The Effect of Whole-Body Vibration Short-Term Exercises on Respiratory Gas Exchange in Overweight and Obese Women

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Abstract

Aims: To assess the effect of whole body vibration on oxygen uptake and carbon dioxide production among overweight and obese women. Methods: In a controlled randomized trial, anthropometric measurements were taken in 20 adult overweight women. Ventilation of oxygen, carbon dioxide, and heart rate were measured using a portable gas-analysis system. After each exercise, a Borg's scale score was assessed. Exercises were performed on a vibration platform with a frequency of 35 Hz and with the intensity set on "high" (amplitude of 4 mm). Two dynamic exercises (squatting and calf raises) and one static exercise (standing) were performed during 3 minutes with and without vibration in a randomized order, with 10 minutes rest between exercises. Mean values of the third minute of exercise were compared. Results: Ventilation of oxygen and carbon dioxide were consistently, significantly higher in the exercises with vibration compared with the exercises without vibration. Borg's scale scores only showed a significant difference between calf raises with and without vibration. Conclusion: The addition of whole body vibration to both static and dynamic exercises appears to significantly increase oxygen uptake in overweight and obese women. More research is needed to determine the physiological pathway and clinical relevance of this increase.

Keywords: acceleration; body weight; exercise; exercise expenditure; oxygen consumption

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Introduction

Increasing interest in whole body vibration (WBV) has resulted in the use of WBV exercise in fitness centers, not only among healthy and physically active persons but also among overweight and obese persons. As research in this area has grown, the commercial market for vibration platforms and the number of sports professionals embracing the concept has increased as well. By standing on a vibration platform while performing an exercise, additional muscle contractions, caused by a myotatic and tendon reflex, are triggered. This contraction as a reaction to vibration stimulus has been described as "tonic vibration reflex" (TVR).[1,2] The generation of the TVR by vibration is used as a method of treatment in physiotherapy, and can be measured by electromyography (EMG).[3–5] The first studies that investigated the effects of WBV as opposed to locally administered vibration were published in the late 1990s.[3,6,7] Focus had previously been on the health risks of WBV in an occupational environment, particularly with regard to low back pain.[2,8,9]

Rehn et al[10] stated strong-to-moderate evidence for the effects of long-term WBV exercise on the leg muscular performance in untrained individuals and elderly women, with no clear evidence for effects on muscular performance after short-term vibration stimuli. Different types of vibration platforms have been used in different populations to study the effect of WBV. There are 2 types of WBV training devices commercially available: a device with a platform that rotates about a central horizontal axis, and a device in which the entire platform translates up and down (this is the type used in this study). These devices vibrate with high frequencies from 15 to 60 Hz.[11]

Different hypotheses about the adaptive mechanisms have been stated, including preactivation and synchronization, stimulation of Golgi tendon organs, activation of antagonist muscles, variation of neurotransmitter concentrations (dopamine, serotonin) and excitation of sensory receptors such as muscle spindles, leading to improvements in the stretch reflex cycle.[12,13] Despite the different hypotheses that have been suggested about teh mechanisms that could exlpain physiological adaptions through the use of whole body vibration (possibly leading to enhanced performance), the exact parameters for enhanced athletic performance and injury prevention are not yet clearly understood.

Rittweger et al[14,15] demonstrated oxygen uptake to be significantly higher in healthy subjects using an exercise protocol with WBV compared with the same exercise protocol without WBV. Furthermore, they revealed a dose-response relationship for frequency, amplitude, and load on oxygen uptake. Whole body vibration has been suggested to have a beneficial effect on muscle strength, and strength training has been described to be a promising approach in the prevention and the treatment of overweight individuals.[16,17] Because overweight or obese individuals carry an extra load, it could be suggested that the response to WBV would be higher. However, it remains unclear whether body composition can influence the effect of WBV.

