups. Significant changes were not observed in different variables (height, peak power, and rate of force development) derived from the vertical jumps for any of the groups submitted to study. The vibration training, whatever the amplitude, produced significant improvements in isokinetic strength. However, high vibration amplitude training presents better adaptations for hypertrophy than the training with low vibration amplitude. In this sense, GH would be a better training if the practitioners want to develop both strength and hypertrophy of the lower limbs.

KEY WORDS vibration platform, strength, power, body composition, DEXA

INTRODUCTION

Different physical attributes such as strength and power are important elements in many sports. Training methods that enhance these qualities are determining for the development and progression of the athlete. Several methods have been used to improve the physical condition of athletes in both the gym and in the field. However, a new addition to training has become popular both in sports and health exercises. This new trend in training acts through whole-body vibrations (WBV). The WBV has been introduced in health and physical activity as an alternative method and a measure to reduce body fat and to increase muscle mass and strength (37).

Several scientific studies explain the effects of vibration training focusing on strength and power gains that occurs with this type of training resulting mainly from neuromuscular adaptations (38,44). Some studies conducted in the field of WBV, relating to changes on the cardiovascular system or the $\dot{V}O_2$ kinetic (36), have shown hormone increases after application of WBV (3) and have even found potential for applications of WBV in the prevention of osteoporosis (41).

The reduction of body fat and increase in muscle mass and muscle strength are the most popular aims at the beginning of an exercise program (37). Different authors (14,22,27,37,43) assert that WBV increases the dynamic strength of the muscles of the lower limbs. Similar results (14,27) were found regarding isokinetic strength after vibration training for several weeks. Apparently, this increased strength could be induced by the magnitude of vibration (38). This high magnitude might produce neuromuscular adaptations resulting in enhanced neuromuscular activation (14,33). In fact, vibration elicits a response called "tonic vibration reflex," including activation of muscle spindles, mediation of the neural signals by Ia afferents, and activation of muscle fibers via large α-motoneurons (19). The tonic vibration reflex is also able to cause an increase in

Address correspondence to Pedro E. Alcaraz, palcaraz@ucam.edu.

27(7)/1798–1806

Journal of Strength and Conditioning Research
© 2013 National Strength and Conditioning Association

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

recruitment of the motor units through activation of muscle spindles and polysynaptic pathways (11). Furthermore, when the long-term effects of WBV were evaluated on vertical jumps, improvements in the performance of the squat jump (SJ) (9,17) and countermovement jump (CMJ) (13,14,17,37,39) were found.

Regarding body composition, it is largely unknown what effects the use of vibrating platforms, with the purpose of altering body composition in humans, produces. There was a reciprocal increase in lean mass in untrained young women after 24 weeks of WBV; however, there was no change in total fat (37). Moreover, the different studies found on body composition have sparked some controversy (35,37,42,45). For this reason, more research is needed regarding this concern.

Specifically, the vibration exercise is based on controlled oscillations, where the vibration is transferred from a device to the human body. The effects of WBV are strongly dependent on magnitude of the vibration parameters (31), namely, vibration frequency, amplitude, duration, and mode. The frequency is measured in the unit of hertz (Hz) and shows oscillations ranging from 15 to 60 Hz (7). Peak-to-peak amplitude or displacement is defined as the difference between the maximum and minimum values of periodic oscillation (amplitude is defined as half the difference between the maximum values of the oscillation). However, the selective effects of different vibration amplitude parameters are not clearly understood (24). A variety of amplitudes are used in different studies, but not all of them were tested within the same protocols. Marin et al. (29) analyzed the effects of different vibration magnitudes via feet during a set of elbow-extension exercise suggesting that greater amplitudes may be used during vibration training to elicit a greater neuromuscular stimulus. In another cross-sectional study, Marin et al. (28) found that the magnitude of the WBV effect was clearly higher with the amplitude high mode (3.1 mm) than low mode (1.0 mm) on the surface electromyography (sEMG) analysis of all the muscles, and it showed conclusive changes with the different amplitudes of high vs. low treatment (28). Most studies included in the Rehn et al. (34) review show the amplitudes used for long-term exercise varied from 1.7 to 5.0 mm. This rather wide variety in vibration parameters between studies could explain the various outcomes found.

It is clear that the magnitude of the amplitude produces different neuromuscular adaptations. However, an evaluation of the general trends in treatment effects, when different amplitudes of vibration exercises are employed, is much needed. Therefore, the aim of this research was to study the effects, when using WBV, of two different amplitudes (2 and 4 mm) on the development of strength, mechanical power of the muscles of the lower limbs, and changes in body composition in active adults. Therefore, the following hypothesis was established: the WBV training program, using a high amplitude vibration, produces an increase in mechanical power, strength, and muscle mass in young healthy adults, whereas the low amplitude does not.

METHODS

Experimental Approach to the Problem

A quasi-experimental, pretest/posttest randomized group design using two training groups and a control group (CG) was employed to examine the short-term effects of high amplitude vs. low amplitude when using WBV on the development of the lower-body strength, mechanical power, and body composition. After pretest, subjects were randomly assigned to one of two treatment conditions or the CG: (a) WBV training with high amplitudes (GH, 4 mm), (b) WBV training with low amplitudes (GL, 2 mm), (c) the no training CG. Subjects completed 1 week of familiarization WBV training before an 8-week specific training phase. During the 1-week familiarization phase, subjects performed low load magnitude WBV training; additionally, in this phase, participants were familiarized with the measurement protocols (vertical jump and isokinetic tests).

