



Original Article

Analysis of muscle activation in each body segment in response to the stimulation intensity of whole-body vibration

DAE-YEON LEE, PT, PhD¹⁾

¹⁾ Department of Silver Industrial Engineering, Kangnam University: 40 Kangnam-ro, Giheung-gu, Yongin-si, Gyeonggi-do 446-702, Republic of Korea

Abstract. [Purpose] The purpose of this study was to investigate the effects of a whole-body vibration exercise, as well as to discuss the scientific basis to establish optimal intensity by analyzing differences between muscle activations in each body part, according to the stimulation intensity of the whole-body vibration. [Subjects and Methods] The study subjects included 10 healthy men in their 20s without orthopedic disease. Representative muscles from the subjects' primary body segments were selected while the subjects were in upright positions on exercise machines; electromyography electrodes were attached to the selected muscles. Following that, the muscle activities of each part were measured at different intensities. No vibration, 50/80 in volume, and 10/25/40 Hz were mixed and applied when the subjects were on the whole-vibration exercise machines in upright positions. After that, electromyographic signals were collected and analyzed with the root mean square of muscular activation. [Results] As a result of the analysis, it was found that the muscle activation effects had statistically meaningful differences according to changes in exercise intensity in all 8 muscles. When the no-vibration status was standardized and analyzed as 1, the muscle effect became lower at higher frequencies, but became higher at larger volumes. [Conclusion] In conclusion, it was shown that the whole-body vibration stimulation promoted muscle activation across the entire body part, and the exercise effects in each muscle varied depending on the exercise intensities.

Key words: Whole-body vibration, Muscle activation, Electromyography

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INTRODUCTION

Recently, it was reported that exercises using whole-body vibration (WBV) machines have been attracting much attention from athletes and the general public. These exercises generate positive effects, as they can improve muscle function in older adults and individuals with functional problems¹⁻⁴⁾. WBV exercises are advantageous as they pose a lower risk of injury and can improve muscle strength in shorter periods of time when compared to other resistance exercises, particularly as they can be performed without an external load⁵⁾.

As the use of WBV exercises increase, a number of studies have been conducted to investigate the activation of lower extremities caused by the change in vibration intensity, as well as to propose optimized vibration intensities in a short period of time. When comparing the training intensities of the WBV exercises and conventional squat motions that target male and female college students, both of these two exercise methods offered gradual improvement in the vibration intensity and muscle activations of the lower extremities and lumbar region, and they both showed similar lower extremity and lumbar muscle activation⁴⁾. When investigating the optimized representative muscle activations of the upper/lower extremities with the WBV exercise that targeted male college students, muscle activations in the upper/lower extremities were increased at

Corresponding author. Dae-Yeon Lee (E-mail: leedy@kangnam.ac.kr)

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higher frequencies (35 Hz, 40 Hz, and 45 Hz) and at higher amplitudes (4 mm)⁶). In the case of female volleyball players, the activation of the lower vastus lateralis muscle according to vibration frequency (isometric, 30 Hz, 40 Hz, and 50 Hz) in the WBV exercise was higher than that in the no-vibration exercise. The greatest muscle activation was shown at 30 Hz⁷). In a study on the lower extremity muscle power to investigate the optimized frequency, amplitude, and duration for short-term WBV exercises that target healthy adult males and females, the correlation between vibration stimulation and time was not disclosed; however, high frequencies and high amplitudes, as well as low frequencies and low amplitudes, were effectively related⁸).

As was shown in the aforementioned studies, it was generally found changes in the vibration intensity of WBV exercises affect the activation of various muscles. However, a general consensus about the optimized vibration intensity has not yet been derived. In addition, further multidirectional studies on the effects of WBV exercises on muscles in the entire body, as well as lower-extremity muscles, need to be performed, and current studies on muscle activation in each muscle are also insufficient.

Therefore, this study will investigate the effects of WBV stimulation on the activation of representative muscles in the human body, particularly in response to various intensities using different amplitudes and frequencies, as well as effective vibration intensity.

