

Effects of amplitudes of whole-body vibration training on left ventricular stroke volume and ejection fraction in healthy young men

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ABSTRACT

Objective: The aim of this study was to evaluate the effects of different whole-body vibration (WBV) training amplitudes on left ventricular stroke volume and ejection fraction in healthy young men.

Methods: A total of 24 healthy men (age 21.71±1.49 year, height 176.17±6.61 cm, weight 70.73±10.08 kg, BMI 22.36±3.57 kg/m², and body surface area 1.87±0.13 m²) were divided into two groups: high and low amplitude vibration (n=12). The vibration training consisted of 8 weeks of WBV 3 times a week with amplitudes of 2 or 4 mm and progressive frequencies from 20 Hz with increments of 5 Hz weekly. As outcome measures, left ventricular stroke volume and ejection fraction at baseline and after 8 weeks were evaluated. Mann-Whitney U test was used for the comparison between groups; Wilcoxon signed-ranks tests were used to compare pretest and post-test results in each group. A p value less than 0.05 was considered significant.

Results: Whole-body vibration training with low amplitude (2 mm) caused an numerically increase in stroke volume (pre-test: 72.42±14.34; post-test: 78.42± 23.19 cm³; p=0.06) and ejection fraction (pre-test: 65.22±3.41; post-test: 67.00±4.18%; p=0.52). So; the increase was not significant. In the high-amplitude (4 mm) group, post-test results were nearly unchanged compared to the pre-test results. No significant difference was evident between groups.

Conclusion: The intensity and volume of whole-body vibration training were not enough to affect systolic function.

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Key words: vibration, training, stroke volume, ejection fraction

Introduction

Whole-body vibration (WBV) training is a new exercise mode that is currently being investigated in the field of space travel, sports, and rehabilitation (1). Many studies have focused on the effects of endurance, aerobic, and resistive exercises on the cardiovascular system; however, research on the effects of WBV on the cardiovascular system is scarce. Most research in this area has focused only on the acute hemodynamic changes that occur following a bout of WBV exercise. Increases in blood flow were demonstrated by Yamada et al. (2), who found that blood volume in the leg muscle increased acutely after WBV with a dynamic squat exercise. Maikala et al. (3) suggested that energy expenditures in whole-body vibration training are similar to 'light' work of 0.3 metabolic

energy equivalents. Da Silva et al. (4), however, found that vibration training provides cardiovascular stimuli similar to those experienced during moderate walking at 4 km/h. Cochrane et al. (5) showed that squat exercises on a vibration plate (3 s up, 3 s down) lead to a similar metabolic rate as cycling at 70 Watts. Hazell et al. (6) found that a WBV session increased 24-h oxygen consumption by 10% compared to non-WBV exercise.

Global longitudinal function is a novel and highly sensitive and specific index for the assessment of global LV function from 2-dimensional echocardiographic images. We suggest this method to be used for more accurate measurement of LV function (7).

Increased cardiac filling during upright exercise appears to be an important mechanism, accounting for the greater stroke volume in upright exercises.

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Table 1. The training schedule

Session (every week)	Position of training	Set	Repetition	Frequency in the first week*, Hertz	Amplitudes**, millimeters	Duration of each repetition, seconds	Duration of rest between sets, seconds	Total duration of training in the session, minutes
1 st session of the week	Squat	2	3	20	4 or 2	30	30	9
	Lunges	2	3					
	Deep Squat	2	3					
2 nd session of the week	Squat	2	3	20	4 or 2	45	30	13.5
	Lunges	2	3					
	Deep Squat	2	3					
3 rd session of the week	Squat	2	3	20	4 or 2	60	30	18
	Lunges	2	3					
	Deep Squat	2	3					

*The frequency at the beginning of the program was 20 Hz, which was progressively increased (5 Hz each week) to the final frequency of 55Hz.
**4 mm for the high-amplitude and 2 mm for the low-amplitude groups

The aim of this study was to evaluate the effects of different amplitudes of whole-body vibration training with progressive frequencies on left ventricular stroke volume and ejection fraction.

Methods

Subject selection and measurement

In this blinded clinical trial, a total of 35 healthy young men without any history of thyroid dysfunction, anemia, smoking, diabetes mellitus, and cardiac disease served as subjects. They had not done any exercises regularly for at least 3 months before the start of the training. Men with cardiovascular problems were excluded (5 persons with mitral valve prolapse). All subjects were informed about the procedures, risks, and benefits in advance. Six subjects were excluded, because they did not participate in post-test measurements; 24 healthy men (age 21.71±1.49 year, height 176.17±6.61 cm, weight 70.73±10.08 kg, BMI 22.36±3.57 kg/m², body surface area 1.87±0.13 m²) completed the study. Body surface area was calculated by DuBois formula [BSA (m²)=0.007184 x height (cm) 0.725 x weight (kg) 0.425].