Subjects

Thirty-eight recreationally active subjects (30 men and 8 women; 21.2 ± 3.3 years old; 173.4 ± 7.6 cm; 69.3 ± 9.8 kg) took part in the study. Recreationally active was classified as engaging in low-to-moderate intensity physical activity no more than 3 times per week for approximately 20–30 minutes. Participants were divided in 2 experimental groups and a CG according to the habitual physical activity level measured with the GPAQ questionnaire (2), sex, and isokinetic strength of knee extensor muscles (Table 1). The subjects read and signed statements of informed consent before participation in the study. Approval for the study was given by the Human Subjects Ethics Committee of the San Antonio Catholic University of Murcia, Spain. Subjects were instructed to maintain their accustomed dietary and physical activity habits throughout the course of the study. To verify compliance with these instructions, dietary and activity habits were assessed on 2 occasions (1 and 6 weeks). An experienced instructor obtained dietary and physical activity records from the subjects without warning. On all occasions, dietary logs were recorded for 3 consecutive days, including 1 weekend day. The 3-day dietary records were analyzed for total caloric intake and for carbohydrate, fat, and protein composition using commercially available computer software (DietSource 1.2; Novartis, Barcelona, Spain). To monitor physical activity, the subjects also completed a GPAQ questionnaire.

Procedures

The initial and final assessment was carried out at the beginning and end of the experimental phase. The test was performed over the duration of 1 week. Participants performed the initial and final test in the same sequence and at the same time of the day (Figure 1). Two weeks before the initial data collection, 2 familiarization sessions were

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

TABLE 1. Characteristics of the participants.*

	Age (y)	Height (cm)	Body mass (kg)	Gender	TorqF 270°·s^{-1} (N·m)
GL ($n = 11$)	20.5 ± 1.0	172.9 ± 5.7	69.9 ± 6.4	M = 9; F = 2	121.5 ± 37.8
GH ($n = 16$)	21.5 ± 5.2	175.1 ± 8.1	71.2 ± 12.6	M = 12; F = 4	124.8 ± 37.8
CG ($n = 11$)	21.5 ± 3.8	172.3 ± 8.9	66.8 ± 10.5	M = 9; F = 2	132.0 ± 33.3
Total ($n = 38$)	21.2 ± 3.3	173.4 ± 7.6	69.3 ± 9.8	M = 30; F = 8	126.1 ± 36.3

*TorqF = peak torque in knee extension; M = male; F = female; GL = group of low amplitude (2 mm); GH = group of high amplitude (4 mm); CG = control group.

performed for the jump tests. All tests involving muscle actions were performed with a rest of 48 hours between each measurement session, with the aim of ensuring that the participants were not suffering from fatigue when they had to perform it.

Jump Procedures

Before performing the CMJ and SJ tests, subjects completed a warm-up consisting of 10 minutes of self-paced cycle ergometry followed by 5 minutes of prescribed dynamic stretching. Once positioned on the force platform, subjects performed 1 submaximal practice jump for both the CMJ and SJ. Each subject then performed 4 jumps (2 CMJs and 2 SJs) beginning with either CMJ or SJ, then alternating between jumps with 3 minutes of rest between each jump. Displacement for each CMJ and SJ was measured with an extensometric force platform (Dinascan/IBV, Valencia, Spain), which sampled at a rate of 1,000 Hz, and has been described previously (23). To establish standing reach height, each subject stood side on to the jumping device while keeping the heels on the floor and reached upward as high as possible. Each subject began the CMJ in the standing position, dropped into the squat position, and then immediately jumped vertically. Each subject individually determined the depth of knee flexion used during each CMJ. Takeoff from 2 feet was strictly monitored with no preliminary steps or shuffling permitted during the eccentric or transition phases of the CMJ technique. The SJ technique required the subject to descend to a position of 90° knee flexion, determined using a hand-held goniometer, that positioned the upper thigh parallel with the ground. Subjects were instructed to hold this position for 3 seconds, after which the subject jumped for maximum height without previous countermovement. All SJ and CMJ were executed with both hands on the hips throughout the full range of take off, flight, and landing movements. The best result from each of the CMJ and SJ protocols was used for analysis. The vertical force-time data were filtered using a fourth-order Butterworth low-pass filter with a cutoff frequency of 20 Hz.

Calculation of Force Variables. The force-time data examined during the CMJs and SJs included jump height, maximum mechanical power (Pmax), and the maximum rate of force development (RFDmax). Jump heights (h) were calculated from the take off vertical velocity (v^t) using the following equation: $h = v^{t^2} \cdot 2g - 1$. Absolute and relative mechanical power was calculated as follows: vertical force × instantaneous vertical velocity of the system's center of mass (8), and RFDmax was calculated as the greatest rise in force during 4-millisecond periods from the start of the jump till the end of the concentric phase (20,48) in the SJ and from the start of the CMJ till the highest value of force. The instantaneous vertical velocity was calculated from the integration of the force-time trace. A jump was deemed to have started when the vertical force exceeded (SJ) or decreased (CMJ) 10 N more than the mass of the subject.

Isokinetic Strength

An isokinetic dynamometer (Biodex 6000, New York, NY, USA) was used for the isokinetic strength tests. Each subject underwent a thorough and standardized familiarization session, which included all tests, at least 1 week before being tested. The knee extensors and flexors in the dominant leg were tested concentrically. All movements were tested at 60°·s^{-1}, 180°·s^{-1}, and 270°·s^{-1} angular velocities. Each subject was measured in a standing position and was stabilized with Velcro straps.

