Original Article

J. Phys. Ther. Sci.
27: 1055–1058, 2015

Influence of pelvic position and vibration frequency on muscle activation during whole body vibration in quiet standing

Joong-Hwi Kim, PhD, PT[1)], Hye-Jung Seo, MPH, PT[2)*]

[1)] *Department of Physical Therapy, Catholic University of Deagu, Republic of Korea*
[2)] *Department of Physical Therapy, Graduate School, Catholic University of Deagu: 13-13 Hayang-ro, Hayang-eup, Gyeongsan-si, Gyeongsangbuk-do 712-702, Republic of Korea*

Abstract. [Purpose] The purpose of this study was to investigate muscle activation related to postural stability depending on the pelvic position and frequency of whole body vibration (WBV) during quiet standing, and to identify the most effective training conditions that elicit the highest neuromuscular responses. [Subjects and Methods] Eighteen healthy subjects voluntarily participated in this single-group, repeated-measures study in which surface electromyography (EMG) data for the upper trapezius, rectus abdominis, external oblique abdominis, erector spinae, gluteus maximus, rectus femoris, semitendinosus, and medial gastrocnemius were collected at three frequencies (0 Hz, 10 Hz, and 20 Hz) of WBV and three pelvic positions (neutral, anterior tilt, posterior tilt) for each subject during quiet standing. [Results] The EMG activities of all the recorded muscles showed significant differences between the three frequencies of WBV and three pelvic positions during quiet standing. [Conclusion] The study findings suggest that a higher WBV frequency (20 Hz) should be used to strengthen most muscles, and that using the posterior pelvic tilt during WBV is much more effective at strengthening and training muscles related to core stability.
Key words: : Whole body vibration, Frequency, Pelvic tilt

(This article was submitted Oct. 23, 2014, and was accepted Nov. 28, 2014)

INTRODUCTION

Vibration, defined as an oscillatory motion, can be artificially applied to the human body using a vibrating platform[1)]. The principal descriptors of vibration are frequency, amplitude, and direction of the vibration movement[2)]. The acute effects of vibration therapy are increased oxygen consumption, muscle temperature, skin blood flow, and muscle power. Most studies of the long-term use of vibration treatment for various disorders have pursued three therapeutic aims: increasing muscle strength, improving balance, and increasing bone mass[2, 3)].

Scientific research on whole body vibration (WBV) has increased during the last decade[4)]. WBV training is a method for muscle strengthening which is increasingly being used in various clinical situations. However, functional and neuromuscular adaptations to WBV are not entirely understood[4, 5)]. In the literature addressing the acute responses to WBV, most studies have used surface electromyography (EMG) to measure the level of neuromuscular activity, to evaluate training parameters[4–8)]. High EMG activity is generated when a high number of muscle fibers producing high motor unit discharge frequencies are recruited and is accompanied by high forces generated by the target muscle. Thus, based on these relations, EMG activity could be used to determine the activation intensity of muscles in a given WBV treatment. In other studies, EMG activity was analyzed of specific vibration determinants, i.e., frequency, amplitudes, or additional load or vibration types and body positions, in order to define optimal training conditions[4, 9)]. Different positions of the subject on the platform elicit different muscle responses to the mechanical stimulations. Muscles and tendons are activated during WBV, and evidence suggests that activated muscles can dampen the mechanical waves produced by a vibratory platform[10)].Thus, to characterize the muscle response, identifying the actual vibratory stimulus that is delivered to a target muscle is important[3, 4, 6, 8, 11)].

Numerous studies have addressed fundamental questions such as optimal frequency or body position using WBV[4–6, 11–15)]. However, the interaction between pelvic position and vibration frequency during quiet standing has not been reported in the literature. Therefore, the purpose of this study was to investigate muscle activation related to postural stability depending on different pelvic positions and frequencies of WBV during quiet standing, and to identify the most effective training conditions that elicit the highest neuromuscular responses.

*Corresponding author. Hye-Jung Seo (E-mail: clearday4491@gmail.com)

Table 1. Characteristics of subjects (N=18)

Subjects	Age (yrs)	Height (cm)	Weight (kg)	BMI
9 males	29.3±3.9	170.9±4.9	68.8±9.0	23.5±1.9
9 females	25.6±3.5	159.2±4.9	50.7±4.9	20.0±1.7
Total	27.7±4.1	165.1±7.7	59.7±11.7	21.7±2.5

Mean±SD, BMI: Body Mass Index

SUBJECTS AND METHODS

A single-group, repeated-measure, cross-study design was used. Eighteen healthy adults (9 males, 9 females) who worked at B hospital located in Gyeonggi-do, Republic of Korea, participated in this study (Table 1). The exclusion criteria included a history of any cardiovascular, respiratory, abdominal, urinary, gynecological, neurological, musculoskeletal, or other chronic disease. Before the study, the principal investigator explained all the procedures to the subjects in detail. All the participants understood the purpose of this study and provided their written informed consent prior to participation in the study in accordance with the ethical principles of the Declaration of Helsinki.

