J. Phys. Ther. Sci. 35: 414–420, 2023

The Journal of Physical Therapy Science

Original Article

Effects of short-term whole-body vibration training on muscle strength, balance performance, and body composition

Itaru Hibino, RPT, PhD[1)*], Chinatsu Takeda, RPT[2)], Kouta Takahashi, RPT[3)], Tomoya Aoyama, RPT[4)]

[1)] *Department of Physical Therapy, Faculty of Rehabilitation Sciences, Nagoya Gakuin University: 3-1-17 Taiho, Atsuta-ku, Nagoya, Aichi 456-0062, Japan*
[2)] *Rehabilitation Center, Tokai Memorial Hospital, Japan*
[3)] *Department of Rehabilitation, Handa Central Hospital, Japan*
[4)] *Department of Rehabilitation, Echizen-cho National Health Insurance Ota Hospital, Japan*

Abstract. [Purpose] This study aimed to evaluate the changes in lower-extremity muscle strength, balance performance, and body composition. [Participants and Methods] In this study, 21 healthy university students who underwent short-term whole-body vibration training without previous whole-body vibration training participated. The study design was randomized between-groups design. Participants were randomly assigned to one of the three groups; control, training, and whole-body vibration training. All participants completed a six-week training protocol comprising a first two-week training period, two-week rest period following the first training period, and second two-week training period. Over four periods, the participants' lower-extremity muscle strength, balance performance, and body composition were evaluated. Separate three-by-four repeated-measure analyses of variance, with three exercise mode groups and four periods, were initially used to analyze the primary outcome variables; lower-extremity muscle strength, balance performance, and body composition. [Results] In the three groups, lower-extremity muscle strength, static and dynamic balance performances, and body composition showed no changes during all periods. [Conclusion] This study provides a better insight on the responsiveness of short-term whole-body vibration training and will help determine whole-body vibration programs in revalidation and training.

Key words: Whole-body vibration training, Healthy university students

(This article was submitted Jan. 18, 2023, and was accepted Feb. 23, 2023)

INTRODUCTION

Whole-body vibration (WBV) has gained wide popularity in human fitness and training centers as a safe training method. It was hypothesized that low-amplitude high frequency stimulation of the whole-body positively affects many risk factors of falling and related fractures by simultaneously improving muscle strength, body balance, and the mechanical competence of bones. Thus, WBV training may be an alternative to conventional resistance training. This alternative mode of exercise entails the performance of static or dynamic squatting on oscillating platforms that produce vibrations.

It was reported that WBV training is an effective neuromuscular strength training method for the improvement of athletic performance[1, 2)]. Compared to conventional resistance training, long-term WBV training was reported to show identical gains in muscle strength and jump performance in untrained young males and females[3–7)]. The long-term effects of WBV training appear to be diverse. A previous study reported that a single vibration bout resulted in significant temporary increase in the muscle strength of the lower extremities[8)]; in contrast, other studies found no significant changes[9)]. Some studies that investigated the effect of WBV training on balance are limited and are focused on trained athletes and untrained individuals[10–12)].

*Corresponding author. Itaru Hibino (E-mail: hibino@ngu.ac.jp)

A study that investigated the effect of WBV at two amplitudes on balance, joint position sense, and cutaneous sensation found that none of the amplitudes of WBV affected joint position sense or static balance, but WBV at two amplitudes was found to reduce cutaneous sensation[13)]. Not much is known about the effects of WBV training on static or dynamic balance.

A previous study reported minor increase in the total fat-free mass of young females after 24 weeks of WBV training, with weight measurements performed underwater[14)]. Another previous study reported significant increase in the fat-free mass of children with Down syndrome after 12 weeks of WBV training[15)]. It was reported that WBV training may not be an effective alternative to traditional training in terms of body composition and aerobic capacity[16)].

The immediate and long-term effects of WBV training on lower limb muscle strength, balance ability, and body composition have been reported in previous studies, but there are only a few reports on the short-term and sustained effects of WBV training.

The aim of this study was to investigate changes in lower-extremity muscle strength, balance performance, and body composition in healthy university students who underwent WBV training.