Vibration is mechanical energy generated by a mechanical system; damping is inherently present in such a mechanical system. Internal (material) damping results from mechanical energy dissipation within the material. Fluid damping can also occur. Fluid damping arises from mechanical energy dissipation resulting from drag forces and associated interactions when mechanical energy is conducted in a fluid. This brings up the question of whether body composition and/or excessive body fat could dampen the vibration generated by a WBV platform. If this is the case, there could be an association between the amount of excessive body fat and mechanical energy damping. In this context, this study examines whether oxygen uptake in a population of adult overweight and obese women will be higher when including WBV in the exercise protocol. Secondly, differences in changes in oxygen uptake due to vibration between overweight and obese women are investigated.

Methods

Subjects

Twenty adult premenopausal overweight (n = 10) and obese (n = 10) women volunteered to participate in this study (Table 1). According to the World Health Organization International Classification, women with a body mass index (BMI) $\geq$ 5 kg/m^2 and $<$ 30 kg/m^2 were considered overweight, and women with a BMI $>$ 30 kg/m^2 were considered obese. Subjects were excluded if there was a medical reason for them to not participate in physical activity or if they had joint replacing prosthetic devices. Other exclusion criteria were diabetes, pregnancy, and hypothyroidism.

Table 1. Descpriptive statistics of the overweight (n = 10) and obese participants (n = 10).

	Overweight	Obese	
	Mean (SD)	Mean (SD)	*P* Value
Height (m)	1.70 (0.05)	1.69 (0.06)	0.553
Weight (kg)	77.9 (7.9)	96.5 (11.7)	0.001
BMI (kg/m^2)	26.8 (1.3)	33.8 (2.2)	$<$ 0.001
Age (y)	39 (7)	36 (8)	0.318
Body fat (%)	32.6 (3.8)	37.6 (2.1)	0.002
Resting heart rate	77 (10)	80 (11)	0.589
Resting VO_2 (L/min)	0.290 (0.047)	0.308 (0.036)	0.341

Abbreviations: BMI, body mass endex; SD, standard deviation; VO_2, oxygen uptake.

Measurements

Height was measured to the nearest cm using a stadiometer (SECA 225, Hamburg, Germany). Weight was measured using a digital column scale SECA 701 (SECA Corp., Hamburg, Germany). Skinfold thickness was measured using a Harpenden skinfold caliper (Harpenden, West Sussex, UK) at 4 sites: at the biceps, triceps, subscapular, and suprailiac level. Skinfolds were measured and body fat percentage was calculated as described by Durnin and Womersley.[18]

Oxygen uptake (VO_2), ventilation of carbon dioxide (VCO_2), and heart rate were measured using a portable breath-by-breath gas analysis system (Metamax 3B, Cortex, Leipzig, Germany) and a heart rate monitor (Polar, Kempele, Finland). The portable gas analysis system is a reliable instrument for exercise testing in sports medical routine and research.[19] The device requires the patient to wear a tightly fitting face mask to collect exhaled air. A turbine is connected to the face mask to measure respiratory flow. The oxygen and carbon dioxide analyzer uses an electrochemical cell and infrared system. Immediately after, each exercise-perceived exertion was scored using Borg's 15-point ratings of perceived exertion (RPE).[20]

Protocol

After an initial rest period of 15 minutes, measurements of oxygen and carbon dioxide ventilation were taken while subjects were sitting quietly for 3 minutes. Measurements of oxygen and carbon dioxide ventilation were then taken during 6 exercises in random order: standing, dynamic squatting between 5° and 60° flexion in the knees, dynamic calf raises, standing plus vibration, dynamic squatting plus vibration, and dynamic calf raises plus vibration. The angles in the knees during the squatting exercise were first checked with a goniometer (Enraf-Nonius, Rotterdam, Netherlands). Next, a stick was placed horizontally directly behind the subject to make sure every squat was performed over the same distance. The order of exercises was randomized for each individual. Between each exercise, the participants rested for 10 minutes while sitting quietly. All exercises were performed at a constant pace (3 seconds up, 3 seconds down), which was controlled by a staff member with a chronometer.

