Effects of Whole-Body Vibration on Physiological Responses to One Bout of Resistance Training

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ABSTRACT

Osawa Y, Oguma Y. Effects of Whole-Body Vibration on Physiological Responses to One Bout of Resistance Training. JEPonline 2011;14(2):36-45. It is widely known that sufficient training intensity and volume are needed to improve muscle fitness. Although numerous exercise programs using vibration platforms have been previously evaluated, little is known about the number of training set that are optimal for 3-axial whole-body vibration training (WBV). The purpose of this study was to determine the effects of 3-axial WBV on neuromuscular and cardiovascular responses to one bout of resistance training measured by surface electromyography, oxygen consumption (VO₂), and heart rate (HR). Ten healthy subjects performed 45 sec static squat exercise for 3 sets with a 60 sec rest period with and without WBV (frequency = 35 Hz, amplitude = 2 mm). Oxygen consumption, HR, and surface electromyography (vastus medialis, vastus lateralis, and biceps femoris) were measured throughout the trial. Significant condition-by-time interactions were observed in surface electromyography, VO₂, and HR. In vastus medialis, muscle activities progressively increased throughout the trial only under WBV. Oxygen consumption in the second set was significantly higher than that in the first set in both conditions. In addition, the values for both first and second sets with WBV were significantly higher than those without WBV. Although higher HR was observed under WBV compared with that without WBV throughout the trial, no significant increases were observed throughout the trial. We concluded that whole-body vibration has the potential to influence training intensity and probably lead to an increase in accumulated fatigue caused by resistance training with 2 to 3 sets.

Key Words: Whole-Body Vibration, Oxygen Consumption, Heart rate
INTRODUCTION

The American College of Sports Medicine recommends engaging in regular resistance training to improve muscle strength, power, local muscle endurance, and hypertrophy (18). It is widely known that sufficient training intensity and volume are needed to improve muscle fitness effectively. In conventional resistance training, many training methods have been used to stimulate skeletal muscle. Such methods include barbells, dumbbells, weight-stack machine, and training tube. Recently, whole-body vibration (WBV) has been introduced in fitness clubs, in beauty clinics, and by professional sports teams. Physically, the force generated by a vibration platform (actuator) is transferred to the human body (resonator), which significantly affects the degree of muscle stimulation during WBV exercise (19). In addition, the application of vibration to skeletal muscles causes muscle spindles in both humans and animals to exhibit a harmonized response to frequencies of vibration up to 100 Hz or even higher termed a ‘tonic vibration reflex’ (4,9).

Several studies report that WBV increases muscle activation during exercise, and some studies also suggest that WBV might affect the cardiovascular responses during exercise (1,10,20-24). While WBV might be a new training method for athletes, there are questions about the 3 types of vibration devices (pivot vibration, horizontal vibration, and vertical vibration) that are commercially available (26), and how the effects of acute and long-term exercise may differ in the devices (14,15). The Power Plate® vibration platform, which oscillates in all three planes, is one of the most popular WBV platforms. Delecluse et al. (5) found that a 12-week WBV exercise program increased muscle strength and power compared with the identical exercise without WBV. However, it is not well understood whether 3-axial WBV influences physiological responses during exercise. Although Roelants et al. (24) found that WBV increased leg muscle activity during different squat exercises it is still less clear how the 3-axial WBV might affect muscle activity in one bout of training. In addition, it seems there are no studies that have investigated the cardiovascular responses during WBV. Although numerous exercise programs that use vibration platforms have been evaluated, little is known about the optimal number of training sets used with WBV training. As a result, we investigated the effects of 3-axial WBV on neuromuscular and cardiovascular responses in one bout of training program.

It was hypothesized that the stimulation of WBV would increase physiological responses in addition to the body-weight exercise because vibration increases muscle activation during muscle contractions, primarily owing to the stretch reflex (19). The purpose of the present study was to investigate the effects of WBV on neuromuscular and cardiovascular responses caused during one bout of body-weight exercise measured by surface electromyography (sEMG), oxygen consumption (VO₂), and heart rate (HR).

METHODS

Subjects

Ten healthy subjects (5 males and 5 females; age: 30.2 ± 5.8 years; body mass: 62.9 ± 9.5 kg; height: 168.6 ± 10.2 cm, mean ± SD) who had not previously experienced long-term WBV training volunteered for this study. All subjects were recreationally active. Exclusion criteria were pregnancy, the presence of infectious disease, history of severe orthopedic disease, diabetes, and acute hernia. Subjects were asked to refrain from any vigorous physical activity for 1 day before each test.

