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Effects of 24 Weeks of Whole Body Vibration Training on Body Composition and Muscle Strength in Untrained Females

Abstract

The aim of this study was to investigate and to compare the effect of 24 weeks "whole body vibration" training and fitness training on body composition and on muscle strength. Forty-eight untrained females (21.3 ± 2.0 yr) participated in the study. The whole body vibration group (N = 18) performed unloaded static and dynamic exercises on a vibration platform (35 – 40 Hz, 2.5 – 5.0 mm; Power Plate®). The fitness group (N = 18) followed a standard cardiovascular (15 – 40 min) and resistance training program including dynamic leg press and leg extension exercises (20 – 8 RM). Both groups trained 3 times weekly. The control group (N = 12) did not participate in any training. Body composition was determined by means of underwater weighing. Additionally 12 skinfolds were assessed. Isometric (0°/s) and isokinetic (50°/s, 100°/s, 150°/s) knee-extensor strength was measured by means of a motor-driven dynamometer (Technogym®). Over 24 weeks there were no significant changes ($p > 0.05$) in weight, in percentage body fat, nor in skinfold thickness in any of the groups. Fat free mass increased significantly in the whole body vibration group (+ 2.2%) only. A significant strength gain was recorded in the whole body vibration group (24.4 ± 5.1%; 5.9 ± 2.1%; 8.3 ± 4.4%; 7.6 ± 1.5%) and in the fitness group (16.5 ± 1.7%; 12.0 ± 2.7%; 10.4 ± 2.3%; 10.2 ± 1.9%), at 0°/s, 50°/s, 100°/s and 150°/s respectively. In conclusion, 24 weeks whole body vibration training did not reduce weight, total body fat or subcutaneous fat in previously untrained females. However, whole body vibration training induces a gain in knee-extensor strength combined with a small increase in fat free mass. The gain in strength is comparable to the strength increase following a standard fitness training program consisting of cardiovascular and resistance training.

Key words

Vibration exercise · resistance training · underwater weighing · body fat · fat free mass · skinfold thickness

Introduction

The reduction of body fat and the increase of muscle mass and muscle strength are some of the most popular objectives to start an exercise program. It has been shown that cardiovascular training combined with resistance training may be an efficient way to realize these goals in untrained persons [1]. "Whole body vibration" training (WBV) has recently been introduced in health and fitness centres as an alternative method and may therefore be considered as a measure to reduce body fat and to increase muscle mass and muscle strength. During WBV training the subject performs unloaded static and dynamic exercises on a platform that generates vertical sinusoidal vibrations at a frequency between 18 – 45 Hz [2,3,7,8]. These mechanical stimuli are transmitted to the body where they stimulate in turn sensory receptors, most likely muscle spindles. This leads to activation of

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the alpha-motoneurons and initiates muscle contractions comparable to the "tonic vibration reflex" [2].

Actually there is a lack of scientific information concerning the impact of WBV on body composition. It has been shown that oxygen consumption, heart rate, blood lactate and thus muscular metabolic power increase during WBV training [7,8]. It was concluded that the energy consumption during WBV (26 Hz) is comparable to the level of energy required during walking at moderate intensity [7]. However, it remains questionable whether this type of exercise will result in a reduction of body fat.

Long-term effects of WBV training on muscle strength were investigated in a limited number of studies only [3,9]. These studies did not address changes in muscle mass. Torvinen et al. [9] reported a non-significant gain (2.5%) in isometric limb extension strength after 4 months WBV training. A recent study [3] showed that 12 weeks WBV training has the potential to induce isometric knee-extensor strength gain (16.6%) in untrained females. This gain in strength was significantly higher compared to a control group that performed an identical exercise program on a non-vibrating platform. In the WBV group strength increased to the same extent as following an equal number of moderate resistance training sessions. It was suggested that the stimulation of propriospinal pathways provoked by WBV evoked mainly neural adaptations in the neuromuscular system resulting in strength gain. Changes in muscle mass were not measured but were expected to be limited, comparable to the changes recorded following cardiovascular training combined with resistance training [5]. However it was hypothesized that WBV training, performed over a long period, may induce significant increases in muscle mass.