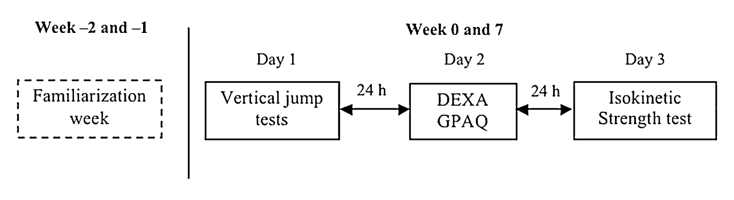

Figure 1. Temporal distribution of all tests. DEXA = densitometry; GPAQ = questionnaire to assess physical activity level.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

Table 2. Weekly distribution of the parameters of vibration training.*

	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6
GL (2 mm)	8 × 60 s	9 × 60 s	10 × 60 s	11 × 60 s	12 × 60 s	13 × 60 s
GH (4 mm)	8 × 60 s	9 × 60 s	10 × 60 s	11 × 60 s	12 × 60 s	13 × 60 s
CG	No vibration training					

*GL = low amplitude group; GH = high amplitude group; CG = control group.

The axis of rotation of the dynamometer lever arm was aligned with the anatomical axis of the knee, as described in the Biodex 6000 test manual. Both the "dynamic ramping" (limb acceleration and deceleration) and "gravity correction" features were used in all tests to avoid previously documented problems, such as torque overshoot and gravity effects. The dynamometer was calibrated, using the protocol from the Biodex 6000 manual, at the beginning of each test session.

At each test velocity, the subject performed between 3 and 5 submaximal warm-up trials followed by 3 maximal warm-up trials. The test started 1 minute after the 6 warm-up trials had been completed. A recovery period of 90 seconds (4) between test velocities was used. After the warm-up trials, 3 maximal trials were performed for each test. The trial in each test that had the greatest peak torque was taken as the measure of maximal strength. Results were normalized, expressed relative to body mass ($\text{kgf}\cdot\text{N}\cdot\text{m}^{-1}$).

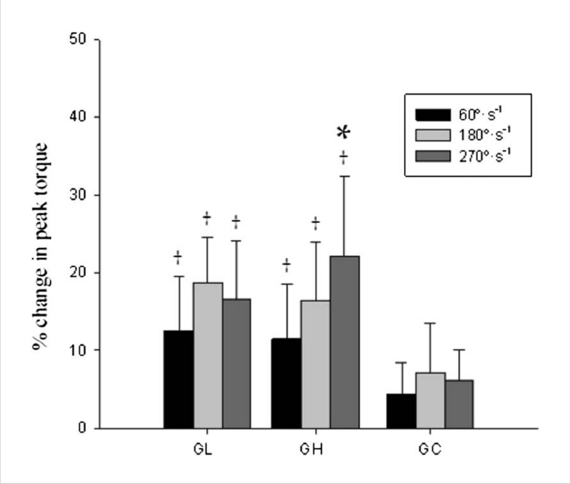

Figure 2. Percentage change in isokinetic peak torque for knee extensors at angular velocities of $60°\cdot s^{-1}$, $180°\cdot s^{-1}$, and $270°\cdot s^{-1}$. Dagger indicates statistically significant differences ($p \leq 0.05$) between pretest and posttest and asterisk indicates statistically significant differences ($p \leq 0.05$) with the control group. GL = low amplitude group; GH = high amplitude group; CG = control group.

Body Composition

Total and regional bone masses and fat and lean (body mass − [fat mass + bone mass]) masses were assessed by DEXA (XR-46; Norland, Corp., Fort Atkinson, WI, USA). The DEXA scanner was calibrated using a lumbar spine phantom as recommended by the manufacturer. Subjects were scanned in the supine position. Lean mass (in grams), fat mass (in grams), and total area (in square centimeters) were calculated from total and regional analysis of the whole-body scan. Lean mass of the limbs was assumed to be equivalent to the muscle mass. The test-retest reliability (ICC) for this device was very high ($R^2 = 0.999$; $p = 0.001$) in both cases.

Vibration Training Protocol

The vibration stimulus consisted of uniform vertical oscillations (Power Plate Next Generation; Power Plate North America, Northbrook, IL, USA). Subjects stood on the platform holding an isometric quarter squat position with the feet shoulder-width apart. After the familiarization week, subjects trained 2 days per week for 6 weeks (with the exception of the CG) using a vibrating incremental training program that began with 8 sets per session and increasing by 1 set weekly maintaining a series of parameters: vibration frequency (50 Hz), working time (60 seconds), and recovery time (60 seconds) constant for the 2 groups (GL = 2 mm and GH = 4 mm) (Table 2).

Table 3. Body composition variables (mean ± *SD*).*

	FM (%)	FFM (kg)	FM (kg)
GL			
Pre	21.3 ± 8.7	52.0 ± 8.0	14.8 ± 5.8
Post	21.4 ± 8.3	52.3 ± 8.0	14.9 ± 5.5
Δ	0.1 ± 2.0	0.3 ± 1.0†	0.1 ± 1.4
GH			
Pre	18.3 ± 6.8	54.7 ± 10.8	13.1 ± 5.9
Post	17.6 ± 7.7	55.6 ± 10.9‡	12.6 ± 6.9
Δ	−0.8 ± 1.7	0.9 ± 1.0	−0.5 ± 1.4
CG			
Pre	20.6 ± 7.6	49.4 ± 10.8	13.1 ± 4.1
Post	21.1 ± 7.3	49.7 ± 10.7	13.8 ± 3.9
Δ	0.6 ± 1.9	0.4 ± 0.7†	0.7 ± 1.4

*FM = fat mass; FFM = fat-free mass; GL = low amplitude group; GH = high amplitude group; CG = control group; Δ = difference.