PARTICIPANTS AND METHODS

Twenty-one healthy university students who had not previously undergone WBV training (11 males and 10 females; mean age=20.9 ± 0.7 years, mean body weight=60.6 ± 8.7 kg, and mean height=167.2 ± 9.5 cm) volunteered to participate in this study. The participants had no history of injury in the three months prior to testing. They also had no lower-extremity pathology. The participants were provided extensive information regarding the experiment procedures and the possible risks and benefits of the study, and written consent was obtained. This study was approved by Nagoya Gakuin University medical research ethics committee (study approval number: 2018-2).

Further, the participants were asked to avoid any additional training throughout the study period and were randomly assigned to one of the following three groups: control group (CON; three males and four females; mean age=21.3 ± 0.8 years, mean height=168.9 ± 11.4 cm, mean body weight=61.7 ± 11.6 kg, mean body mass index [BMI]=21.5 ± 2.4 kg/m^2), training group (TRA; four males and three females; mean age=20.6 ± 0.5 years, mean height=166.4 ± 9.7 cm, mean body weight=58.8 ± 8.7 kg, mean BMI=20.6 ± 0.5 kg/m^2), or WBV training group (WBV; four males and three females; mean age=20.7 ± 0.5 years, mean height=166.4 ± 8.6 cm, mean body weight=61.4 ± 6.0 kg, mean BMI=20.7 ± 0.5 kg/m^2).

The design of this study was randomized between-groups design. The participants were evaluated at four different periods, namely the pre-training period (Pre), after the first two-week training period or post-training 1 (Post 1), after the two-week rest period following the first training period or post-no training 2 (Post 2), and after the second two-week training period or post-training 3 (Post 3). Measurements for the study outcomes were taken in the following order: lower-extremity muscle strength, balance performance, and body composition analysis.

All the participants completed a six-week training protocol consisting of a first training period of two weeks, a two-week rest period following the first training period, and a second training period of two weeks. During the first and second training periods, exercises were performed three days per week. The participants first performed low-intensity warm-up exercises, such as stretching, for five minutes. Isometric training was then performed in the following three positions: half squat, right lateral squat, and left lateral squat. The training time for each exercise was set at 30 seconds per set, and three sets of each exercise were performed. To ensure safety during training, a one-minute rest period was allowed between sets. Participants in the TRA group trained on the floor, whereas participants in the WBV group trained on a WBV device (Power Plate; Protea Japan Co. Ltd., Tokyo, Japan), and the frequency of vibration was 35 Hz. Participants in the CON group were encouraged to maintain their physical activity levels and refrain from beginning a new training program.

The peak torque of the knee strength of participants was measured using isokinetic equipment (Biodex system 3; Biodex Medical System Inc., New York, NY, USA). Biodex provides constant speed and resistance while a joint is being moved within a predetermined range, and it draws a curve showing the muscle torque throughout the movement. The highest point on the curve indicates the peak torque. Participants first performed low-intensity warm-up exercises, such as stretching, for five minutes. They then sat in the Biodex chair and leaned backward. The trunk, thighs, and ankles were immobilized with belts, and the knee was fixed to the torque meter. Muscle torque was measured at angular velocities of 60 deg/s, 180 deg/s, and 240 deg/s for five repetitions at each speed, and the maximal peak torque value was computed across repeated measurements with each leg. Furthermore, measurements were taken by applying the specified knee joint range from 0° to 90°. Participants were encouraged to apply their maximum muscle strength.

Body balance performance tests can be divided into static body balance function tests and dynamic body balance evaluations. In the static balance performance test, the center of pressure (COP) during single-leg standing with closed eyes was measured. COP was measured using a gravicorder (Gravicorder G-7100; Anima Corp., Tokyo, Japan). During testing, participants were instructed to stand as still as possible on one leg, raising the other leg by slight knee flexion and having their arms folded across their chests. During the single-leg standing, participants were instructed to stand as still as possible while focusing on a visual target placed 2 m in front of them. Gravicorder data (the path length and the rectangular area) were collected after establishing stable single-leg standing. In the dynamic balance performance test, participants were also instructed to stand as still as possible on one leg, raising the other leg by slight knee flexion and having their arms folded across their chests. Using the cross-test method, the shift range of voluntary maximum COP in the anterior-posterior and right-left directions was measured during single-leg standing with open eyes. In each of the two performance tests, trials lasted for 30 seconds and were conducted on each leg.