All subjects were divided into two groups: high-amplitude vibration (n=12) and low-amplitude vibration (n=12); their demographic data were not significantly different (p>0.05). The vibration training consisted of 8 weeks of whole-body vibration 3 times a week with amplitudes of 2 or 4 mm and progressive frequencies from 20 Hz, with increments of 5 Hz weekly. As outcome measures, left ventricular stroke volume and ejection fraction at baseline and after 8 weeks were considered.

Echocardiographic examination

A My Lab echocardiograph (Esaote Europe B.V., Maastricht, The Netherlands) equipped with a 2.5 MHz probe was used. Subjects were examined, and conventional two-dimensional (2-D)-guided M-mode and B-mode measurements were recorded. All echocardiographic exams were performed by

just one experienced board-certified cardiologist before and after the intervention (WBV training). Neither the subjects nor the cardiologist knew the grouping, so the study is considered blinded.

From the long-axis view, and following the AHA (American Heart Association) echocardiography guidelines (8), the standard left ventricle (LV) 2-D parameters were obtained at rest. The basal 2-D systolic-diastolic parameters, interventricular septum (IVS) and posterior wall (PW) thicknesses, left ventricular end-diastolic volume (LVEDv), left ventricular end-systolic volume (LVESv), ejection fraction by Simpson's rule (EF), left ventricular stroke volume (LVSV), and LV mass (LV mass) were measured.

Images were obtained in the left lateral decubitus position, after a 15-minute rest. High-quality images were acquired, with excellent visualization of the endocardial and epicardial borders.

Whole-body vibration training

The subjects were familiarized with the testing procedures. Subjects participated in a standardized dynamic 5-10-minute warm-up. Vibration training was performed on a vibration platform (Fit Vib, Germany). During the 8-week experimental period, all subjects continued their conventional living schedule, in addition to the 3-times-weekly WBV training with amplitudes of 4 or 2 mm and progressively increasing frequencies from 20 to 55 Hz with increments of 5 Hz weekly. Each training session consisted of two sets of three repetitions of vibration training in three positions (squat, lunges, and deep squat). The total weekly duration of vibration training was 40.5 minutes. The 1st, 2nd, and 3rd sessions of each week consisted of 9, 13.5, and 18 minutes of vibration training, respectively. Table 1 describes the training schedule in detail.

Statistical analysis

SPSS for Windows, version 19 (SPSS Inc., Chicago, IL, USA) was used for the data analysis. Mean and standard deviations were used for the description of variables. Due to the lack of

normality, in order to make a comparison between groups, we used Mann-Whitney U test. In order to compare pretest and post-test results, we used Wilcoxon signed-ranks test. A *p* value less than 0.05 was considered significant.

Ethical issues

The study protocol was evaluated and accepted by Ethical Committee of the Sports Medicine Federation of Iran, and it complies with the Helsinki Declaration. All participants received adequate information about the study protocol and the possible good and ill effects of training. They entered the study deliberately and were free to quit the protocol upon their request.

Results

In this study showed that the intensity and volume of whole-body vibration training were not enough to affect systolic function.

In the subjects, whole-body vibration training with low amplitude (2 mm) caused an increase in stroke volume (pretest: 72.42 ± 14.34 ; post-test: 78.42 ± 23.19 cm³; *p*=0.06) and ejection fraction (pretest: 65.22 ± 3.41 ; post-test: $67.00 \pm 4.18\%$; *p*=0.52); but the increase was not significant. Whole-body vibration training with progressive frequencies and high amplitude (4 mm) did not change left ventricular stroke volume and ejection fraction significantly. Comparing the effects of training between the two groups, no significant difference was evident. Table 2 shows the data of the pre- and post-intervention measurements.

Table 2. Data of pre- and post-intervention measurements

Variable		Low-amplitude group	High-amplitude group	<i>P</i>
Stroke volume, cubic centimeters	Pretest	72.42±14.34	75.43±15.71	0.47
	Post-test	78.42±23.19	75.85±14.66	0.72
	<i>P</i> value	0.06	1.00	
Ejection fraction, percent	Pretest	65.22±3.41	65.58±3.44	0.97
	Post-test	67.00±4.18	65.75±3.33	0.49
	<i>P</i> value	0.52	0.84	
Values are mean±SD; * <i>P</i> <0.05 significant change; comparison between pre-exercise and post-exercise				

Discussion

In this study showed that the intensity and volume of whole-body vibration training were not enough to affect systolic function. In the high-amplitude (4 mm) group, post-test results were nearly unchanged compared to pretest results. No significant difference was evident between groups.

Stroke volume (SV) is the volume of blood pumped from the left ventricle with each heartbeat. It is calculated by the difference between end-diastolic and end-systolic volume of the left

ventricle. EF represents the volumetric fraction of blood pumped out of the ventricle with each heartbeat, and EF indicates the contractile status of the heart (9).