SUBJECTS AND METHODS

The subjects in this study included 10 healthy men in their 20s without orthopedic disease (age: 22.5 ± 1.7 years; height: 180.8 ± 7.5 cm; weight: 79.4 ± 9.2 kg). The subjects received a complete explanation of the objective and contents of this study, as well as the study procedures, subjects' rights, and safety issues. Following that, they voluntarily agreed to participate in the study, and signed an informed consent form in accordance with the ethical standards of the Declaration of Helsinki. The subjects stood on the vibration exercise machines (TT2590P; Turbosonic, Seoul, Korea) in comfortable positions with dangling arms. They were exposed to either no-vibration or each vibration stimulus for 10 seconds; they stood with their feet shoulder-width apart while staring straight ahead. They had 5-minute break times after each intensity to minimize the effect caused by each stimulus. The analysis intensity was set at 10 Hz, 25 Hz, and 40 Hz for a volume of 50, and 10, 25, and 40 Hz for a volume of 80; the measurement sequence was selected at random.

A Bagnoli 8-channel wireless electromyography system (Delsys, Boston, MA, USA) was used to measure the muscle activation. The electrodes were attached to 8 muscle bellies: the lateral gastrocnemius, soleus, tibialis anterior, vastus lateralis, and biceps femoris in the lower extremities, and the rectus abdominis, erector spinae, and trapezius upper fiber in the body. To minimize the skin resistance, the electrode areas were shaved and cleaned with cotton soaked in alcohol to increase the adhesive property of the electrodes and to minimize any effects on the measurement. The cutoff frequency of the EMG signal was set to 20–450 Hz and the common mode rejection ratio (CMRR) of the electrodes was set to 110 dB. The amplified analog EMG signal was measured as 2,000 Hz. For the EMG data, the intermediate 5-second section was analyzed excluding the front/rear 2.5-second sections from the total exposure time of 10 seconds. To compare the relative increases/reductions, a standing posture with no vibration stimulation was set as 100%, and the measured data for each intensity were normalized, compared, and analyzed.

The collected data were statistically analyzed using the SPSS software for Windows, version 18.0 (IBM Corporation, Armonk, NY, USA). The mean (M) and the standard deviation (SD) for the results of each factor were calculated, and repeated-measures ANOVA with Bonferroni correction were performed to compare the differences by the intensities in each muscle. All statistical significance levels were set as $\alpha=0.05$.

RESULTS

With respect to the results of the measurement, the muscle activation effects were different in all 8 muscles according to the intensities of the WBV stimulation; these differences were statistically meaningful ($p<0.01$ and $p<0.001$).

The volume tended to have greater muscle activation at 80 than at 50. The frequency (Hz) tended to be maximized at 10 Hz. The maximum EMGrms values were found at 10 Hz in 80 volume of SOL, VL, BF, RA, and ES muscles, and at 25 Hz in 80 volume of LG, TA, and TRA muscles (Table 1). In addition, the maximum EMGrms values were 2.16 times greater in LG, 1.65 times greater in SOL, 1.59 times greater in TA, 1.94 times greater in VL, 1.92 times greater in BF, 1.55 times greater in RA, 1.39 times greater in ES, and 1.72 times greater in TRA than the values in the no-vibration condition (Table 2).

DISCUSSION

WBV exercises are known to improve not only muscular functions, but also cardiovascular functions, particularly given its relatively short exposure, which safely and comfortably stimulates the muscles, skeletal system, and circulatory system. The applicability of WBV exercises has widely expanded, especially in light of the diverse nature of related studies that have been carried out^{9–11}). The intensity of WBV is controlled by its amplitude and frequency; however, the current method used to optimize the exercise intensity setting, which is currently based according to the purpose of each exercise, is not sufficient.

Table 1. Muscle activation of the different whole-body vibration intensity (unit: V)

Vol.	Hz	LG	Sol	TA	VL	BF	RA	ES	Tra
NO Vibration		0.12 ± 0.02	0.27 ± 0.07	0.16 ± 0.06	0.14 ± 0.04	0.19 ± 0.04	0.14 ± 0.04	0.15 ± 0.03	0.10 ± 0.01
	10	0.20 ± 0.06	0.33 ± 0.09	0.17 ± 0.06	0.14 ± 0.06	0.30 ± 0.15	0.19 ± 0.04	0.17 ± 0.05	0.14 ± 0.04
50	25	0.18 ± 0.03	0.35 ± 0.07	0.20 ± 0.09	0.24 ± 0.10	0.26 ± 0.09	0.17 ± 0.04	0.17 ± 0.03	0.14 ± 0.02
	40	0.14 ± 0.02	0.37 ± 0.09	0.13 ± 0.04	0.15 ± 0.04	0.15 ± 0.02	0.12 ± 0.02	0.15 ± 0.03	0.11 ± 0.02
	10	0.21 ± 0.07	0.45 ± 0.12	0.19 ± 0.07	0.28 ± 0.11	0.36 ± 0.14	0.22 ± 0.07	0.21 ± 0.05	0.16 ± 0.04
80	25	0.25 ± 0.07	0.42 ± 0.10	0.26 ± 0.12	0.24 ± 0.08	0.35 ± 0.10	0.20 ± 0.05	0.20 ± 0.03	0.18 ± 0.06
	40	0.16 ± 0.03	0.37 ± 0.07	0.17 ± 0.06	0.16 ± 0.06	0.23 ± 0.05	0.14 ± 0.03	0.16 ± 0.03	0.13 ± 0.02
Significance		***	***	**	***	***	***	**	***