The subjects were asked to quietly stand on a WBV platform (Novotec Medical, Pforzheim, Germany), and to look forward and distribute their weight equally on both feet. The subjects assumed three pelvic positions (neutral, anterior tilt, posterior tilt) for EMG measurements at WBV frequencies of 0 Hz, 10 Hz, and 20 Hz. Vibration exposure during a single trial was limited to 10 s with at least 10 s of rest in between trials. Three trials of each position and condition were recorded.

To measure the subjects' muscle activities, bipolar surface EMG of eight muscles were recorded using a WEMG-8 (LAXTHA, Daejeon, Korea). Disposable electrodes were placed over the muscle bellies approximately midway between the center of the innervation zone and the furthest tendon. Before the electrodes were attached, the skin was carefully shaved, rubbed, and cleaned with alcohol. The eight sites on the dominant side were the upper trapezius (UT) muscle, one half the lateral distance between the cervical spine at C-7 and the acromion; the erector spinae (ES) muscles, 1–2 finger widths lateral from the L1 spinous process; the rectus abdominis (RA) muscle, at the level of the anterior superior iliac spine, 1–2 cm lateral to the midline; the external oblique (EO) muscle, just below the rib cage at the inferior angle of the rib; the gluteus maximus (GM) muscle, 50% of the distance from the sacral vertebrae to the greater trochanter, at the greatest prominence of the middle buttocks, parallel to a line from the posterior superior iliac spine to the middle posterior thigh; the rectus femoris (RF) muscle, 50% of the distance from the anterior superior iliac spine to the superior patella; the semitendinosus (ST) muscle, 50% of the distance from the ischial tuberosity to the medial tibial epicondyle; and the medial gastrocnemius (MG) muscle, distal from the knee and 2 cm medially from the midline. The reference electrode was placed on the pectoralis major muscle[8].

The EMG signals were preamplified, filtered (input impedance, $10^{12}\Omega$; common mode rejection ratio, 110dB; bandpass digital filter, 50–300 Hz) and sampled at 1,024 Hz. The raw EMG data were converted to root mean square (RMS) values using the TeleScan program (ver 2.0). For normalization, a reference contraction (no vibration during quiet standing on the WBV platform) was used, and the EMG data were expressed as percentages of the reference voluntary contraction (%RVC).

The data were analyzed using SPSS for Windows (ver. 19.0) and a significance level of $\alpha = 0.05$. All data are expressed as the mean and standard deviation. To analyze the differences in the EMG data, two-way analysis of variance was used. Bonferroni's correction was used for multiple comparisons.

RESULTS

The EMG activities of all the recorded muscles (UT, ES, RA, EO, GM, RF, ST, and MG) showed significant differences among the three frequencies and three pelvic positions of WBV during quiet standing ($p < 0.05$) (Table 2). In the multiple comparisons, significant differences were observed for all of the different frequency conditions except between 0–10 Hz for RA, 10–20 Hz for EO and ST. Significant differences were also found in the EMG activities between neutral-anterior tilt and anterior tilt-posterior tilt of ES, neutral-posterior tilt of EO, and neutral-posterior tilt and anterior tilt-posterior tilt of GM (Table 3).

DISCUSSION

The purpose of this study was to investigate the effects of between three vibration frequencies and three pelvic positions during quiet standing on a WBV platform using EMG activity.

Neuromuscular activation during WBV has been shown to be closely related to the vibration frequency: a higher frequency elicits higher EMG activity. In this study, the EMG activity increased in response to progressive increase in vibration frequency in all the recorded muscles (Table 2). These observations are in line with the finding of Pollock et al.[14] who documented linear increases in EMG activity with increasing vibration frequency.

Numerous studies have been conducted on the effects of different WBV frequencies in different body positions, especially the angle of the knee and the ankle[6, 11, 13, 16–18]. However, we couldn't find a study in the literature which had investigated EMG activities of muscles related to core stability in different pelvic positions during WBV. Therefore, we investigated EMG muscles activities in various pelvic positions during quiet standing with WBV. This is the first study to investigate the influence of pelvic position during

Table 2. Mean %RVC of neuromuscular activation of the different whole-body vibration frequencies and pelvic positions