To enable a steady state to set in, each exercise was performed for 3 minutes. The mean values of the third minute of VO_2, VCO_2, and heart rate were compared. Every exercise was performed on a vibration platform (Power-Plate, Next Generation, Netherlands). The vibration device was set on a frequency of 35 Hz and high intensity (amplitude of 4 mm) for exercises with vibration. The protocol of the study was approved by the ethical committee of the Antwerp University Hospital in Antwerp, Belgium. All persons gave their informed written consent prior to their inclusion in the study.

Statistical Analysis

Data were analysed using Microsoft Excel 2003 and SPSS for windows 12.0. Normality was checked performing a Kolmogorov-Smirnoff test. Differences between mean values were analyzed using a 2-way analysis of variance (ANOVA) with repeated measures. To correct for multiple comparisons, the 0.01 level was used as a cut-off to determine statistical significance. A linear regression analysis was performed for separate and pooled data. A post hoc power analysis was performed based on a type I error probability of 0.01, a sample size of 20, the respective standard deviations and differences in population means, and a control/experimental patient ratio of 1. Power for 2-way ANOVA with repeated measure results of VO_2 (mL/kg/min) was 1 for standing, 0.999 for squatting, and 0.987 for calf raises.

Results

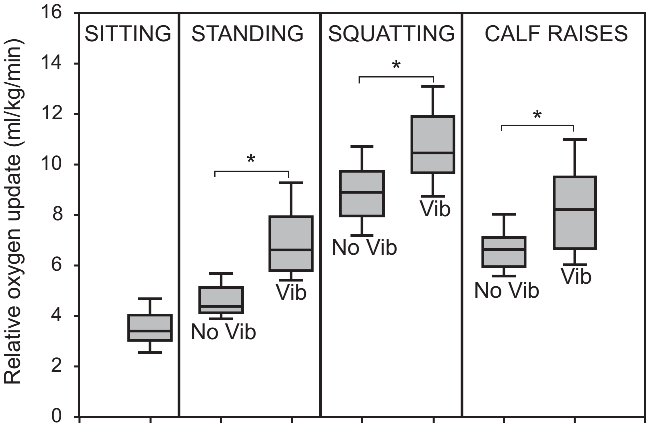
Carbon dioxide production and heart rate were consistently, significantly higher during exercises with vibration compared with the same exercises without vibration (Table 2). Analysis of the relative oxygen uptake (mL/kg/min) showed a significantly higher uptake in exercises with vibration compared with oxygen uptake without vibration (Figure 1). Scores of the Borg's 15-point RPE were also consistently higher after the exercises with vibration, but were only significant for calf raises (Table 2). A linear regression analysis was computed for relative oxygen uptake (mL/kg/min) during exercises with and without vibration, resulting in similar coefficients for all 3 exercise types (Figure 2). A linear regression analysis was performed for the pooled data of all 3 exercises yielding a positive correlation ($r = 0.807$). The regression line has an intercept of 2.72 mL/kg/min and a slope of 0.89 ($P < 0.001$). Separate linear regression analyses were computed for oxygen uptake during exercise with and without vibration among overweight and obese individuals (Figure 3). If the data were pooled for all 3 exercises, the equation for overweight

Table 2. Mean (SD) values of ventilation of oxygen (VO_2) and carbon dioxide production (VCO_2) during exercises without vibration and with vibration.

	Standing			Calf Raises			Squatting		
	No Vibration	**Vibration**	***P* Value**	**No Vibration**	**Vibration**	***P* Value**	**No Vibration**	**Vibration**	***P* Value**
VO_2 (L/min)	0.40 (0.06)	0.60 (0.11)	< 0.001	0.58 (0.10)	0.71 (0.11)	< 0.001	0.77 (0.15)	0.93 (2.55)	< 0.001
VCO_2 (L/min)	0.27 (0.05)	0.41 (0.09)	< 0.001	0.39 (0.09)	0.49 (0.10)	< 0.001	0.51 (0.09)	0.64 0.12)	< 0.001
Heart rate	90 (12)	95 (14)	0.014	95.6 (12.09)	103 (15)	< 0.001	103 (12)	111 (14)	0.002
Borg's RPE	9.1 (2.2)	10.0 (2.7)	0.179	11.3 (1.8)	12.3 (2.5)	0.018	10.9 (2.55)	11.7 (2.0)	0.218
Metabolic equivalents	1.31 (0.19)	1.97 (0.37)	< 0.001	1.90 (0.29)	2.37 (0.49)	< 0.001	2.49 (0.38)	3.06 (0.47)	< 0.001

Abbreviation: RPE, perceived exertion scale; SD, standard deviation.