Body composition, including body weight, BMI, soft lean mass (SLM), and body fat mass (BFM), was estimated by bioelectrical impedance analysis using InBody430 (Inbody Japan, Tokyo, Japan).

The descriptive data (i.e., age, height, body weight, and BMI) of each group were analyzed using one-way analysis of variance. Separate three-by-four (protocol×time) repeated-measures analysis of variance, with three groups of exercise mode (CON group, TRA group, and WBV group) and four periods (Pre, Post 1, Post 2, and Post 3), was initially used to analyze the main outcome variables, which are lower-extremity muscle strength, balance performance, and body composition. Data were analyzed using SPSS (version 29; IBM, Armonk, NY, USA). The statistical significance level was set at 0.05.

RESULTS

The physical characteristics of the study participants are presented in Table 1. No significant pre-training differences in age, height, body weight, or BMI were observed between the three groups.

The results of the lower-extremity muscle strength evaluation are presented in Tables 2, 3, and 4. We observed no significant differences in the four periods within or between the three groups ($p>0.05$). No intervention effects of isokinetic knee extension or flexion muscle strength at 60°/s, 180°/s, and 240°/s were observed.

The results of the static balance performance test are presented in Table 5. We observed no significant differences in the four periods within or between the three groups ($p>0.05$).

The results of the dynamic balance performance test are shown in Table 6. Three-by-four repeated-measures analysis of variance revealed no significant main effects or interactions between the groups. Further, no time, intervention, or interaction effects were observed in the static and dynamic balance performance measurements, indicating similar responses in all the groups over time.

The mean and standard deviation values of SLM and BFM are presented in Table 7. Three-by-four repeated-measures analysis of variance revealed no significant main effects or interactions of SLM or BFM. No significant changes in SLM or BFM were observed between the groups.

Table 1. Participant characteristics of the three groups

Characteristic	Group		
	CON (n=7)	TRA (n=7)	WBV (n=7)
Age, years	21.3 ± 0.76	20.6 ± 0.53	20.7 ± 0.49
Height, cm	168.9 ± 11.44	166.4 ± 9.66	166.4 ± 8.62
Body weight, kg	61.7 ± 11.59	58.8 ± 8.72	61.4 ± 5.96
BMI, kg/m^2	21.5 ± 2.43	20.6 ± 0.53	20.7 ± 0.49

Values are expressed as mean ± standard deviation.
BMI: body mass index; CON: control group; TRA: training group; WBV: whole-body vibration group.

Table 2. Maximal peak torque of the knee extensors and flexors of each leg measured at 60 deg/s on isokinetic equipment

Group	Movement	Leg	Pre	Post 1	Post 2	Post 3
CON	Extension	Right	129.4 ± 58.74	139.9 ± 40.83	137.4 ± 45.68	143.3 ± 50.38
		Left	120.0 ± 44.35	130.5 ± 43.14	144.8 ± 48.98	132.0 ± 40.72
	Flexion	Right	64.3 ± 31.93	72.3 ± 29.54	74.6 ± 30.41	74.1 ± 32.41
		Left	57.4 ± 24.34	59.9 ± 21.48	66.6 ± 33.04	66.2 ± 27.81
TRA	Extension	Right	129.5 ± 27.81	136.2 ± 37.55	119.7 ± 24.13	122.5 ± 15.90
		Left	116.6 ± 43.02	130.9 ± 37.74	118.8 ± 31.24	130.0 ± 33.41
	Flexion	Right	67.4 ± 23.25	67.3 ± 24.41	67.8 ± 23.36	64.8 ± 22.83
		Left	58.2 ± 18.01	64.8 ± 22.31	58.7 ± 17.47	62.2 ± 16.82
WBV	Extension	Right	129.5 ± 45.99	142.0 ± 47.63	145.8 ± 53.61	165.9 ± 36.01
		Left	129.8 ± 48.69	143.4 ± 47.12	131.8 ± 52.37	137.0 ± 39.35
	Flexion	Right	62.5 ± 18.71	75.9 ± 26.05	76.9 ± 27.55	72.0 ± 24.11
		Left	62.4 ± 19.92	70.6 ± 18.70	70.5 ± 21.53	72.7 ± 18.60

Values are expressed as mean ± standard deviation.
Values of maximal peak torque are presented in N•m.
CON: control group; TRA: training group; WBV: whole-body vibration group.