Studies demonstrating WBV have utilized training time periods ranging from 10 days to 6 months, frequencies between 12 and 60 Hz, and amplitudes ranging from 1.7 to 10 mm (10, 11). A wide variety of amplitudes, frequencies, and durations have been utilized, and a clear pattern is not evident. The controlled use of vibration to cause positive physical and biological responses requires the use of proper doses of vibration, consisting of three aspects: volume, intensity, and strength of the vibration load. The intensity of the vibration load refers to the mechanical characteristics of the frequency and amplitude of the vibration stimulus. The volume of the vibration load refers to the volume of time under the vibration stimulus. The term 'strength of the vibration load' describes the observational characteristics of the muscle impacted by the vibration load. WBV requires fewer physical skills and shorter training sessions than aerobic exercise (AE) and resistance exercise (RE). Therefore, the expected findings could be of considerable importance for routine sports training and various therapeutic procedures.

Factors that potentially affect cardiac filling during exercise include total blood or plasma volume, pericardial and myocardial compliance, active diastolic relaxation, and arteriolar and veno-motor tone. Several studies have evaluated the effect of endurance exercise training on LV systolic functions. The data showed that there were no significant differences between sedentary controls and athletes with regard to LVEF (12). Baggish et al. (13) demonstrated in a longitudinal study that a 90-day period of endurance exercise training increased the LV strain without changing the LVEF. The study by Mantziari et al. (14) also demonstrated similar results. Systolic strain is defined as the change of myocardial fiber length during the cardiac cycle, and it is affected by after-load, pre-load, and intrinsic contractility (15). Stroke volume increased progressively with increasing levels of exercise in most subjects, but the relation between stroke volume and VO₂ (oxygen consumption) was not linear. Ekblom et al. (16) reported a progressive increase in SV with increasing exercise intensity (between 40% and 80% VO₂ max) in 8 elite (VO₂ max=74.6 mL/kg/min) and 5 regional level (VO₂ max=66.0 mL/kg/min) endurance athletes. Nine of these athletes (69%) achieved their highest SV during maximal exercise. Jensen-Urstad et al. (17) reported that training-induced increases in myocardial contractility and possibly a decreased after-load were the main contributing factors to the increase in stroke volume during incremental exercise in elite male runners. Similarly, Vanfraechem et al. (18) reported that left ventricular ejection times decreased at each workload in male soccer players. The authors hypothesized that the continued increase in stroke volume, despite the decrease in ventricular ejection time, may be due to an increase in ejection fraction during exercise of increasing intensity (18). Lentini et al. (19) examined the effects of repetitive leg-press exercise at 95% of 1 repetition maximum (1RM) performed with brief Valsalva maneuvers (VMs) on LV

volumes and systolic function in younger healthy males. The major finding was that LV end-diastolic and end-systolic volumes decreased during exercise compared with resting values. Consequently, preload reserve and stroke volume declined. However, since leg-press exercise mediated greater LV contractility and heart rate, cardiac output and ejection fraction increased (19). Some studies have shown improvements in EF following exercise; however, others did not show this effect (20). Ejection fraction is supposed to be increased during exercise but not at rest. A single bout of WBV exercise was found to increase leg muscle blood flow (21, 22) and reduce leg arterial stiffness (23). Recent studies reported that repeated bouts of WBV (24, 25) up-regulate the nitric oxide dilator system and improve endothelial function. However, while positive results in vascular function were reported after acute intermittent vibration protocols (21, 22), others have not (26), and to date, no studies have explored the chronic effects of WBV exercise training on cardiovascular function. Evidence of reduced arterial stiffness and wave reflection in young overweight or obese non-diabetic women following WBV exercise training (22) suggests that WBV may be an effective training mode for improving leg artery blood flow. Vibration training uses an oscillating platform that delivers sinusoidal vibrations (21) that evoke reflexive muscle contractions (27) while the person performs steadily controlled dynamic and static exercises. The vibration mechanically stimulates sensory receptors, leading to the activation of alpha-motor neurons and, consequently, muscle contractions through the tonic vibration reflex (28). These contractions explain the increased levels of electromyography in working muscle during WBV exercise (29) and the increased energy output that is shown to result from the addition of vibration to squat exercises (4).

Variables of vibration training, like other training protocols, consist of frequency (Hz), amplitude (mm), and duration (s). As the movement of the platform is sinusoidal, the acceleration transmitted to the body is calculated as $a=A(2\pi f)^2$, where "A" is the amplitude of the oscillations and "f" is the frequency (30). Small changes in amplitude and frequency determine relatively large changes in the acceleration and magnitude of the vibration being transmitted to the body. It seems that in this study, the intensity and volume of whole-body vibration training were not enough to affect systolic function.

Study limitations

A major limitation of this study was the small sample size (power 0.05-0.24). Another limitation may have been that the exercise training volume and duration were not enough to elicit adaptations.

Conclusion

WBV is a fast and effective alternative to resistance training. The low-impact nature of this exercise makes WBV an attractive exercise mode that can be a good training option for persons

wishing to minimize the amount of repetitive joint load. Eight weeks of whole-body vibration did not affect systolic function significantly.

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