†Statistically significant difference ($p \leq 0.05$) with the GH group.

‡Statistically significant difference ($p \leq 0.05$) between pretest and posttest.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

Table 4. Flying height in SJ and CMJ, and relative to body mass (mean ± *SD*).*

	SJ_h (cm)	CMJ_h (cm)	$SJ_{h/bm}$ ($cm \cdot kgf^{-1}$)	$CMJ_{h/bm}$ ($cm \cdot kgf^{-1}$)
GL				
Pre	29.0 ± 3.6	30.9 ± 5.4	0.4 ± 0.1	0.4 ± 0.1
Post	28.0 ± 5.0	31.5 ± 6.1	0.4 ± 0.1	0.4 ± 0.1
Δ	−1.0 ± 4.5	0.6 ± 2.7	0.0 ± 0.1	0.0 ± 0.7
GH				
Pre	28.7 ± 5.0	31.7 ± 5.3	0.4 ± 0.1	0.5 ± 0.1
Post	27.3 ± 4.7	31.5 ± 5.0	0.4 ± 0.1	0.5 ± 0.1
Δ	−1.4 ± 3.6	−0.2 ± 3.1	0.0 ± 0.1	0.0 ± 0.0
CG				
Pre	27.4 ± 3.9	30.3 ± 4.1	0.4 ± 0.1	0.5 ± 0.1
Post	27.5 ± 6.0	30.1 ± 4.5	0.4 ± 0.1	0.5 ± 0.1
Δ	0.1 ± 2.8	−0.2 ± 2.1	0.0 ± 0.1	0.0 ± 0.0

*SJ = squat jump; CMJ = countermovement jump; *h* = vertical height; bm = body mass; GL = low amplitude group; GH = high amplitude group; CG = control group; Δ = difference.

Statistical Analyses

Data were registered and stored using the spreadsheet Excel 2003 (Microsoft, Corp., Redmond, WA, USA). Statistical analysis of data was performed with SPSS 19.0 (SPSS 19.0, Chicago, IL, USA) in the Windows environment. A descriptive analysis was performed to detail and analyze the characteristics of the sample participating in the study.

For the inferential analysis, we performed the Kolmogorov-Smirnov test to establish the normality of sampling distribution and analysis of runs to observe the independence of observations. To determine the effect of independent variables on the dependent variable, repeated-measures analysis of variance (ANOVA) measurements were carried out for the entire sample. If there were statistically significant differences ($p \leq 0.05$) for the time factor, ANOVA was performed by repeated measurements of each group to differentiate between pretest and posttest. If there were statistically significant differences ($p \leq 0.05$) for time × group factor, ANOVA and Tukey post hoc test were performed, to see if there were significant differences between groups.

RESULTS

This study was designed to investigate the effects of 6 week of training with body vibrations modifying amplitude. Below the results are shown for isokinetic strength, vertical jump, and body composition variables.

Isokinetic Strength

Figure 2 presents relative gains in the peak torque between the pretest and posttest for each group: GL ($60° \cdot s^{-1}$ = 12.51 ± 14.13%, $180° \cdot s^{-1}$ = 18.73 ± 11.67%, $270° \cdot s^{-1}$ = 16.63 ± 14.90%), GH ($60° \cdot s^{-1}$ = 11.49 ± 13.98%, $180° \cdot s^{-1}$ = 16.50 ± 14.74%, $270° \cdot s^{-1}$ = 22.14 ± 20.34%), and CG ($60° \cdot s^{-1}$ = 4.38 ± 8.15%; $180° \cdot s^{-1}$ = 17.07 ± 12.69%, $270° \cdot s^{-1}$ = 6.24 ± 7.61%). We also observed significant differences when comparing the effect of time on the experimental groups with the CG. Significant differences were found between GH and CG ($p = 0.041$) at angular velocities of $270° \cdot s^{-1}$.

Body Composition

Table 3 shows the results of body composition variables for the experimental groups and the CG in the pretest and posttest and changes (mean ± *SD*). Statistically significant

Table 5. Peak mechanical power in SJ and CMJ, absolute and relative to body weight (mean ± *SD*).*

	SJ_{Pmax} (W)	CMJ_{Pmax} (W)	$SJ_{Pmax/bm}$ ($W \cdot kgf^{-1}$)	$CMJ_{Pmax/bm}$ ($W \cdot kgf^{-1}$)
GL				
Pre	3,011 ± 545	3,145 ± 654	46.8 ± 6.1	44.4 ± 7.8
	3,446 ± 735	3,216 ± 690	45.4 ± 9.2	45.4 ± 8.0
Post				
Δ	135.1 ± 339.5	71.6 ± 147.9	−1.4 ± 5.7	1.0 ± 2.2
GH				
Pre	3,518 ± 868	3,177 ± 736	48.9 ± 6.2	44.4 ± 6.2
	3,382 ± 847	3,155 ± 765	48.1 ± 15.4	43.7 ± 5.7
Post				
Δ	−136.2 ± 379.9	−21.1 ± 225.7	−0.8 ± 13.0	−0.7 ± 3.3
CG				
Pre	3,207 ± 743	2,928 ± 610	47.8 ± 6.2	43.9 ± 4.4
	3,373 ± 743	2,946 ± 609	52.2 ± 11.4	43.8 ± 3.9
Post				
Δ	165.9 ± 290.4	18.2 ± 107.9	4.4 ± 9.7	−0.1 ± 2.3

*SJ = squat jump; CMJ = countermovement jump; Pmax = maximum instantaneous power; bm = body weight; GL = low amplitude group; GH = high amplitude group; CG = control group; Δ = difference.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

differences were observed ($p \leq 0.05$) between pretest and posttest on the lean mass for GH ($p = 0.005$). Furthermore, these differences were significantly different than those observed in both the low amplitude and in the CG.