Procedures

A single group repeated-measure design under no vibration (No-VIB) and whole-body vibration (VIB) conditions was used to determine the effects of WBV on the acute responses to a squat exercise
program. A whole-body platform-oscillating device (Power Plate®, Power Plate International, Northbrook, IL, U.S.) was used in this study at a frequency of 35 Hz and an amplitude of 2 mm. Keio University’s local ethics committee approved this study. Written informed consent to participate in this study was obtained from all subjects.

**Exercise Protocol**
The subjects performed an exercise program comprising a series of body-weight squat exercises under No-VIB and VIB conditions in a randomized order on different days within 1 week. The program consisted of 3 sets of a 45-sec static squat exercise (knee angles at about 90-degree flexion) with a 60-sec rest period on the vibration platform. Two points were marked on the vibration platform to maintain a toe-to-toe distance of 40 cm in all exercises. Before commencing a test, a supervisor checked the distance between the feet of the subjects. The subjects wore socks without shoes during the test. All subjects were supervised throughout the tests by the investigators. In particular, knee angles were constantly checked during the exercises, and if necessary, the subjects’ position was modified.

**Measurements**
The sEMG signals (Noraxon TELEMYO 2400T V2, Scottsdale, AZ) from the vastus medialis (VM), vastus lateralis (VL), and biceps femoris (BF) muscles of the right thigh were recorded using disposable Ag/AgCl snap electrodes (EM-272, Noraxon, Scottsdale, AZ). The dimensions of the figure-8-shaped adhesive area were 4 cm × 2.2 cm. The diameter of each of the 2 circular conductive areas was 1 cm and the inter-electrode distance was 2 cm. After the skin over the muscle belly was lightly abraded, the electrodes were fixed in accordance with the guidelines of Surface Electromyography for the Non-Invasive Assessment of Muscles (11). The sEMG signals were sampled at 3,000 Hz and band-pass filtered (15–500 Hz) thereafter. After the electrodes were attached, the participants sat on a chair for at least 5 min to acclimatize the skin to the electrodes. Before the exercise program was conducted, muscle activity was recorded twice for 5 sec each during isolated isometric maximum voluntary contractions (MVC) (Figure 1).

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![Figure 1. Graphical representation of an exercise program comprising a series of squats. sEMG: surface electromyography, MVC: maximal voluntary contraction.](image-url)
The MVCs of the VM and VL muscles were recorded at a 60-degree knee angle sitting on a chair; whereas, the MVC of the BF was recorded at an 80-degree knee angle in the prone position. Data processing was performed using MyoResearch XP, Master Package ver. 1.06.74 (Noraxon Inc., Scottsdale, AZ). It is recommended that a short duration (0.25 to 0.5 sec) is used for sustained isometric contraction level over 50% of MVC (16,17). The raw EMG signals from 30.0 to 30.5 sec were converted to EMG root-mean-square (EMGrms) to compare the VIB and No-VIB conditions.

Oxygen consumption was continually recorded by a breath-by-breath pulmonary gas exchange system (Quark b2®, Cosmed, Rome, Italy). Before each test, the turbine of Quark was calibrated with a 3-L syringe, and Quark was also calibrated with ambient air (oxygen, 20.93%; carbon dioxide, 0.03%). Heart rate was recorded at the same time of the VO$_2$ recordings, using a HR monitor (POLAR T41 CE0537 N2965, Polar Electro, Finland) that was connected to the breath-by-breath pulmonary gas exchange system.

To avoid possible artifact and strong breath-holding at the beginning of each exercise, data recorded during the 16- to 45-sec interval of each set were used for further analyses. Almost all the subjects had a decrease in HR and a VO$_2$ value = 0 was seen several times within the first 15 sec of each set. However, an oxygen consumption value = 0 was not found after 15 sec. Because the VO$_2$ was recorded per expiration, the number of measurements was not the same in each minute of exercise. Therefore, the data were averaged by 10-sec intervals.

**Statistical Analyses**

All values are presented as the mean ± SD. Normality assumptions were performed using Kolmogorov-Smirnov test, and equal variance assumptions were performed using Levene test for equal variance. If normality and equal variance were assumed, longitudinal changes in all outcomes were compared within the groups using a two-way ANOVA (condition-by-time) with repeated measurements. After an F-value was found to be significant, preplanned contrast analyses (Bonferroni correction) were performed to evaluate the significance of effects (pre vs. post, and between groups). The PASW version 18.0 for Macintosh (SPSS, Inc., Tokyo, Japan) was used for the statistical analyses. The level of significance was set at $p < 0.05$.