Figure 1. Relative oxygen uptake (mL/kg/min) was consistently significantly higher in exercises with vibration.



*P < 0.001.

individuals was: y = 0.8178x + 3.6074 (R^2 = 0.5989) and for obese individuals: y = 0.9124x + 2.1156 (R^2 = 0.739).

There was a positive correlation between weight and oxygen consumption (L/min) during the exercises, which was strongest for dynamic squat (r = 0.733; $P < 0.001$), calf raises (r = 0.678; $P < 0.001$), and dynamic squat with vibration (r = 0.598; $P = 0.001$). Although the differences in oxygen uptake between exercises with and without vibration decreased with increasing body fat percentage, this correlation was only significant for calf raises (r = –0.607; $P = 0.005$).

Discussion

In this study, we aimed to demonstrate that the addition of WBV to an exercise protocol leads to an increase in oxygen uptake. To the best of our knowledge, this is the first time that this effect has been described in overweight and obese women exercising on a vibration platform in which the entire platform translates up and down. The lack of a normal weight group could be considered a shortcoming of this study. However, the effect of vibration on oxygen uptake in normal weight individuals has been documented by Rittweger et al.[15] They also reported that additional load during exercises can increase the oxygen uptake while exercising on a vibration platform. Our results show that there is a positive correlation between body weight and oxygen uptake, but we could not find a significant higher increase of oxygen uptake due to the addition of vibration in obese participants compared with overweight participants, although there was a trend. A reason for the lack of significance could be the use of a cut-off (BMI = 30 kg/m^2) to

Figure 2. Linear regression between relative oxygen uptake (mL/kg/min) during exercises with and without vibration.