Vertical Jump Performance

Table 4 shows the results of the height of the SJ and the CMJ jumps, the results of the height of these vertical jumps relative to body mass for the experimental groups, and CG in the pretest and posttest and the changes (mean ± *SD*). After a repeated-measures ANOVA, no statistically significant change were found ($p \leq 0.05$) between pretest and posttest of any of the groups under study: SJ_h ($p = 0.112$), CMJ_h ($p = 0.646$), $SJ_h \cdot Bm^{-1}$ ($p = 0.473$), $CMJ_h \cdot Bm^{-1}$ ($p = 0.254$).

The results of peak mechanical power when performing a vertical jump (SJ and CMJ) and peak mechanical power of these vertical jumps on the weight of each participant can be seen in Table 5. By applying a repeated-measures ANOVA, no statistically significant changes were observed ($p \leq 0.05$) in peak power developed during the SJ ($p = 0.689$) and during the CMJ ($p = 0.542$) for any of the groups under a study of the pretest and posttest. There were no statistically significant changes ($p \leq 0.05$) in peak power comparative to body weight during the SJ ($p = 0.423$) and during the CMJ ($p = 0.833$) in the experimental groups and the CG between pretest and posttest.

Table 6 shows the maximum rate of force development (RFD) obtained when performing the vertical jumps (SJ and CMJ) with the experimental groups and the CG in the pretest and posttest and the difference (mean ± *SD*). No statistically significant differences between pretest and posttest in the SJ and CMJ were found for any of the groups under study nor were significant changes observed between groups for any vertical jumps studied.

Table 6. Maximum rate of force development in SJ and CMJ.*

	SJ_{RFDmax} ($N \cdot s^{-1}$)	CMJ_{RFDmax} ($N \cdot s^{-1}$)
GL		
Pre	799 ± 282	1,073 ± 498
Post	1,120 ± 458	1,261 ± 573
Δ	320.6 ± 345.7	188.4 ± 493.0
GH		
Pre	1,055 ± 506	1,243 ± 544
Post	1,316 ± 693	1,313 ± 562
Δ	161.1 ± 393.6	70.2 ± 733.0
CG		
Pre	936 ± 349	1,197 ± 365
Post	1,116.0 ± 343.0	1,260.0 ± 543.0
Δ	179.8 ± 375.6	62.7 ± 486.8

*SJ = squat jump; CMJ = countermovement jump; RFDmax = ratio of maximum development of strength; GL = low amplitude group; GH = high amplitude group; CG = control group; Δ = difference.

DISCUSSION

The aim of this study was to compare the effect of 6 weeks of training with body mechanical vibration on the strength and power of the lower limb, and changes in body composition, varying the amplitude of vibration. An important finding from this study was the increased strength of the knee extensor muscles for the groups that were subjected to vibration. Furthermore, there was significant gain in the total lean mass in the group that underwent high amplitude vibration training. On the other hand, no significant changes in vertical jumping performance were found.

Regarding body composition, we found no statistically significant difference in the change in fat mass after vibration training. However, lean mass increased significantly in the group that trained with high amplitude (GH) between the pretest and posttest, without significant changes in the experimental group that trained low amplitude vibration (GL) or the control group (CG). In addition, these differences were statistically different between GH with the GL and CG groups. There are several studies suggesting that muscle hypertrophy may be because of a hormonal response induced by vibration. The exercise on a vibratory device causes endocrine reactions that can be understood as mediating signals for the training effect (46). These hormonal responses manifest themselves as an increase in testosterone (3), growth hormone (3,5,25), increased catecholamines (18), decreased cortisol (3,25), and increases in protein synthesis (47). The literature shows that there is a greater increase in the production of growth hormone with exposure to WBV (3). These endocrine effects could be one explanation for the increase in lean mass after vibration training. Comparing our study with that by Roelants et al. (37), similar results can be observed. The authors assessed the body composition of 48 young women after 24 weeks of vibration training (35–40 Hz and 2.5–5.0 mm), obtaining a significant increase of 2.2% lean mass between pretest and posttest (37). In our research, we observed an increase of 1.6% in the GH group with only 6 weeks of training. Lamont et al. (26) found similar results for lean body mass changes (compared with a control condition) as assessed by DEXA applied for a similar duration (6 weeks) in conjunction with a squat training program. In the study of Roelants et al. (37), exposure to vibration was longer; however, relative smaller increases were observed in lean mass when compared with this study. This could be because of the difference in the sample used because Roelants et al. (37) used only young women, whereas this study used a greater proportion of young men, who produce higher levels of testosterone and thus greater increases in lean mass.

The GH group had greater increases in isokinetic strength, especially at high velocities ($270° \cdot s^{-1}$). One might suggest, although there is insufficient scientific evidence for

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

this, that vibration training at high amplitude can affect the hypertrophy of type II muscle fibers. Eckhardt et al. (16) found that vibration training increased lactate significantly compared with exercise performed without vibration. They suggested this could be because of increased recruitment of type II glycolytic fibers during WBV, although to confirm this would require muscle biopsies. All these data create a new line of research because if vibration training can be used to maintain or increase the amount of muscle fibers, it is possible that it could be implemented in sports in which the maximum force or power qualities are relevant to improving performance.

