Acute Effects of Whole-Body Vibration Exercises at 2 Different Frequencies Versus an Aerobic Exercise on Some Cardiovascular, Neuromotor and Musculoskeletal Parameters in Adult Patients With Obesity

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Abstract
Whole-body vibration exercise (WBVE), a nonimpact, viable and safe type of exercise, has been reported to be useful in the physical rehabilitation of obesity. Aim of the study was to compare the acute effects of WBVE with a session of walking and running (AER) on cardiovascular, neuromotor and musculoskeletal parameters in obese subjects. Sixteen adult obese subjects performed 3 tests (WBVE at 30 and 45 Hz, AER) randomly in different days. An increase in heart rate was recorded after AER and 45 Hz WBVE (p < 0.001), while only AER increased systolic (p = 0.003) and diastolic blood pressure (p = 0.004) and ratings of perceived exertion (p < 0.001). All 3 exercises determined lactate increase [AER p < 0.001, 45 Hz (p = 0.04), 30 Hz (p = 0.03) WBVE] and sit-and-reach (AER p = 0.002, 45 and 30 Hz WBVE p < 0.001) and fingertip-to-floor improvements (AER p = 0.003, 30 and 45 Hz WBVE p < 0.001), while only 30 Hz WBVE determined improvement in stair climbing test (p < 0.05). Considering the lack of effects of 30 Hz WBVE on the cardiovascular system and fatigue and its positive effect on flexibility and muscle power, this procedure can be considered an appropriate exercise protocol for the obese population.

Keywords
obesity, whole-body vibration, aerobic exercise, rehabilitation, flexibility

Introduction
Obesity has progressively become a largely widespread clinical condition, affecting quality of life and resulting in many functional physical limitations¹ which frequently hamper these patients to perform common daily routine activities (i.e. walking, climbing stairs, etc.).² In particular flexibility, which is important to perform both simple and complex movements involved in daily activity,³ is gradually impaired in subjects with obesity, causing postural changes which further compromise their motor performance.⁴

Increased physical activity is a fundamental element in the comprehensive lifestyle intervention and in the clinical rehabilitation of individuals with obesity,¹ who need specific physical exercises aiming to improve different components of their physical fitness.

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Authors reported that general aerobic warm-up protocols, such as brisk walking, jogging or running, are able to improve muscle performance\(^6\) and also flexibility since warmer muscle are more extensible.\(^6\) However, it is clearly evident that running is not always an appropriate exercise for obese subjects, considering that their excessive body mass causes a greater impact force when the foot lands on the ground increasing their risk of injury,\(^7\) joint pain and inflammation due to the overload on joints\(^8\) and higher physical fatiguability.\(^9\)

Whole-body vibration exercise (WBVE) is reported to be a safe, feasible and non-impact type of exercise, able to improve physical fitness, furthermore suitable and well-tolerated by patients with different disorders,\(^10-12\) including obesity.\(^13\) WBVE is able to improve both muscle strength\(^14\) and flexibility,\(^2\) these improvements being hardly achieved with the other traditional training exercises\(^15\) requiring a higher level of agility.

The ability of WBVE to increase flexibility and muscle power involves muscular, neural, circulatory and thermoregulatory factors.\(^16\) WBVE stimulates blood circulation by increasing peripheral blood flow without altering skeletal muscle oxygenation\(^17\) and generating a thermal effect, which is widely used in facilitating flexibility.\(^18,19\) Moreover, WBVE induces non-voluntary muscle contractions followed by muscle relaxation and raises the pain threshold allowing to stretch further.\(^16\)

Several studies have indeed reported that WBVE can lead to greater improvements in both muscle strength and power,\(^14,20,21\) so it can be considered to be a highly effective tool to enhance muscular performance.

An important factor to be considered in WBVE is vibration frequency of the mechanical vibration generated in the vibrating platform that is transmitted to the individual.\(^16\) In fact, it has been reported how frequency is a fundamental parameter that can influence and change the general WBVE positive effects. In this context, lower frequencies (i.e. equal or below to 35 Hz) have shown acute enhancement in neuromuscular performance, flexibility\(^22\) and muscle activity\(^23,24\) compared to higher frequencies\(^22,25\) (i.e. above 40 Hz).

Taking into account all the above considerations, the aim of the present study is to compare the acute effects of WBVE at 2 different frequencies (30 Hz and 45 Hz) with those obtained following a session of walking and running at constant speed on some cardiovascular, neuromotor and musculoskeletal parameters, in particular flexibility and lower limb muscle power, in a group of adult subjects with obesity.