**RESULTS**

**VO$_2$ and Heart rate Responses**

Figure 2a shows the results of VO$_2$ in this trial. Significant condition-by-time interactions were observed in VO$_2$ [F (7,63) = 1.94, $p = 0.04$]. Post hoc test revealed significant condition differences in the first set, the first rest interval, and the second set. In the VIB condition, significant time effects were observed between the first set and the second set. In the No-VIB condition, significant time effects were also found between the first and second sets. As for the HR, significant condition-by-time was observed between the conditions [F (7,63) = 3.54, $p = 0.03$] (Figure 2b). Significant condition differences were observed at all time points except the pre-exercise value.

**sEMG: The VM Muscle**

Figure 3 shows %EMGrms of the muscles in each set. In the VM muscle, significant condition-by-time was observed [F (2,18) = 6.69, $p = 0.02$]. The post hoc test between the conditions revealed that %EMGrms was significantly higher under the VIB condition than with the No-VIB condition in each set: 1st set, $p = 0.02$; 2nd set, $p = 0.02$; 3rd set, $p = 0.004$. In each set, %EMGrms was significantly higher in the VIB condition than that in the No-VIB condition. Significant differences were observed between the 2nd and 3rd sets under the No-VIB condition (1st set vs. 2nd set, $p = 0.054$; 2nd set vs.
3rd set, \( p = 0.03 \); 1st set vs. 3rd set, \( p = 0.57 \)), whereas significant differences were observed in all sets under the VIB condition (1st set vs. 2nd set, \( p = 0.01 \); 2nd set vs. 3rd set, \( p = 0.002 \); 1st set vs. 3rd set, \( p = 0.048 \)).

**sEMG: The VL muscle**

In the VL muscle, no significant condition-by-time difference was observed \([F (2,18) = 0.80, p = 0.48]\). In the condition analysis, a significant difference was observed \([F (1,9) = 10.9, p = 0.03]\). In the time analysis, a significant difference was observed \([F (2,18) = 11.2, p = 0.005]\).

**sEMG: The BF Muscle**

In the BF muscle, no significant condition-by-time differences were observed \([F (2,18) = 0.63, p = 0.56]\). In the condition analysis, a significant difference was observed \([F (1,9) = 0.70, p = 0.45]\). In the time analysis, a significant difference was observed \([F (2,18) = 0.13, p = 0.88]\).

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**DISCUSSION**

The present study demonstrates the effects of 3-axial WBV using a Power Plate® next generation on neuromuscular and cardiovascular responses caused by one bout of body-weight exercise measured by a sEMG, \( VO_2 \), and HR. The present study had 2 major findings. First, higher muscle activity was found in VM muscle compared with that in the No-VIB condition. In VM muscle, muscle activities progressively increased throughout the trial only in the VIB condition. Second, \( VO_2 \) in the second set

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**Figure 2a.** Results of \( VO_2 \) in an exercise program comprising a series of squats. Rest 3-1 represents the first 60 sec of the rest period, and rest 3-2 represents the second such period. VIB, whole-body vibration. No-VIB, without whole-body vibration. * \( p < 0.05 \) (two-way ANOVA); † \( p < 0.05 \) (Bonferroni’s post hoc test revealed a significant difference between the conditions), ‡ \( p < 0.05 \) (Bonferroni’s post hoc test revealed a significant difference between the sets or intervals within a given condition), § \( p < 0.05 \) (vs. baseline value by Bonferroni’s post hoc test).
was higher than that in the first set in both conditions. Higher VO$_2$ was observed in both first and second sets in the VIB condition compared with that in the No-VIB condition.

**Neuromuscular Responses**

The neuromuscular responses and differences with and without WBV became greater with ensuing sets in VM muscle. It has been reported that muscle activities (frequency and amplitude) measured by EMG analysis would be increased by muscle fatigue (6). Leg extensor muscle (VM) activities were increased by WBV; whereas, those of leg flexor muscle (BF) were not. This is in line with the findings of a previous study (1). Larger responses of muscle activities **apposed** [with an application to] vibration were found when the muscles were pre-stretched or pre-activated than when they were relaxed (2,3). Quadriceps muscles are stretched in a 90-degree knee flexion squat position, resulting in the enhancement of muscle activation by WBV.