With regard to fat mass, there were no statistically significant changes, in absolute or relative terms, after the 6-week vibration training. There were also no significant differences between the different groups. These results might be explained by Hazell et al. (21), who claim that the cardiovascular stress produced by exposure to WBV is moderate, and energy requirements could be compared with walking at a moderate intensity (10,36). In addition, the total duration of WBV in the longest session in this study was 13 minutes, being a period too short to produce changes in body fat. It seems that the stimulus caused by WBV is insufficient to produce a high metabolic burden leading to a reduction in fat mass. Rittweger (35) states that a person weighing 70 kg while performing WBV would consume oxygen approximately 20 L h^{-1}, assuming an energy equivalent of 20.9 $kJ \cdot L^{-1}$ of oxygen and an caloric equivalent of 39 $kJ \cdot g^{-1}$ of fat, this would imply a weight loss of only 10 g of fat per hour with this exercise. Thus, it is reasonable to conclude that this type of exercise produces no loss of fat mass. It is possible that the duration of training sessions in this study were too short to cause changes in body fat. This study provides results similar to those published by Roelants et al. (37), who assessed the body composition of 48 women with an age and activity level similar to those of the participants in this study. After 24 weeks of WBV, 3 sessions per week, with a frequency, amplitude, and time of exposure to vibration similar to those in this study, there were no changes in body fat (37). We may suggest that the use of vibration training within a fitness training program should be implemented with other aerobic exercises to reduce body fat mass.

After 6 weeks of vibration training, there were significant gains in isokinetic strength of knee extensor muscles in both experimental groups between pretest and posttest. These significant improvements in isokinetic strength were developed at different angular velocities ($60^\circ \cdot s^{-1}$, $180^\circ \cdot s^{-1}$, and $270^\circ \cdot s^{-1}$). The group that showed greater gains in strength was the one that used the high amplitude, and specifically when strength was evaluated at a high velocity ($270^\circ \cdot s^{-1}$). In addition, the only statistically significant difference when compared with the CG was found at this velocity. This finding could be because of the gains in the lean mass produced in the GH group. Our research shows that the GH group significantly improves strength when compared with the CG, whereas the GL group did not; therefore, we may assert that the increased strength is induced by the magnitude of the amplitude of the vibration. This high amplitude might produce neuromuscular adaptations resulting in enhanced neuromuscular activation (14,33). There is now enough scientific evidence to show that when the vibratory stimulus acts directly on muscle or tendon, the tonic vibration reflex produces the activation. On the other hand, some working groups (6,38) suggest that when an individual undergoes training on a WBV platform, it acts on a gravitational force that induces the muscles to generate a discharge to maintain the balance. This could explain the strength gains observed in our study. These results are consistent with those published by other authors, who say that WBV increases the dynamic strength of the muscles of the lower extremities (14,22,27,37,43). Mahieu et al. (27) studied the effect of 6 weeks of WBV in young skiers; isokinetic strength in knee extensors improved significantly when compared with baseline. Similar results were found by Delecluse et al. (14), who, after subjecting 74 untrained young women to 12 weeks, significantly improved WBV isokinetic strength of the lower extremities. In a recent review about the effects of vibration on muscle strength, Marin et al. (31) described that greater strength gains are produced with high amplitudes. However, to our knowledge, there is no work that has studied this in an experimental way. A possible explanation for the higher gains found in the groups trained at a high amplitude in this study is that, when working with high vibration amplitudes, the acceleration forces to which the human body is exposed on the platform has increased. This increases the tension generated by muscles, which eventually causes a greater increase in strength. On the other hand, several authors have suggested that WBV training specifically activates the fast twitch fibers (14,36), which are responsible for explosive movements and produce higher values of strength. This would explain why the greatest increases in strength observed in our study occur when the force is generated at high speed ($270^\circ \cdot s^{-1}$). Thus, it seems appropriate to use such platforms, ranging on the vertical axis, and allow working with high frequency and amplitude with sports that require both high levels of maximum force and a large explosive strength in their athletic modality.

The mechanical power and RFD have been studied on the vibration training, being assessed through vertical jump, such as SJ and CMJ (30). In this study, there were no statistically significant differences in any of the variables studied for any of the jumps performed (SJ and CMJ) between pretest and posttest. Similar results were found by de Ruiter et al. (12); they assessed the effects of 11 weeks of WBV in semi-static squat on jump height without obtaining significant improvements. In contrast, other studies that assessed long-term effects of WBV on vertical jump performance, both the SJ (9,17) and the CMJ (13,14,17,37,39), showed an improvement in the jump performance. The differences in

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

the results obtained by this investigation and de Ruiter et al. (12) could be because of the fact that exercise protocols performed on the platform were different. In this study, as in the de Ruiter et al. (12) study, participants performed a semi-squat statically, unlike other studies that involved doing different exercises on the platform dynamically. One possible explanation could be that assuming that WBV causes increased muscle activation, the application of vibration occurs through the legs and these factors increase the activation of agonist and antagonist muscles (coactivation) (40), raising questions about the benefits of muscle coordination in dynamic actions, such as jumping (17). Another explanation may be because of prolonged exposure to vibrations has been shown to have detrimental effects on the soft tissues, including muscle fatigue (1), reductions in motor unit firing rates and muscle contraction force (32), decreases in nerve conduction velocity, and attenuated perception (15). Thus, it could be hypothesized that for an improvement through WBV, the long-term effects on the jump that requires some intermuscular coordination, athletes should not use static exercise protocols on the vibration platform, using them only for participants without experience because it is simple to learn.