**Methods**

**Participants**

Sixteen adults with severe obesity (7 males and 9 females) were recruited for this study (mean ± standard deviation: age 32.2 ± 7.6 years; body mass (BM): 123.6 ± 21.7 kg; height: 1.68 ± 0.1 m; body mass index (BMI): 44.2 ± 8.6 kg/m\(^2\)). All the participants were hospitalized for a 3-week multidisciplinary integrated body weight reduction program at the Division of Metabolic Diseases, *Istituto Auxologico Italiano*, Verbania, Italy. Before the admission to the study protocol, all the patients gave their written consent after being fully informed of the nature and the procedures of the study. The protocol was approved by the Ethical Committee of *Istituto Auxologico Italiano*, Milan, Italy (project code: 01C026_2020, acronym: VIBRADUOB).

All of the participants were sedentary and were not involved in any strenuous activity in the 48 hours preceding the first experimental session. None of them reported any cardiorespiratory problem or musculoskeletal disorder that could have influenced the execution of the 3 interventions.

**Training Sessions**

Each training session was performed in the morning and the participants were admitted to the laboratory 1 hour before the beginning of the tests. Each patient performed 3 tests, in random order and in different days: (1) aerobic session (walking/run, AER), (2) WBVE at 30 Hz (30 Hz WBVE), (3) WBVE at 45 Hz (45 Hz WBVE). The randomization was obtained throughout the use of the “random sequence generator” available on the website random.org. The training sessions lasted 15 minutes each and were separated by a day of rest as wash-out period.

The AER session was performed on a motorized treadmill (RUN-XT 500, Technogym S.p.A., Cesena, Italy) without inclination. Subjects started with a 5-minute walk at a constant speed of 3 km/h, followed by a 10-minute light run at a constant speed of 5 km/h.

During the 30 Hz WBVE session, individuals stood in a static squat position with a 130° knee flexion on the vibrating platform (Nevisys H1©, RME, Ferrara, Italy) with vertical sinusoidal vibrations at a frequency of 30 Hz and a peak-to-peak displacement of 3 mm for 60 seconds. The acceleration peak of the vibration was 2.85 g, as assessed by magnetic monoaxial accelerometer (Vibration Meter, Lutron VB-8200). Then, subjects rested for 30 seconds in a relaxed stood position on the vibrating platform. This sequence was repeated 10 times in a row. The 130° knee flexion was controlled by using a large articulation Jamar stainless steel goniometer (Performance Health, Warrenville, IL, USA) by a trained researcher.

During the 45 Hz WBVE session, individuals performed the same test just described for 30 Hz, but with the vibrating platform set at a frequency of 45 Hz and peak-to-peak displacement of 3 mm.

**Outcome Measures**

**Anthropometric Measures**

A scale with a stadiometer (Wunder Sa.Bi., WU150, Trezzo sull’Adda, Italy) was used to determine height and weight.
BMI was calculated as the ratio between BM (kg) and height squared (m²).

Body composition was evaluated by a multifrequency tetrapolar impedance meter (BIA, Human-IM Scan, DSI-Medigroup, Milan, Italy) with a delivered current of 800 µA at a frequency of 50 kHz. In order to reduce errors of measurement, attention was paid to the standardization of the variables that affect measurement validity, reproducibility, and precision. Measurements were performed according to the method of Lukaski et al. (1987)²⁶ after 20 minutes of rest in a supine position with arms and legs relaxed and not in contact with other body parts. Fat free mass (FFM) was calculated using the predictive equation developed by Lazzer et al. (2008),²⁷ and fat mass (FM) was derived as the difference between BM and FFM.

All the following parameters were evaluated before and immediately after the end of each 1 of the 3 exercise sessions.

**Blood Pressure, Heart Rate and Peripheral Oxygen Saturation**

Systolic (SBP) and diastolic (DBP) blood pressure were measured twice (3-min interval in-between) on the dominant arm with an aneroid sphygmomanometer (TemaCertus, Milan, Italy), by using appropriately sized cuffs. Heart rate (HR) and peripheral oxygen saturation (SpO₂) were measured with a pulse oximetry device (Nonin Medical Inc., Plymouth, MN, USA) placed on the patient’s second finger.