Table 3. Maximal peak torque of the knee extensors and flexors of each leg measured at 180 deg/s on isokinetic equipment

Group	Movement	Leg	Pre	Post 1	Post 2	Post 3
CON	Extension	Right	81.5 ± 44.22	89.7 ± 36.98	89.3 ± 34.44	96.6 ± 33.58
		Left	76.3 ± 41.48	83.6 ± 33.33	96.5 ± 34.80	95.3 ± 34.14
	Flexion	Right	47.5 ± 27.68	52.3 ± 26.66	51.3 ± 27.74	55.2 ± 28.28
		Left	44.7 ± 22.37	50.2 ± 25.99	52.2 ± 25.15	55.9 ± 26.11
TRA	Extension	Right	86.4 ± 24.29	101.8 ± 30.96	95.3 ± 23.42	97.5 ± 19.24
		Left	80.8 ± 26.54	100.7 ± 29.50	88.9 ± 24.67	97.8 ± 20.40
	Flexion	Right	47.0 ± 17.78	53.9 ± 23.49	56.9 ± 22.73	55.1 ± 24.99
		Left	45.3 ± 15.60	53.4 ± 17.41	48.2 ± 17.92	53.5 ± 17.17
WBV	Extension	Right	94.5 ± 37.37	97.0 ± 32.82	99.6 ± 34.87	98.2 ± 23.89
		Left	91.7 ± 32.72	97.7 ± 29.86	99.5 ± 31.32	97.6 ± 26.27
	Flexion	Right	52.0 ± 21.33	59.2 ± 25.15	60.1 ± 25.02	60.8 ± 17.79
		Left	54.0 ± 17.59	56.5 ± 21.21	58.5 ± 20.28	57.6 ± 18.04

Values are expressed as mean ± standard deviation.
Values of maximal peak torque are presented in N•m.
CON: control group; TRA: training group; WBV: whole-body vibration group.

Table 4. Maximal peak torque of the knee extensors and flexors of each leg measured at 240 deg/s on isokinetic equipment

Group	Movement	Leg	Pre	Post 1	Post 2	Post 3
CON	Extension	Right	69.3 ± 39.89	81.4 ± 33.72	78.7 ± 31.30	83.9 ± 33.01
		Left	64.8 ± 35.50	77.1 ± 29.23	80.4 ± 31.45	79.6 ± 24.87
	Flexion	Right	47.1 ± 27.17	59.3 ± 21.26	48.5 ± 24.33	25.1 ± 24.35
		Left	43.0 ± 19.94	49.3 ± 22.95	49.7 ± 21.41	54.3 ± 23.30
TRA	Extension	Right	81.5 ± 26.51	94.7 ± 28.72	87.7 ± 25.21	88.1 ± 20.76
		Left	76.4 ± 28.92	86.0 ± 22.34	82.3 ± 29.47	82.0 ± 19.44
	Flexion	Right	45.1 ± 17.11	57.5 ± 22.17	53.0 ± 23.00	52.2 ± 23.10
		Left	47.2 ± 13.09	52.0 ± 14.06	59.6 ± 17.70	47.8 ± 17.49
WBV	Extension	Right	80.4 ± 25.48	85.1 ± 26.30	91.0 ± 31.87	86.7 ± 22.28
		Left	77.0 ± 31.65	88.4 ± 27.66	86.8 ± 30.76	90.4 ± 25.27
	Flexion	Right	50.1 ± 20.51	55.9 ± 22.40	57.0 ± 23.51	55.6 ± 18.37
		Left	52.1 ± 17.90	55.8 ± 20.86	56.4 ± 20.50	55.9 ± 16.63

Values are expressed as mean ± standard deviation.
Values of maximal peak torque are presented in N•m.
CON: control group; TRA: training group; WBV: whole-body vibration group.