Based on the foregoing information, we propose a number of considerations to be taken into account in future research, for example, checks to determine if there are gains of lean mass in other sectors of the population, using the same protocol as in this study. Also, one might compare the effects of WBV has on body composition, strength, and power comparing 2 vs. 3 days. Finally, it would be very interesting to compare the static exercise vs. dynamic exercise on the vibration platform to ascertain if the long-term effects that involve a loss of coordination in tasks such as jumping, when carrying out a static-only exercise on the platform.

PRACTICAL APPLICATIONS

The current investigation indicates that using an incremental vibratory training, 2 days per week during 6 weeks of high amplitude WBV may increase isokinetic strength and total lean mass. We would recommend this protocol for recreationally active subjects to accomplish the greatest effects for physical fitness and sport performance. Thus, we consider high amplitude WBV training as a useful tool for personal trainers and physical education teachers when looking for improved fitness and a full workout. This has been shown in this study where it is evident that 6 weeks of training, using a vertical vibration platform at 50 Hz and peak-to-peak displacement of 4 mm, produces muscle hypertrophy in active subjects. However, more studies would be needed to establish which training protocol is most appropriate based on the individual characteristics of other population.

ACKNOWLEDGMENTS

The researchers would like to express gratitude to the subjects in this investigation who made this study possible. No funding was received for this article. The results from this study do not constitute endorsement of the products by the authors or by the National Strength and Conditioning Association.

REFERENCES

1. Adamo, DE, Martin, BJ, and Johnson, PW. Vibration-induced muscle fatigue, a possible contribution to musculoskeletal injury. *Eur J Appl Physiol* 88: 134–140, 2002.
2. Armstrong, T and Bull, F. Development of the World Health Organization Global Physical Activity Questionnaire (GPAQ). *J Public Health* 14: 66–70, 2006.
3. Bosco, C, Iacovelli, M, Tsarpela, O, Cardinale, M, Bonifazi, M, Tihanyi, J, Viru, M, De Lorenzo, A, and Viru, A. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol* 81: 449–454, 2000.
4. Brown, LE. *Isokinetics in Human Performance.* Champaign, IL: Human Kinetics, 2000.
5. Cardinale, M and Erskine, JA. Vibration training in elite sport: Effective training solution or just another fad? *Int J Sports Physiol Perform* 3: 232–239, 2008.
6. Cardinale, M and Lim, J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 17: 621–624, 2003.
7. Cardinale, M and Wakeling, J. Whole body vibration exercise: Are vibrations good for you? *Br J Sports Med* 39: 585–589; discussion 589, 2005.
8. Caserotti, P, Aagaard, P, and Puggaard, L. Changes in power and force generation during coupled eccentric-concentric versus concentric muscle contraction with training and aging. *Eur J Appl Physiol* 103: 151–161, 2008.
9. Colson, SS, Pensini, M, Espinosa, J, Garrandes, F, and Legros, P. Whole-body vibration training effects on the physical performance of basketball players. *J Strength Cond Res* 24: 999–1006, 2010.
10. Da Silva, ME, Fernandez, JM, Castillo, E, Nunez, VM, Vaamonde, DM, Poblador, MS, and Lancho, JL. Influence of vibration training on energy expenditure in active men. *J Strength Cond Res* 21: 470–475, 2007.
11. De Gail, P, Lance, JW, and Neilson, PD. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J Neurol Neurosurg Psychiatry* 29: 1–11, 1966.
12. de Ruiter, CJ, Van Raak, SM, Schilperoort, JV, Hollander, AP, and de Haan, A. The effects of 11 weeks whole body vibration training on jump height, contractile properties and activation of human knee extensors. *Eur J Appl Physiol* 90: 595–600, 2003.
13. Delecluse, C, Roelants, M, Diels, R, Koninckx, E, and Verschueren, S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *Int J Sports Med* 26: 662–668, 2005.
14. Delecluse, C, Roelants, M, and Verschueren, S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 35: 1033–1041, 2003.
15. Dupuis, H and Jansen, G. Immediate effects of vibration transmitted to the hand. In: *Man Under Vibration: Suffering and Protection, Proceedings of the International CISM-IFToMM-WHO Symposium.* G Biachi, K Frolov, and A Olędzki, eds. Udine, Italy: Elsevier, 1981. pp. 76–86.
16. Eckhardt, H, Wollny, R, Muller, H, Bartsch, P, and Friedmann-Bette, B. Enhanced myofiber recruitment during exhaustive squatting performed as whole-body vibration exercise. *J Strength Cond Res* 25: 1120–1125, 2011.
17. Fernandez-Rio, J, Terrados, N, Fernandez-Garcia, B, and Suman, OE. Effects of vibration training on force production in female basketball players. *J Strength Cond Res* 24: 1373–1380, 2010.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.