**Rating of Perceived Exertion**

Ratings of perceived exertion (RPE), defined by the feelings of general fatigue, stress, strain and discomfort felt by the participant, were obtained before and immediately after each training session and determined by using the Borg CR10 scale.²⁸

**Stair Climbing Test**

The stair climbing test (SCT) is a standardized procedure, previously validated by our group, used to measure maximal lower limb muscle power and assess motor control.²⁹-³¹ In this test, previously validated by our group, used to measure maximal lower limb muscle power and assess motor control.²⁹-³¹ In this test, subjects were asked to climb up ordinary stairs (13 steps of 15.3 cm each vertical distance 1.99 m) at their highest speed, in a supine position with arms and legs relaxed and not in contact with other body parts. Fat free mass (FFM) was calculated using the predictive equation developed by Lazzer et al. (2008),²⁷ and fat mass (FM) was derived as the difference between BM and FFM.

The PSTCT values obtained with the equation were normalized by BM and by FFM.

**Sit-and-Reach**

Subjects performed the sit-and-reach test (SR) for flexibility, according to the protocol described by Chen et al.³³ A flexible measuring tape was fixed to an exercise mat where subjects sat keeping their knees extended and the tape between their legs. Subjects were asked to reach forward slowly, as far as possible, with their hands overlapped and to hold the end position for 2 seconds. Three attempts were allowed and the mean farthest point reached with the fingertips was the obtained SR distance. The level of the heels was used as recording zero so that any measure that did not reach the heels was negative and any measure beyond the heels was positive.

**Fingertip-to-Floor Test**

The fingertip-to-floor test (FTF) was also used to analyze patient’s flexibility. In this test, subjects stood erect on the vibrating platform, without shoes and keeping their feet together, and were asked to bend forward as far as possible, while maintaining the knees, arms, and fingers fully extended. The vertical distance between the tip of the middle finger and the platform was measured with a measuring tape. The vertical distance between the platform and tip of the middle finger was positive for any measure that did not reach the platform and negative for any that could go further.³⁴

**Lactate**

Before each training session, a small blood sample (5 µL) was obtained from the earlobe for the determination of basal lactate (LA) concentration. The same procedure was performed immediately after the end of every exercise and at 2-min intervals until the detection of the peak value. Blood LA was measured by a portable analyzer (Lactate Pro 2, Akray, Japan).

**Statistical Analysis**

All continuous variables were reported as mean ± standard deviation. The nonparametric Wilcoxon signed rank sum test was used to test the differences between baseline and post-exercise (i.e. after) values for each variable of interest of each session. In addition, the delta (Δ) value (between baseline and post-exercise) for each variable was also calculated. The Friedman test was used for baseline comparison and inter-group comparison of delta values. A level of significance of p < 0.05 was used for all data analyses.

**Results**

Anthropometric data (height, body mass, BMI, FM, FFM) of the study group are reported in Table 1. Baseline values of SBP, DBP, HR, SpO₂, RPE, LA, SR, FTF, PSTCT and PSTCT normalized by BM and by FFM were
Table 1. Anthropometric Data of the Study Group. a

| n   | Sex (m/f) | Age (years) | Height (m) | Body mass (kg) | BMI (kg/m²) | FM (kg) | FFM (kg) |
|-----|-----------|-------------|------------|----------------|-------------|---------|---------|
| 16  | 7/9       | 32.2 ± 7.6  | 1.68 ± 0.1 | 123.6 ± 21.7   | 44.2 ± 8.6  | 61.6 ± 16.8 | 62.2 ± 13.4 |

BMI: body mass index; FM: fat mass; FFM: fat free mass.
aData are shown as mean ± standard deviation.

Table 2. Effects of AER, 30 Hz WBVE and 45 Hz WBVE on SBP, DBP, HR and SpO2. a

|                   | AER (intra-group comparison) | 30Hz WBVE (intra-group comparison) | 45Hz WBVE (intra-group comparison) |
|------------------|-----------------------------|-----------------------------------|-----------------------------------|
| Baseline,        | Mean ± SD                   | Mean ± SD                         | Mean ± SD                         |
| After, p value   | Mean ± SD                   | p value                           | Mean ± SD                         | p value                           |
| SBP (mm Hg)      | 120.9 ± 9.2                 | 120.3 ± 11.2                      | 118.3 ± 11.8                      | 0.003                             |
| DBP (mm Hg)      | 77.8 ± 5.5                  | 81.4 ± 8.6                        | 78.7 ± 8.8                        | 0.004                             |
| HR (bpm)         | 87.1 ± 11.7                 | 85.4 ± 7.8                        | 83.4 ± 10.6                       | <0.001                            |
| SpO2 (%)         | 96.6 ± 1.4                  | 97.1 ± 1.1                        | 96.8 ± 1.7                        | 0.001                             |

WBVE: whole-body vibration; SD: standard deviation; SBP: systolic blood pressure; mmHg: millimeters of mercury; DBP: diastolic blood pressure; HR: heart rate; bpm: beats per minute; SpO2: peripheral oxygen saturation; statistical significance was set at p < 0.05.
aData are shown as mean ± standard deviation.