Table 5. Static balance performance parameters during single-leg standing with closed eyes

Group	Leg	Parameter	Pre	Post 1	Post 2	Post 3
CON	Right	PL	98.5 ± 20.68	107.1 ± 34.64	101.2 ± 31.64	99.7 ± 17.86
		RA	31.3 ± 12,75	39.5 ± 25.24	30.1 ± 12.83	28.0 ± 11.43
	Left	PL	87.8 ± 24.62	109.0 ± 46.58	89.4 ± 22.45	90.7 ± 21.13
		RA	27.9 ± 11.97	27.7 ± 15.30	28.5 ± 10.38	25.7 ± 7.86
TRA	Right	PL	124.8 ± 42.34	120.4 ± 37.52	141.3 ± 55.30	148.4 ± 44.52
		RA	48.1 ± 26.56	33.8 ± 10.74	44.7 ± 28.84	48.6 ± 21.55
	Left	PL	118.5 ± 21.52	138.4 ± 42.81	133.1 ± 44.41	140.6 ± 42.09
		RA	42.1 ± 15.37	39.2 ± 22.46	40.1 ± 22.49	37.2 ± 14.95
WBV	Right	PL	91.6 ± 48.24	98.6 ± 42.77	95.8 ± 39.31	88.1 ± 32.77
		RA	27.5 ± 14.38	29.2 ± 12.04	28.1 ± 20.23	27.1 ± 12.02
	Left	PL	99.0 ± 50.98	88.3 ± 25.01	100.9 ± 39.31	82.9 ± 16.12
		RA	30.2 ± 13.06	31.0 ± 25.10	30.7 ± 18.30	24.5 ± 6.59

Values are expressed as mean ± standard deviation.
PL. path length (cm); RA. rectangle area (cm^2); CON: control group; TRA: training group; WBV: whole-body vibration group.

DISCUSSION

The primary objective of this study was to investigate the short-term and sustained effects of WBV training on the lower-extremity muscle strength, balance performance, and body composition of healthy university students.

The results of this study showed that there was no change in lower-extremity muscle strength, static and dynamic balance performance, and body composition in the three groups after Post 1. Furthermore, no change in lower-extremity muscle strength, static and dynamic balance performance, and body composition was observed after Post 2 and Post 3. These findings can be explained by general muscular adaptation to the WBV training program. WBV training was performed at various frequencies and amplitudes, resulting in inconsistencies in training load and different effects of training protocols[17].

Strength training includes isometric, shortening, and stretching training, depending on the classification of activity mode. When training primarily in one of the activity modes, the rate of increase in muscle strength under the same activity condition as the training is higher than that under other activity conditions.

In other words, isometric muscle strength increases when isometric strength training is performed, and isokinetic muscle strength at low speeds increases the most when low-velocity isokinetic training is performed. Furthermore, as earlier mentioned, some studies have reported statistically significant effects of WBV intervention on strength outcome.

The effect of WBV training on isolated maximal voluntary isokinetic or isometric muscle activation and strength is unclear, and more research is needed in this area. Since the training performed in this study was isometric training, isometric muscle strength should have been assessed considering the specificity of muscle training.

The initial increase in muscle strength during strength training is primarily due to improvements in the nervous system, followed by muscle hypertrophy, which in turn increases muscle strength. In this study, no short-term effect of training on muscle strength was observed.