This is the first study that investigates the effects of 24 weeks of WBV training on body composition and on strength in young females, and which compares the effects of WBV to those following a fitness program consisting of cardiovascular training and resistance training. Changes in percentage body fat, in fat free mass, in skinfold thickness and in knee-extensor strength were analysed. The findings of this study should give a better insight regarding the potential benefits of WBV training within the context of health and fitness.

Methods

Subjects and training groups

Forty-eight untrained female students (21.3 ± 2.0 years), recruited through advertisements and direct mailings to different student groups of the university, volunteered to participate in this study. None of them were engaged in regular organized physical activities, nor in sports or resistance training. Reasons for exclusion were: pregnancy, acute hernia and any history of severe musculo-skeletal problems. Subjects with a history of diabetes or epilepsy were also excluded from the study. All subjects were assigned to a control group (CO, N = 12) or to one of the training groups: the Whole Body Vibration group (WBV, N = 18) or the Fitness group (FIT, N = 18). Considering the unknown feasibility and motivation to follow 24 weeks WBV training, subjects were able to choose the type of training they preferred. All intervention programs consisted of 72 training sessions within a 24-week period. Training frequency was three times weekly with at least one day of rest between two sessions. The CO group did not participate in any training program.

The subjects of the WBV group performed unloaded static and dynamic leg and arm exercises (high squat, deep squat, lunge, biceps curl,…) on a vibration platform (Power Plate®). The acceleration of the platform varied between 2.28 g and 5.09 g. The training volume increased systematically over the 24 weeks by increasing: the total duration of vibration in one session (from 3 to 20 minutes), the number of series of one exercise or the number of different exercises for one muscle group (from 1 to 3). The training intensity was increased by: shortening the rest periods (from 60 s to 5 s) or by increasing the amplitude (from 2.5 mm to 5.0 mm) and/or the frequency (from 35 Hz to 45 Hz) of the vibration stimulus. The duration of the WBV sessions varied between 20 and 30 minutes.

The FIT group trained in the university fitness center. After their cardiovascular training on bicycle, step or treadmill, they performed a resistance training program for the total body including leg press and a leg extension (Technogym®). The duration of the cardiovascular training was increased systematically according to the ACSM guidelines [1] from 15 minutes to 40 minutes/session. Training intensity varied between 60 and 80% of heart rate reserve. Resistance training started at a moderate intensity (2 sets at 20 RM), the training intensity increased up to 8 RM (2 sets). The duration of the FIT sessions varied between 45 minutes and 75 minutes. Certified (ACSM) health and fitness instructors closely supervised all WBV training and FIT training sessions.

It was not the aim of this study to compare two exercise programs with an identical training volume and/or training intensity. However the magnitude of the effects of WBV training on body composition and on muscle performance will be compared to the changes following a FIT program that traditionally is prescribed in health and fitness centres [1].

Test protocol

Underwater weighing, the method of reference for body composition assessment, was used to calculate percentage body fat and fat free mass (FFM) [6]. In addition, subcutaneous fat was measured at the left side of the body using a Harpenden skinfold caliper. Twelve skinfold thicknesses were selected: biceps, triceps, subscapular, suprailiac, chin, side, waist, abdomen, thigh anterior and posterior, calf lateral and medial [6]. Before and after the training period, subjects recorded their dietary food and drink intake by using 4-day food-record questionnaires.

The strength of knee-extensors was recorded on a motor-driven dynamometer (REV9000, Technogym®) by a standard protocol of isometric and isokinetic tests. The tests were performed unilaterally on the right side. After a standardized warm-up the maximal voluntary isometric (0°/s) torque (Nm) of the knee extensors at a knee joint angle of 130° was measured. The subjects also performed a series of three consecutive isokinetic flexion-extension movements against the lever arm of the dynamometer that moved at a velocity of 50°/s, 100°/s or 150°/s respectively. The knee extension was initiated at a joint angle of 90° and ended at 160°. Following each extension, the leg was returned passively to

Table 1 Physical and body composition characteristics of the subjects before (pre) and after 24 weeks (post)