Table 3. Effects of AER, 30 Hz WBVE and 45 Hz WBVE on SBP, DBP, HR and SpO2, Inter-Group Comparison of the Delta Values. a

|                  | Δ SBP (mm Hg) | Δ DBP (mm Hg) | Δ HR (bpm) | Δ SpO2 (%) |
|------------------|---------------|---------------|------------|------------|
|                  | AER           | 30 Hz WBVE    | 45 Hz WBVE | AER        | 30 Hz WBVE | 45 Hz WBVE | AER        | 30 Hz WBVE | 45 Hz WBVE | AER        | 30 Hz WBVE | 45 Hz WBVE |
| Mean ± SD        | 9.9 ± 11.4    | 4.9 ± 10.1    | 5.4 ± 6.6  | -4.3 ± 11.8| 3.0 ± 2.3  | -4.8 ± 1.1 | 0.7 ± 1.2  | -4.2 ± 1.1 | -0.7 ± 2.0 | -0.4 ± 1.1 | 0.0001     |               |
| p value          | 0.0001        | 0.004         | 0.004      | 0.03       | 0.002      | 0.006      | 0.48       |               |

WBVE: whole-body vibration; SD: standard deviation; SBP: systolic blood pressure; mmHg: millimeters of mercury; DBP: diastolic blood pressure; HR: heart rate; bpm: beats per minute; SpO2: peripheral oxygen saturation; statistical significance was set at p < 0.05.
aData are shown as mean ± standard deviation.

Comparable in the 3 experimental interventions, the only exception being observed for T SCT (p < 0.05).

The effects of AER, 30 Hz WBVE and 45 Hz WBVE on SBP, DBP, HR and SpO2 are shown in Table 2. SBP and DBP values significantly increased after AER (p = 0.003 and p = 0.004, respectively), while no significant effects were recorded following 30 Hz WBVE and 45 Hz WBVE.

HR significantly increased after AER (p < 0.001) and after 45 Hz WBVE (p < 0.001), no effects being detected after 30 Hz WBVE.

SpO2 values were not modified after the 3 experimental condition.

The mean Δ values between basal and post-exercise of these parameters and the results of the inter-group comparison are shown in Table 3. The changes of SBP, DBP and HR were significantly different between the 3 interventions, while no difference were recorded in SpO2.

The effects of AER, 30 Hz WBVE and 45 Hz WBVE on fatigue, flexibility, lower limb muscle power and LA concentrations are shown in Table 4.

RPE significantly increased only after AER (p < 0.001), no significant changes being observed after WBVE, both at 30 Hz and at 45 Hz, while LA significantly increased after all the 3 experimental conditions (AER p < 0.001, 30 Hz WBVE p = 0.03, 45 Hz WBVE p = 0.04).

AER, 30 Hz WBVE and 45 Hz WBVE determined a marked improvement of SR (p = 0.002 for AER and p < 0.001 for both 30 Hz and 45 Hz WBVE) and of FTF (p = 0.003, p < 0.001 and p < 0.001, respectively).

T SCT was not modified by AER and 45 Hz WBVE, while a significant time reduction was observed after 30 Hz WBVE (p = 0.049). As a direct consequence, P SCT did not change after AER and 45 Hz WBVE, while it significantly increased after 30 Hz WBVE (p = 0.03) even when normalized by BM and FFM (p = 0.04 for both normalizations).

The mean Δ values between basal and post-exercise of these parameters and the results of the inter-group comparison are shown in Table 5. The changes of RPE and LA were significantly different between the 3 interventions, while no differences were recorded in SR, FTF, T SCT, P SCT, P SCT,BM and P SCT,FFM.