18. Goto, K and Takamatsu, K. Hormone and lipolytic responses to whole body vibration in young men. *Jpn J Physiol* 55: 279–284, 2005.
19. Hagbarth, KE. The effect of muscle vibration in normal man and it patients with motor disease. In: *New Developments in Electromyography and Clinical Neurophysiology.* JE Desmedt, ed. Basel, Switzerland: Karger, 1973. pp. 428–443.
20. Harrison, AJ and Bourke, G. The effect of resisted sprint training on speed and strength performance in male rugby players. *J Strength Cond Res* 23: 275–283, 2009.
21. Hazell, TJ, Thomas, GW, Deguire, JR, and Lemon, PW. Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise. *Eur J Appl Physiol* 104: 903–908, 2008.
22. Jacobs, PL and Burns, P. Acute enhancement of lower-extremity dynamic strength and flexibility with whole-body vibration. *J Strength Cond Res* 23: 51–57, 2009.
23. Kibele, A. Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study. *J Appl Biomech* 14: 105–117, 1998.
24. Krol, P, Piecha, M, Slomka, K, Sobota, G, Polak, A, and Juras, G. The effect of whole-body vibration frequency and amplitude on the myoelectric activity of vastus medialis and vastus lateralis. *J Sports Sci Med* 10: 169–174, 2011.
25. Kvorning, T, Bagger, M, Caserotti, P, and Madsen, K. Effects of vibration and resistance training on neuromuscular and hormonal measures. *Eur J Appl Physiol* 96: 615–625, 2006.
26. Lamont, HS, Cramer, JT, Bemben, DA, Shehab, RL, Anderson, MA, and Bemben, MG. Effects of a 6-week periodized squat training with or without whole-body vibration upon short-term adaptations in squat strength and body composition. *J Strength Cond Res* 25: 1839–1848, 2011.
27. Mahieu, NN, Witvrouw, E, Van de Voorde, D, Michilsens, D, Arbyn, V, and Van den Broecke, W. Improving strength and postural control in young skiers: Whole-body vibration versus equivalent resistance training. *J Athl Train* 41: 286–293, 2006.
28. Marin, PJ, Herrero, AJ, Garcia-Lopez, D, Rhea, MR, Lopez-Chicharro, J, Gonzalez-Gallego, J, and Garatachea, N. Acute effects of whole-body vibration on neuromuscular responses in older individuals: Implications for prescription of vibratory stimulation. *J Strength Cond Res* 26: 232–239, 2012.
29. Marin, PJ, Herrero, AJ, Sainz, N, Rhea, MR, and Garcia-Lopez, D. Effects of different magnitudes of whole-body vibration on arm muscular performance. *J Strength Cond Res* 24: 2506–2511, 2010.
30. Marin, PJ and Rhea, MR. Effects of vibration training on muscle power: A meta-analysis. *J Strength Cond Res* 24: 871–878, 2010.
31. Marin, PJ and Rhea, MR. Effects of vibration training on muscle strength: A meta-analysis. *J Strength Cond Res* 24: 548–556, 2010.
32. Necking, LE, Lundborg, G, and Friden, J. Hand muscle weakness in long-term vibration exposure. *J Hand Surg Br* 27: 520–525, 2002.
33. Nordlund, MM and Thorstensson, A. Strength training effects of whole-body vibration? *Scand J Med Sci Sports* 17: 12–17, 2007.
34. Rehn, B, Lidstrom, J, Skoglund, J, and Lindstrom, B. Effects on leg muscular performance from whole-body vibration exercise: A systematic review. *Scand J Med Sci Sports* 17: 2–11, 2007.
35. Rittweger, J. Vibration as an exercise modality: How it may work, and what its potential might be. *Eur J Appl Physiol* 108: 877–904, 2010.
36. Rittweger, J, Beller, G, and Felsenberg, D. Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin Physiol* 20: 134–142, 2000.
37. Roelants, M, Delecluse, C, Goris, M, and Verschueren, S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med* 25: 1–5, 2004.
38. Roelants, M, Verschueren, SM, Delecluse, C, Levin, O, and Stijnen, V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *J Strength Cond Res* 20: 124–129, 2006.
39. Ronnestad, BR. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J Strength Cond Res* 18: 839–845, 2004.
40. Rothmuller, C and Cafarelli, E. Effect of vibration on antagonist muscle coactivation during progressive fatigue in humans. *J Physiol* 485(pt 3): 857–864, 1995.
41. Rubin, C, Xu, G, and Judex, S. The anabolic activity of bone tissue, suppressed by disuse, is normalized by brief exposure to extremely low-magnitude mechanical stimuli. *FASEB J* 15: 2225–2229, 2001.
42. Russo, CR, Lauretani, F, Bandinelli, S, Bartali, B, Cavazzini, C, Guralnik, JM, and Ferrucci, L. High-frequency vibration training increases muscle power in postmenopausal women. *Arch Phys Med Rehab* 84: 1854–1857, 2003.
43. Spiliopoulou, SI, Amiridis, IG, Tsigganos, G, Economides, D, and Kellis, E. Vibration effects on static balance and strength. *Int J Sports Med* 31: 610–616, 2010.
44. Turner, AP, Sanderson, MF, and Attwood, LA. The acute effect of different frequencies of whole-body vibration on countermovement jump performance. *J Strength Cond Res* 25: 1592–1597, 2011.
45. Verschueren, SM, Roelants, M, Delecluse, C, Swinnen, S, Vanderschueren, D, and Boonen, S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res* 19: 352–359, 2004.
46. Viru, A. Plasma hormones and physical exercise. *Int J Sports Med* 13: 201–209, 1992.
47. Wilcock, IM, Whatman, C, Harris, N, and Keogh, JW. Vibration training: Could it enhance the strength, power, or speed of athletes? *J Strength Cond Res* 23: 593–603, 2009.
48. Wilson, GJ, Lyttle, AD, Ostrowski, KJ, and Murphy, AJ. Assessing dynamic performance: A comparison of rate of force development tests. *J Strength Cond Res* 9: 176–181, 1995.

Copyright © National Strength and Conditioning Association Unauthorized reproduction of this article is prohibited.