	WBV group (N = 13)		*FIT group (N = 15)*		*CO group (N = 12)*		*P-value*	
	pre	*post*	*pre*	*post*	*pre*	*post*	*time*	*group × time*
age (yr)	21.5 (0.5)		21.6 (0.5)		20.6 (0.5)			
height (cm)	167.1 (1.1)		165.1 (1.3)		167.9 (2.1)			
weight (kg)	62.6 (1.7)	64.3 (2.4)	58.8 (1.5)	57.7 (1.5)	62.8 (3.4)	62.7 (3.7)	0.13	0.43
body fat (%)	28.3 (1.1)	28.6 (1.3)	25.8 (0.9)	24.8 (0.7)	26.8 (1.3)	26.5 (1.4)	0.06	0.72
fat free mass (kg)	44.6 (0.8)	45.6 (1.3)*	43.5 (0.9)	43.3 (1.1)	45.8 (1.8)	45.9 (1.9)	<0.001	0.09
sum of 12 skinfolds (mm)	257 (22)	272 (21)	219 (12)	220 (13)	246 (26)	261 (29)	0.24	0.17

Mean (SEM), p-values from ANOVA for repeated measures, * significantly different ($p < 0.05$) from pre-test (contrast analyses), WBV = Whole Body Vibration group, FIT = fitness group, CO= control group

the starting position from which the next contraction was immediately initiated. The peak torque (Nm) recorded at each velocity was determined as maximal isokinetic strength.

Statistical analysis

The sample size of the experimental groups was projected to provide a power of 80% with alpha = 0.05 to detect a 5% difference in body composition variables. Differences in pre-test values between groups were assessed using one-way ANOVA. The effect of the different interventions on body composition and muscle strength were analyzed by means of ANOVA for repeated measures [3 (group) × 2 (time)] and [3 (group) × 2 (time) × 4 (velocity)] respectively. After an overall F-value was found to be significant, pre-planned contrast analyses were performed to evaluate significant pre-post changes in each group and differences in time between groups. Bonferroni correction was used to adjust the p-value in relation to the number of contrasts that were performed. All analyses were executed using the statistical package Statistica, version 6 (Statsoft, Inc.). The dietary questionnaires were coded and analyzed for energy content and carbohydrate, fat, and protein composition. All values are reported as means ± standard error of mean (SEM). Significance level was set at $p < 0.05$.

Results

Training experiences and drop-out

The subjects enjoyed the WBV sessions and reported no adverse side effects. There were eight dropouts (WBV = 5; FIT = 3). Six dropouts were related to an incompatibility of the training program with other commitments of daily living. Two dropouts were the result of injuries, unrelated to the training intervention. All remaining subjects of the WBV group (N = 13) and the FIT group (N = 15) performed all 72 training sessions (24 weeks) properly. So all of these subjects had a 100% compliance.

Body composition

At the start of the study no significant differences in age, weight, height, percentage fat, FFM, nor in skinfold thickness among groups were detected (Table 1). Neither an overall "time" effect nor a "group × time" effect was found for weight, percentage body fat or for any of the skinfold thicknesses. For FFM an overall "time" effect was detected. Contrast analyses revealed a significant increase ($p < 0.001$) in FFM in the WBV group only, whereas no significant ($p > 0.05$) change occurred in the FIT or in the CO group. However, as no significant "group × time" effect was detected, the changes in the WBV group over time were not significantly different from the FIT or the CO group.

Caloric intake at pre-test was similar in the WBV, the FIT and the CO-group (2191 ± 90 kcal/day, 2102 ± 92 kcal/day and 2201 ± 97 kcal/day respectively). The proportion of proteins, fats and carbohydrates was on average 15.1%, 39.1% and 45.8% respectively. No significant changes ($p > 0.05$) in dietary intake (kcal/day) were found after 24 weeks in all groups.

Knee-extensor strength

At pre-test no significant differences ($p > 0.05$) in knee-extensor strength (0°/s, 50°/s, 100°/s and 150°/s) were found among groups. The data in Fig. 1 clearly show a shift to the right of the force-velocity curve from pre-test to post-test in the WBV group and the FIT group, whereas there was no change in the CO group. Statistical analyses revealed a significant "group × time × velocity" effect over the 24 week training period [$F(6) = 6.42$; $p < 0.001$]. Contrast analyses detected significant strength gains ($p < 0.001$) in the WBV group (24.4 ± 5.1%; 5.9 ± 2.1%; 8.3 ± 4.4%; 7.6 ± 1.5%) and in the FIT group (16.5 ± 1.7%; 12.0 ± 2.7%; 10.4 ± 2.3%; 10.2 ± 1.9%), at 0°/s, 50°/s, 100°/s and 150°/s respectively. No significant difference ($p > 0.05$) was found in training effect between the WBV and the FIT group at any velocities, whereas both groups differed significantly ($p < 0.001$) in time from the CO group. In the WBV group the gain in isometric strength was significantly higher ($p < 0.001$) compared to the gain in isokinetic strength.