Discussion

It is well known that obesity is associated to physical impairments, which prevent the accomplishment of common daily
routine activities.2 Lifestyle interventions are fundamental for the rehabilitation of subjects with severe obesity, mainly devoted to introduce physical activity into their life and to ameliorate their musculoskeletal functions.35 However, it is fundamental to find the appropriate type of exercise that has to be effective, safe, acceptable, adapted and suitable for the obese population.1

For these reasons, the aim of the present study was to establish whether WBVE, a nonimpact, viable, and safe type of exercise, suitable and well-tolerated by the obese population, would be able to determine beneficial effects on some musculoskeletal parameters, in particular flexibility and lower limb muscle power, and to compare these effects to those obtained with a classical session of walking and running. WBVE was performed at 2 different frequencies, one lower, 30 Hz, and one higher, 45 Hz to determine which protocol has the best outcome.

No significant changes were observed in SpO2 after the 3 tests. WBVE did not determine any statistically significant changes in SBP and DBP, while a significant increase in both parameters was observed after AER. HR significantly increased after AER and after 45 Hz WBVE, whereas it was not modified after 30 Hz WBVE. Taking into account that only 30 Hz WBVE did not determine any effect on HR and blood pressure, both systolic and diastolic, WBVE at this specific frequency might be considered as a safe choice for the obese population, considering their well-known increased cardiovascular risk.36

AER was associated with a significant increase in RPE, while no changes were observed after the 2 WBVE, this finding indicating that only AER determined fatigability in obese patients. Fatigue in an important parameter to be taken into consideration since obese individuals are reported to suffer from a lower fatigue resistance,37 causing a greater chance of withdraw during physical rehabilitation.

Although it is undoubt that the AER-induced monitored changes in cardiovascular parameters may be very positive and desired, the employment of WBVE (not impacting on HR, SBP and DBP) can be useful at least in the first phases of multidisciplinary metabolic rehabilitation for severely hospitalized obese patients (as ours). AER exercises represented and will represent obviously a not replaceable opportunity in our standardized protocols for these patients, which could be integrated by WBVE in the future.

LA levels at peak were significantly increased after all 3 exercises, being although significantly higher after the AER session than after both WBVE.

All 3 exercises determined a significant and comparable increase in flexibility, which was assessed through SR and FTF. Since flexibility is a physical feature particularly important in the maintenance of the mobility and in the ability to move joints and considering its impairment in obesity,3 its improvement is highly desirable for the obese subjects to preserve their capability to perform daily activities.

Interestingly, only 30 Hz WBVE was able to reduce T SCT, indicating an improvement in the stair climbing performance and consequently a significant increase in P SCT, even when normalized by BM and FFM, indicating that this effect is independent of body weight and body composition. The exclusive ability of WBVE administered at 30 Hz to enhance lower limb muscle power represents an indication to use this frequency for obtaining these beneficial effects on muscular performance. A plausible explanation for the specific effect of 30 Hz WBVE on T SCT (and derived indexes) might be related to the lower effect on fatigability and RPE in comparison with AER, while it remains to be elucidated the difference observed with the 2 WBVE frequencies.

These findings are in agreement with our previous observation,13 demonstrating that WBVE at a low frequency (i.e. 35 Hz) was capable of improving both flexibility and muscle power without affecting the cardiovascular system in male obese adolescents.

Although the results of our studies (the above mentioned13 and the present one) suggest that both adults and adolescents suffering from severe obesity can benefit from WBVE, it should be however mentioned that the results of this preliminary study should be carefully interpreted considering the small obese population recruited. Another limitation requiring to be
mentioned is the lack of a control group, which it should have been useful to understand the benefits of the 3 interventions in a better way. In this respect, further additional studies with larger study population (including also a control group) are requested to confirm these preliminary observations.

As conclusion, taking all the above findings into consideration, 30 Hz WBVE appears to be a satisfactory exercise protocol, capable to determine a significant acute improvement in flexibility and muscle power without affecting the cardiovascular system and without overloading joints. Moreover, since the majority of obese subjects has a sedentary lifestyle and is frequently reluctant to start an exercise program, WBVE might represent a form of well-tolerated exercise to be considered in their physical rehabilitation in order to gradually introduce physical activity and avoid the risk of withdraw.

Authors’ Note
A.S., S.T. and M.B.F. designed the study. R.D.M. and G.T. enrolled the participants and performed the tests. S.T., R.D.M. and G.T. elaborated the database and analyzed the data. S.T., A.S. and M.B.F wrote the manuscript. R.D.M. and G.T. contributed to the interpretation and discussion writing. All authors contributed to the revision of manuscript. The present study was approved by the ethical committee of Istituto Auxologico Italiano (research project code: 01C026_2020, acronym: VIBRADUOB). Written informed consent was obtained from the parents of all patients.

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