Table 6. Dynamic balance performance parameters during single-leg standing

Group	Leg	Parameter	Pre	Post 1	Post 2	Post 3
CON	Right	PL	166.0 ± 46.27	178.2 ± 46.08	187.3 ± 32.08	197.0 ± 48.12
		RA	50.2 ± 21.71	52.4 ± 19.57	42.9 ± 16.53	51.8 ± 12.80
	Left	PL	155.7 ± 41.26	179.1 ± 42.92	184.6 ± 44.36	176.4 ± 37.15
		RA	43.4 ± 17.09	45.5 ± 15.68	43.7 ± 15.32	45.2 ± 13.73
TRA	Right	PL	188.2 ± 54.79	201.7 ± 55.25	215.6 ± 51.62	215.6 ± 51.62
		RA	39.2 ± 10.62	40.3 ± 15.74	37.9 ± 16.81	45.4 ± 21.84
	Left	PL	181.5 ± 38.62	203.3 ± 53.07	200.3 ± 55.15	213.2 ± 57.06
		RA	36.7 ± 13.19	34.9 ± 15.96	36.7 ± 23.29	38.1 ± 19.41
WBV	Right	PL	172.5 ± 25.51	185.9 ± 42.67	199.0 ± 33.46	204.5 ± 36.98
		RA	41.9 ± 10.58	37.1 ± 11.21	41.7 ± 10.84	44.6 ± 17.39
	Left	PL	180.8 ± 30.36	193.2 ± 36.01	197.7 ± 39.76	205.4 ± 39.04
		RA	49.6 ± 12.60	41.2 ± 11.81	37.0 ± 10.36	42.7 ± 19.85

Values are expressed as mean ± standard deviation.
PL: path length (cm); RA: rectangle area (cm^2); CON: control group; TRA: training group; WBV: whole-body vibration group.

Table 7. Body composition parameters of the three groups

Group	Parameter	Pre	Post 1	Post 2	Post 3
CON	SLM	27.1 ± 7.11	27.7 ± 7.12	27.2 ± 7.14	27.1 ± 7.22
	BFM	12.9 ± 4.00	12.5 ± 4.03	13.4 ± 4.86	13.1 ± 4.35
TRA	SLM	26.2 ± 6.48	26.5 ± 6.25	26.5 ± 6.45	26.5 ± 6.31
	BFM	11.6 ± 3.95	11.8 ± 3.56	11.6 ± 3.64	12.2 ± 4.04
WBV	SLM	26.8 ± 4.96	26.8 ± 4.77	27.1 ± 5.07	26.9 ± 4.97
	BFM	13.2 ± 5.50	13.5 ± 5.40	13.1 ± 5.76	13.3 ± 5.59

Values are expressed as mean ± standard deviation.
SLM: soft lean mass (kg); BFM: body fat mass (kg); CON: control group; TRA: training group; WBV: whole-body vibration group.

It was suggested that the same acceleration vibration training with varying frequencies and amplitudes undertaken for eight weeks significantly increased jumping performance, which involves the stretch-shortening cycle of muscle function, and improved body balance[1].

Previous studies reported significant improvements in static postural stability after eight weeks of vibration training[11, 18]. In this study, no significant changes in static or dynamic balance were observed. However, the chronic effect of training is probably achieved via neuromuscular and neural adaptations.

Our results show that WBV training does not affect body composition. This observation is consistent with the report of no significant changes in the percent body fat of untrained females after 24 weeks of WBV training[14].

Our results are also consistent with those of a previous study that reported no significant changes in lean body mass after six months of WBV training, supporting the lack of improvement in lean body mass observed in this study[19].

WBV training increases metabolic demand with the addition of external load and high frequency/amplitude settings, but it does not seem to match the intensity of traditional aerobic exercise that is required to induce change in body composition[20].

However, due to the short workout time and unique environment of WBV training compared to aerobic training and circuit training, WBV training may be a viable alternative to these more traditional forms of exercise, thereby effectively promoting physical activity through high adherence rate. WBV training focuses on the neuromuscular spindle that is activated by the tonic vibration reflex. Just standing on the vibrator platform can keep the muscle spindles active. Thus, WBV exercise may be an efficient training stimulus.

However, the results of this study showed that short-term WBV training did not affect the muscle strength, balance performance, or body composition of healthy university students.

This study has some limitations. We assumed that the effects of WBV training are partly due to factors such as differences in the functional state of participants and a lack of standardization of the frequency, duration, and intensity of training. Future studies should focus on comparing the performance-enhancing effects of WBV training to those of a conventional resistance training.