Discussion

This was the first study to investigate the long-term effects of WBV training on body composition and muscle strength in untrained young females. No reduction in body fat or subcutaneous fat was found following 24 weeks WBV training. However, it was shown that WBV training is an efficient alternative to conventional exercise programs to improve the strength of knee-exten-

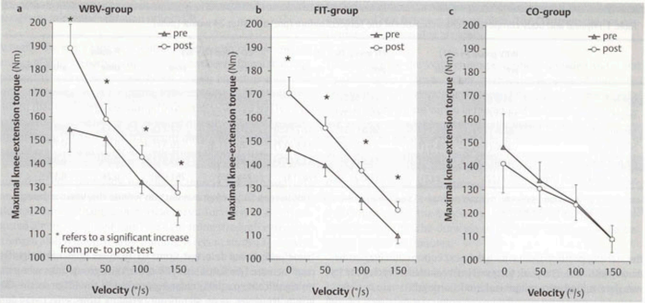

Fig. 1 Force-velocity curve of knee-extensors at 0°/s, 50°/s, 100°/s and 150°/s: A. in the whole body vibration (WBV) training group, B. the fitness (FIT) training group and C. the control (CO) group before (pre) and after 24 weeks (post). Average data are presented with SEM bars. * Refers to a significant increase from pre- to post-test.

sors in untrained females. This strength gain was accompanied by a significant increase in FFM.

In this study there was no significant reduction in weight or in percentage body fat following WBV training. Likewise, no reduction in subcutaneous fat was found as none of the 12 skinfolds showed significant changes. This finding is not unexpected as it has been shown that the cardiovascular stress produced by WBV is mild and the energy requirements may be compared to those during walking at a moderate intensity [7]. In addition, the total duration of vibration in one session was 20 minutes maximally. The WBV program used in this study is probably too short to induce changes in body fat.

To ensure that subjects were highly motivated to continue their exercise program for 24 weeks they were offered the free choice of participating in the WBV program or in the FIT program. Remarkably, at the start of the study subjects of the WBV group were 3.8 kg heavier and their percentage of body fat was 2.5% higher compared to the FIT group. Despite the fact that these differences were not significant ($p > 0.05$) it is remarkable that 6 of 18 subjects in the WBV group compared to 1 of 18 subjects in the FIT group could be considered obese, as their percentage body fat exceeded the 30% threshold for obesity [1]. These subjects started the WBV program most probably with the belief that it would beneficially affect body composition without much effort. As most obese people are not really attracted to intense physical activity, WBV may reduce the threshold to start an exercise program as it initiates muscle activity partly reflexively [3]. Unfortunately in this study no significant changes in body fat or in body weight were recorded in the WBV group, or in the FIT group. However the overall "time" effect on percentage fat was close to significance ($p = 0.06$). This can be explained by the fact that body fat in the FIT group was reduced by 3.9%. Scientific research already indicated that cardiovascular training and resistance training, performed according to ACSM standards, has a rather limited impact on body fat, as long as it is not combined with caloric restriction [5].

Both training programs showed clear benefits regarding to muscle strength. The gain in isometric knee-extensor strength is higher in the WBV group (24.4%) compared to the FIT group (16.5%). The mean gain in isokinetic strength (50°/s, 100°/s and 150°/s) was somewhat lower in the WBV group (7.2%) compared to the FIT group (10.9%). However, these training effects on knee-extensor strength were not significantly different between both groups. The WBV group showed greater ($p < 0.05$) gains in isometric strength compared to the increases in isokinetic strength. Velocity specific adaptations could probably explain these findings as the WBV group performed predominantly static exercises compared to the dynamic exercises in the FIT group.