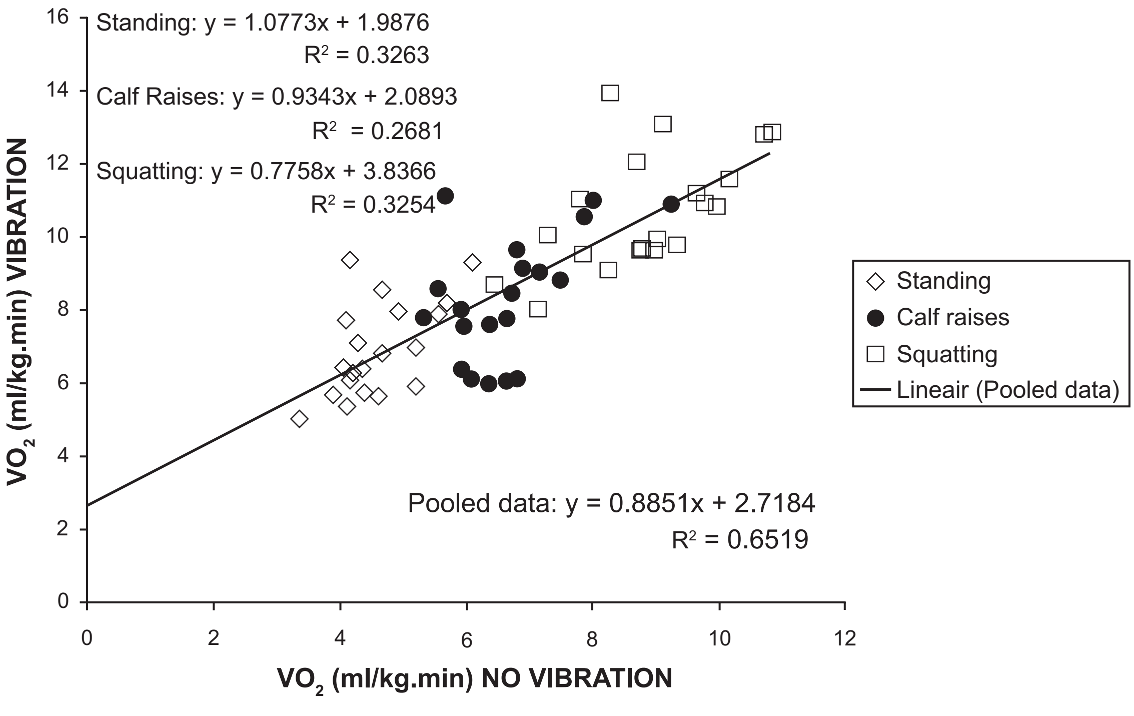
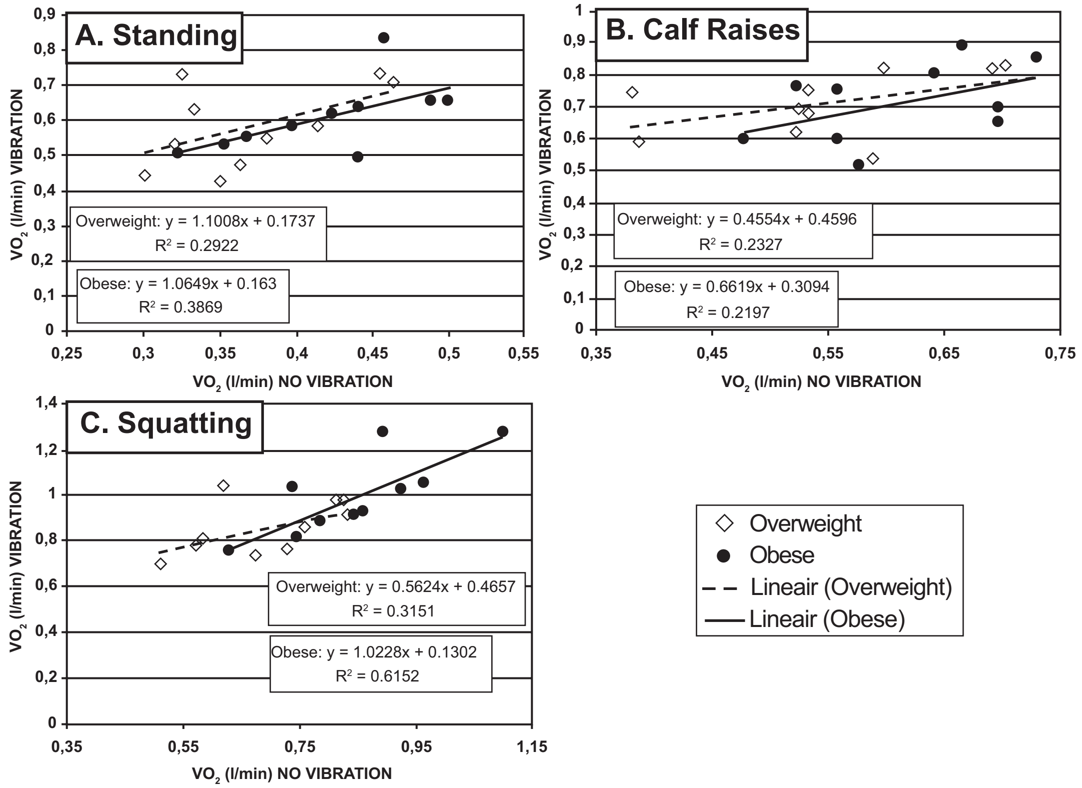


Figure 3. Linear regression between oxygen uptake (L/min) during stand **(A)**, calf raises **(B)**, and squatting **(C)**, with and without vibration in overweight (n = 10) and obese (n = 10) subjects.