Therefore, this study provides a better insight into the responsiveness of short-term WBV training, which will help the professionals in health, fitness, and therapeutic sectors to determine WBV programs in revalidation and training.

Funding and Conflict of interest

All the authors confirm that no conflicts of interest are present in relation to this manuscript. No funding has been granted for this research project.

REFERENCES

1) Chen CH, Liu C, Chuang LR, et al.: Chronic effects of whole-body vibration on jumping performance and body balance using different frequencies and amplitudes with identical acceleration load. J Sci Med Sport, 2014, 17: 107–112. [Medline] [CrossRef]
2) Preatoni E, Colombo A, Verga M, et al.: The effects of whole-body vibration in isolation or combined with strength training in female athletes. J Strength Cond Res, 2012, 26: 2495–2506. [Medline] [CrossRef]
3) Bogaerts A, Delecluse C, Claessens AL, et al.: Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. J Gerontol A Biol Sci Med Sci, 2007, 62: 630–635. [Medline] [CrossRef]
4) Delecluse C, Roelants M, Verschueren S: Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc, 2003, 35: 1033–1041. [Medline] [CrossRef]
5) Roelants M, Delecluse C, Verschueren SM: Whole-body-vibration training increases knee-extension strength and speed of movement in older women. J Am Geriatr Soc, 2004, 52: 901–908. [Medline] [CrossRef]
6) Roelants M, Verschueren SM, Delecluse C, et al.: Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. J Strength Cond Res, 2006, 20: 124–129. [Medline]
7) Torvinen S, Kannus P, Sievänen H, et al.: Effect of four-month vertical whole body vibration on performance and balance. Med Sci Sports Exerc, 2002, 34: 1523–1528. [Medline] [CrossRef]
8) Bosco C, Colli R, Introini E, et al.: Adaptive responses of human skeletal muscle to vibration exposure. Clin Physiol, 1999, 19: 183–187. [Medline] [CrossRef]
9) Delecluse C, Roelants M, Diels R, et al.: Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. Int J Sports Med, 2005, 26: 662–668. [Medline] [CrossRef]
10) Dallas G, Mavvidis A, Kirialanis P, et al.: The effect of 8 weeks of whole body vibration training on static balance and explosive strength of lower limbs in physical education students. Acta Gymn, 2017, 47: 153–160. [CrossRef]
11) Fort A, Romero D, Bagur C, et al.: Effects of whole-body vibration training on explosive strength and postural control in young female athletes. J Strength Cond Res, 2012, 26: 926–936. [Medline] [CrossRef]
12) Runge M, Rehfeld G, Resnicek E: Balance training and exercise in geriatric patients. J Musculoskelet Neuronal Interact, 2000, 1: 61–65. [Medline]
13) Pollock RD, Provan S, Martin FC, et al.: The effects of whole body vibration on balance, joint position sense and cutaneous sensation. Eur J Appl Physiol, 2011, 111: 3069–3077. [Medline] [CrossRef]
14) Roelants M, Delecluse C, Goris M, et al.: Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. Int J Sports Med, 2004, 25: 1–5. [Medline] [CrossRef]
15) Emara H: Effects of whole body vibration on body composition and muscle strength of children with Down syndrome. Int J Ther Rehabil Res, 2016, 5: 1–8.

16) Tapp LR, Signorile JF: Efficacy of WBV as a modality for inducing changes in body composition, aerobic fitness, and muscular strength: a pilot study. Clin Interv Aging, 2014, 9: 63–72. [Medline]
17) Mester J, Kleinöder H, Yue Z: Vibration training: benefits and risks. J Biomech, 2006, 39: 1056–1065. [Medline] [CrossRef]
18) Ritzmann R, Kramer A, Bernhardt S, et al.: Whole body vibration training—improving balance control and muscle endurance. PLoS One, 2014, 9: e89905. [Medline] [CrossRef]
19) Verschueren SM, Roelants M, Delecluse C, et al.: 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, 2004, 19: 352–359. [Medline] [CrossRef]
20) Cochrane DJ: Is vibration exercise a useful addition to a weight management program? Scand J Med Sci Sports, 2012, 22: 705–713. [Medline] [CrossRef]