Both WBV and FIT training induced an overload to the body, resulting in neural and/or morphological adaptations [4]. It is well known that during the first months of training muscle strength increases particularly due to neural adaptations. It is commonly assumed that the chronic exposure to WBV induced an increased excitatory state of the neuromuscular system due to an increase in the sensitivity of stretch reflexes [2,3]. Likewise, the stimulation of specific areas of the brain may trigger the secretion of anabolic hormones, which could improve neuromuscular function [2]. As training continues over several months, increases in muscle mass normally become more important [4]. Although both training groups showed clear increases in strength, FFM increased significantly only in the WBV group. However this gain in FFM was small (2.2%) and there was no significant "group × time" effect. These changes are comparable to what was expected in the FIT group and according to findings in previous studies [5].

In conclusion, in this study no reduction in body weight, total body fat or subcutaneous fat was measured following 24 weeks WBV training in previously untrained females. However, the results clearly showed that WBV training induced a gain in knee-extensor strength attended by small increases in fat free mass. The gain in strength was comparable to the strength increase following a standard fitness training program consisting of cardiovascular and resistance training.

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Evidence of Exercise-Induced O_2 Arterial Desaturation in Non-Elite Sportsmen and Sportswomen Following High-Intensity Interval-Training

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Abstract

The aim of this study was to investigate the development of exercise-induced hypoxemia (EIH defined as an exercise decrease > 4% in oxygen arterial saturation, i.e. SaO_2 measured with a portable pulse oximeter) in twelve sportsmen and ten sportswomen (18.5 ± 0.5 years) who were non-elite and not initially engaged in endurance sport or training. They followed a high-intensity interval-training program to improve $\dot{V}O_2max$ for eight weeks. The training running speeds were set at ~140% $\dot{V}O_2max$ running speed up to 100% 20-m maximal running speed. Pre- and post-training pulmonary gas exchanges and SaO_2 were measured during an incremental running field-test. After the training period, men and women increased their $\dot{V}O_2max$ ($p < 0.001$) by 10.0% and 7.8%, respectively. Nine subjects (seven men and two women) developed EIH. This phenomenon appeared even in sportsmen with low $\dot{V}O_2max$ from 45 ml × min^{-1} × kg^{-1} and seemed to be associated with inadequate hyperventilation induced by training: because only this hypoxemic group showed 1) a decrease in maximal ventilatory equivalent in O_2 ($\dot{V}E/\dot{V}O_2$, $p < 0.01$) although maximal ventilation increased ($p < 0.01$) with training, i.e. in EIH-subjects the ventilatory response increased less than the metabolic demand after the training program; 2) a significant relationship between SaO_2 at maximal workload and the matched $\dot{V}E/\dot{V}O_2$ ($p < 0.05$, $r = 0.67$) which strengthened a relative hypoventilation implication in EIH. In conclusion, in this field investigation the significant decrease in the minimum SaO_2 inducing the development of EIH after high-intensity interval-training indicates that changes in training conditions could be accompanied in ~40% non-endurance sportive subjects by alterations in the degree of arterial oxyhemoglobin desaturation developing during exercise.

Key words

Healthy men and women · arterial desaturation · field measurements · young recreational athletes

Introduction

During exercise, most healthy individuals are able to maintain arterial oxygenation adequately to meet the increased metabolic demands at sea level. However, it is well known that exercise may induce arterial hypoxemia in highly-trained endurance athletes [5,6,28,29]. Exercise-induced hypoxemia (EIH) is characterised by a drop in O_2 arterial partial pressure and/or in arterial saturation in oxygen (SaO_2). The mechanisms involved in the development of this EIH have long been debated and two major explanations have been proposed: 1) a lack of compensatory hyperpnea [10,12,24,30,31], and/or 2) a pulmonary gas exchange alteration that may result from functionally based mechanisms during exercise. The latter may involve ventilation/perfusion ($\dot{V}A/\dot{Q}$) and diffusion alterations induced by an incomplete O_2 equilibrium between alveolar gas and pulmonary capillary blood as a result of a rapid red blood cell pulmonary transit time and/or a pulmonary interstitial and peribronchial vascular edema during exhaustive exercise [5,10,13,23,31].

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