The present study suggests that the effects of resistance training with WBV on muscle activities become greater in a standard static squat exercise program. This study provides important findings on the effects of resistance training with WBV. A series of standard resistance training (more than 2 to 3 sets per session) with WBV leads to muscle fatigue, while the same exercise without WBV does not lead to an increase in muscle activations.

![Graph](image)

**Cardiovascular Responses**

Significantly higher VO$_2$ during the second set under the VIB condition was observed compared with that during the first set in both conditions, and higher VO$_2$ was observed in the VIB compared with
that in the No-VIB. WBV would increase the slow component of VO\(_2\). In anaerobic exercise, it is well known that, after the fast rise lasting 2 to 3 min, further VO\(_2\) increases occur during aerobic exercise, which is called the slow component of VO\(_2\). The extra energy expenditure, similar to the slow component of VO\(_2\) in aerobic exercise, would appear when successive sets are performed in anaerobic exercise (25). The increase in the slow component of VO\(_2\) would be caused by exercising skeletal muscles (e.g., the increase in recruitment of muscles caused by fatigue, muscle acidosis, the increase in muscle temperature, and the increase in O\(_2\) demand for gluconeogenesis) (8,13). One possible explanation of our results is that WBV appears to increase accumulated fatigue primarily because of higher demands in muscle activities in a single session of resistance training. The progressively increased muscle activity throughout the training program would be related to the cardiovascular responses.

Figure 3. Results of surface electromyography for an exercise program comprising a series of squats. EMG: electromyography root-mean-square, VM: vastus medialis, VL: vastus lateralis, BF: biceps femoris. VIB, whole body vibration; No-VIB, without whole body vibration. * p < 0.01 (two-way ANOVA), † p < 0.05 (Bonferroni’s post hoc test revealed a significant difference between the conditions), ‡ p < 0.05 (Bonferroni’s post hoc test revealed a significant difference between the sets or intervals within a given condition).

A novel aspect of the present study is the exclusion of the first 15 sec of each exercise set to remove the data produced by breath-holding from the cardiovascular data. This prevents misinterpretation of the cardiovascular responses to the exercise and to WBV. Holding of breath is frequently observed during anaerobic exercise and, in particular, the Valsalva maneuver often occurs in heavy weightlifting and isometric exercise, resulting in an increase in arterial pressure and a reduction of venous return (7). Holding of breath confounds the assessment of VO\(_2\) during the exercise period. Thus, we performed data analysis excluding intervals with breath-holding to investigate the effects of WBV on VO\(_2\) and HR. The application of exclusion of the first 15 sec results in an overestimation of
the true magnitude of the cardiovascular responses to anaerobic exercise and WBV because VO$_2$ data = 0 and a decrease in HR was often found in the first 15 sec. However, if the exclusion is not applied, then, VO$_2$ data = 0 and the decrease in HR causes an underestimation of cardiovascular responses during anaerobic exercise.

Another possibility that could affect cardiovascular and neuromuscular responses is that vibration influences postural responses. The findings of the study by Kavounoudias et al. (12) imply that skin mechanoreceptors are more sensitive to mechanical vibration than muscle spindles when vibration at a frequency of 20 to 40 Hz is applied to the soles of the feet, and that vibration within these frequencies affects postural regulation. In the present study, WBV and the 90-degree static squat position may require more postural control, resulting in increased VO$_2$, HR, and sEMG activity. However, it is unclear if WBV-induced changes in muscle activity are enhanced not by the increase in stretch reflex alone but by the increase in background muscle activity as well. Further investigations are needed to determine the roles played by the postural control during WBV exercise.

The limitations of this study should be considered when interpreting and generalizing the findings. First, we examined neuromuscular and cardiovascular responses only in a single condition. In the vibration exercise, further studies are needed to investigate the effects of WBV in exercise with the other conditions (e.g., vibration parameter; frequency, and amplitude along with weight-loaded conditions). Second, the exercise in the present study was only a 90-degree knee flexion static squat without any load. Therefore, this study does not clarify the effects of WBV on body fatigue during dynamic exercise.

**CONCLUSIONS**

This study provides important findings for programming WBV training on the basis of the results, showing that neuromuscular and cardiovascular responses increased with WBV in a successive set program. Multiple sets (2 to 3 sets) of body-weight exercise coupled with WBV might increase training intensity and enhance training fatigue in resistance training with 3-axial WBV. Therefore, the number of sets per session should be taken into consideration on the basis of training status (novice or professional) more than in the case of resistance training without WBV.

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