Abbreviations: VO_2, oxygen uptake.

separate overweight from obese individuals. Thus, 2 individuals could be categorized into 2 different BMI categories, although their body weight and BMI could be very similar. The use of an additional fixed load during exercise would probably lead to a more obvious separation between groups.

As shown in Figures 1 and 2, the mean oxygen uptake increases from standing over calf raises to squatting. As the mean oxygen uptake increases between these exercises, the coefficients of the regression lines decrease, indicating that the correlation between the exercise without vibration and the exercise with vibration becomes weaker. Thus, the more oxygen that is consumed during an exercise, the smaller the effect of additional vibration on oxygen uptake becomes (although the effect was significant in all 3 exercises). The negative correlations between body fat percentage and change in oxygen uptake due to vibration were only significant for calf raises. It could be assumed that the mechanical energy generated by the vibration platform is partly absorbed by fat mass, thus decreasing the effect of vibration on oxygen consumption and possibly on muscle activation.

The strength of correlation (for absolute VO_2 in standing and calf raises), testing conditions between with and without vibration are similar in both subgroups; however, the strength of correlation was quite different in the squatting testing position (Figure 3). This could be due to the fact that a difference in VO_2 between overweight and obese women becomes more evident the "harder" the exercise gets or when large muscle groups (eg, quadriceps) are used. The increase in oxygen uptake due to vibration (in the total group) is supported by the fact that a comparable level of exhaustion and muscular fatigue is reached more rapidly with vibration than without, as suggested by Rittweger et al.[21] Vibrating the agonist increases antagonist coactivity, which could also explain an increase in oxygen uptake.[22] An improvement of muscle activation during WBV training is reported by some authors, although de Ruiter et al[23] clearly found no such effect.[4,14]

Physical training, both cardiovascular and strength training, is important in the treatment of overweight and obese individuals. Strength training can potentially reduce overweight-related health risks.[24] Roelants et al[25] reported WBV to induce a gain in muscle strength, combined with a small increase in fat free mass. This means WBV could be an effective way to increase strength in overweight individuals. The specific interval-like protocols used in most fitness centers and the modest mean values of oxygen uptake and heart rate suggest its limited use for cardiovascular training. Regarding the amount of extra calories burned due to the vibration, our data show that the mean difference between 15 minutes standing with and without vibration is 14.2 kcal (± 6.1 kcal), which is the energetic equivalent of a few minutes of cycling. Thus, the potential added value of WBV for overweight individuals does not seem to be a cardiovascular improvement or the burning of excessive calories, but rather an increase in muscle activation. The clinical relevance of WBV training could be described as producing a gain in strength that is comparable with the strength increase following a standard fitness training program consisting of cardiovascular and resistance training.[25] Adding resistance training to a weight loss program can lead to the preservation of lean body mass and to favorable body composition changes.[17,26] Furthermore, recent findings in animal studies show that WBV reduced body fat accumulation and serum leptin without affecting muscle function or food consumption in Fischer rats.[27] Interestingly, Rubin et al[28] recently reported that adipogenesis is inhibited in mice by brief, daily exposure to low-magnitude mechanical signals, delivered via WBV. When attempting to describe the underlying mechanism of the effects of WBV, it should be noted that WBV may elicit secondary responses through interaction among different systems: the skeletal, muscular, endocrine, nervous, and vascular systems.[29]

Conclusions

These results support previous evidence in adults of normal weight that supplementing exercises with vibration leads to an increase in oxygen uptake. The physiological pathways behind this increase in oxygen uptake remains unclear. More research is needed to investigate the possible effect of WBV on different tissues of the human body and whether this could lead to clinically relevant changes in obese adults. Based on our results, we conclude that there is a significant increase in oxygen uptake due to the addition of WBV to an exercise protocol in overweight and obese women.

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Conflict of Interest Statement

Dirk Vissers, MSc, PhD, Jean-Pierre Baeyens, PhD, Steven Truijen, PhD, Kris Ides, MSc, Carl-Christian Vercruysse, MSc, and Luc Van Gaal, MD, PhD disclose no conflicts of interest.

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