LG: lateral gastrocnemius; Sol: soleus; TA: tibialis anterior; VL: vastus lateralis; BF: biceps femoris; RA: rectus abdominis; ES: erector spinae; Tra: trapezius upper fiber. **p<0.01; ***p<0.001

Table 2. Normalized muscle activation of the different whole-body vibration intensity (unit: %)

Vol.	Hz	LG	Sol	TA	VL	BF	RA	ES	Tra
NO Vibration		1	1	1	1	1	1	1	1
	10	1.75	1.22	1.02	1	1.61	1.33	1.12	1.31
50	25	1.54	1.30	1.22	1.64	1.42	1.17	1.12	1.33
	40	1.23	1.36	0.82	1.01	0.81	0.84	1	1.05
	10	1.78	1.65	1.14	1.94	1.92	1.55	1.39	1.51
80	25	2.16	1.56	1.59	1.69	1.90	1.42	1.30	1.72
	40	1.37	1.35	1.06	1.09	1.23	0.95	1.09	1.28

LG: lateral gastrocnemius; Sol: soleus; TA: tibialis anterior; VL: vastus lateralis; BF: biceps femoris; RA: rectus abdominis; ES: erector spinae; Tra: trapezius upper fiber

In this study, muscle activation was analyzed to determine whether the WBV can improve muscular functions while participants were in a standing position. Muscle activity was measured after selecting 8 muscles from the lower extremity and trunk muscles. As a result of the analysis, all of the lateral gastrocnemius, soleus, tibialis anterior, vastus lateralis, biceps femoris, rectus abdominis, erector spinae, and trapezius upper fiber muscles showed the most statistically significant differences in the muscle activation effect, which was dependent on the intensity of the WBV stimulation. The volume, which is the amplitude factor, tended to have higher muscle activation at 80 than at 50. The frequency tended to be maximized at 10 Hz. As a result, we could see that the muscle activation effect became greater as the volume increased and the frequency decreased. Unlike the preceding studies, however, the muscle activity did not increase in direct proportion to the increase in vibration frequency. The muscle activity had the highest value at 10 Hz, but it was reduced at 40 Hz¹²). Both the excitatory inflow and the resultant muscle activity increase in the early stages as the vibration frequency increases; however, the inhibitory inflow predominates and the muscle activity is lowered as the muscle tone increases. As a result, the greatest muscle activity emerges in the balanced frequency between the excitatory inflow and the inhibitory inflow, so the muscle activity is maximized at a specific frequency less than 25 Hz; in this range, muscle activity was reduced in this study¹³).

When considering each specific body part assessed in this study, the muscle activity of the lower extremities was generally higher than that of the whole body. We could see that the vibration stimulation from the soles of feet provided a WBV effect, in sequence, in the lower legs, thighs, and trunk; however, this effect became weak as the stimulation proceeded to the upper part. This disadvantage might be compensated through changes in various postures; however, the fact that the muscle activation effect was observed while subjects were standing is meaningful in itself, as it highlights the comfortableness and safety of these exercises—the biggest advantages of WBV exercises^{14, 15}).

In the preceding studies, it was reported that the muscles to be activated varied depending on frequency. This seems to be due to the fact that some of the vibration energy is absorbed, passing through each joint and affecting the response of nerve root in the upper muscle.

In conclusion, we can see that the WBV stimulation discriminatorily affects the entire body and, consequently, it provides a muscle activation effect. Since muscle activity differs according to frequency, and given that this will result in variable exercise effects, a greater exercise effect will be obtained if diverse motions (rather than the standing posture) are combined. Studies regarding such motions need to be carried out continuously. In addition, it is estimated that the different levels of intensity that were applied during detailed studies that aimed to assess the maximum activity for each individual muscle in each frequency band will be of importance to maximize the effects of WBV exercises.

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