Variable	Frequency	Neutral	Anterior tilt	Posterior tilt
	0 Hz	100	122.6±43.6	127.9±44.4
UT*	10 Hz	194.4±142.0	201.2±149.2	159.4±79.7
	20 Hz	300.6±299.8	290.1±230.3	182.1±70.7
	0 Hz	100	213.5±101.5	107.9±38.1
ES*	10 Hz	152.3±63.3	316.3±225.0	179.0±136.8
	20 Hz	276.3±199.3	476.9±288.3	309.1±280.8
	0 Hz	100	113.8±16.8	130.9±22.9
RA*	10 Hz	237.3±142.8	242.1±136.3	316.5±288.1
	20 Hz	417.1±327.9	354.5±171.7	724.9±1205.6
	0 Hz	100	156.3±133.3	197.6±86.5
EO*	10 Hz	262.1±218.8	288.3±223.4	297.6±213.4
	20 Hz	337.1±208.7	344.9±245.5	449.5±358.2
	0 Hz	100	104.4±43.1	415.2±381.3
GM*	10 Hz	381.1±280.4	361.0±323.5	637.7±301.5
	20 Hz	846.9±800.6	557.9±318.6	1034.6±603.6
	0 Hz	100	235.6±269.3	441.9±418.8
RF*	10 Hz	1381.0±1299.3	1420.5±1424.5	1145.6±1323.2
	20 Hz	2345.8±2360.4	1870.1±2011.9	1993.5±2127.9
	0 Hz	100	285.4±402.0	377.0±310.5
ST*	10 Hz	1159.1±1265.2	775.4±485.4	994.2±893.5
	20 Hz	1138.6±808.7	1316.2±1073.0	1362.±809.7
	0 Hz	100	140.9±91.5	117.9±55.2
MG*	10 Hz	453.1±469.7	487.2±573.5	323.2±173.7
	20 Hz	1076.7±1232.7	953.8±837.9	842.2±572.8

Mean±SD of %RVC. *$p < 0.05$
UT: upper trapezius, ES: erector spinae, RA: rectus abdominis, EO: external oblique, GM: gluteus maximus, RF: rectus femoris, ST: semitendinosus, MG: medial gastrocnemius

Table 3. Multiple comparisons of interactions between vibration frequencies and pelvic positions

	UT	ES	RA	EO	GM	RF	ST	MS
Frequency								
0–10 Hz	0.00*	0.01*	0.09	0.00*	0.00*	0.00*	0.00*	0.01*
0–20 Hz	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
10–20 Hz	0.04*	0.00*	0.02*	0.06	0.00*	0.03*	0.14	0.00*
Pelvic position								
Neutral-anterior tilt	0.57	0.00*	1.00	0.41	1.00	1.00	1.00	1.00
Neutral-posterior tilt	0.29	0.42	0.13	0.02*	0.00*	1.00	1.00	1.00
Anterior tilt-posterior tilt	1.00	0.00*	0.21	0.61	0.00*	1.00	1.00	1.00

*$p < 0.05$

WBV on EMG, and we found that muscle activities related to core stability changed depending on the pelvic position.

In multiple comparisons of interactions between the three vibration frequencies and three pelvic positions, two main effects were observed (Table 3). First, significant differences were observed among all of the frequencies except 0–10 Hz for RA, 10–20 Hz for EO and ST. Based on this result, we suggest that higher WBV frequencies should be used to strengthen most muscles. Second, in the comparison of different pelvic positions, the results show that some muscles demonstrated optimal muscle activation in a specific pelvic position. For example, ES showed a significant difference between neutral and anterior pelvic tilt, EO showed a significant difference between neutral and posterior pelvic tilt, and GM also showed a significant difference between neutral and posterior tilt and between anterior and posterior pelvic tilt. According to Neumann[19], anterior pelvic tilt is performed by a force-couple between the hip flexors and the low-back extensor muscles. The hip extensor (GM) and abdominal muscles (RF) act as a force-couple to posteriorly tilt the pelvis. Thus the primary or secondary muscles related to pelvic motion are more activated than the other muscles in WBV during standing. Therefore, we suggest that it is more beneficial to activate and train target specific muscles, using a specific pelvic position with a higher WBV frequency.

Another interesting finding of this study is that the muscles closest to the trunk were more activated (Table 2). In contrast, previous studies have reported the muscles adjacent to the vibration plate were more activated than the muscles furthest from the vibration plate because of the loss of vibration energy[7, 9]. This difference is explained by our study having investigated muscle activation related to core stability in a specific pelvic position during standing with WBV. Core stability is the ability of the lumbo-pelvic-hip complex to return to equilibrium following a perturbation without buckling of the vertebral column, and the ability to control the position and motion of the trunk over the pelvis and leg[20]. Thus, moving the pelvis during standing with WBV was effective at strengthening the muscles used for core stability.

Our findings were limited to studying the effect of three pelvic positions and three vibration frequencies on certain muscle groups related to core stability. Another limitation was the small sample size. Future studies are needed that use various pelvic positions, including lateral pelvic tilt, and segmental vibration frequencies.

In conclusion, the objective of this study was to evaluate the influence of different vibration frequencies and different pelvic positions on muscle activation. The results show that WBV has a positive effect on muscle activities, which is dependent on the vibration frequency and the pelvic position. Based on these results, we suggest that higher WBV frequencies (20 Hz) should be used to strengthen most muscles, and that using posterior pelvic tilt during WBV is much more effective at strengthening and training target muscles related to core stability. Finally, we suggest that WBV is a good method for individuals with muscle weakness due to injury because it is safe and effective.

REFERENCES

1) Bressel E, Smith G, Branscomb J: Transmission of whole body vibration in children while standing. Clin Biomech (Bristol, Avon), 2010, 25: 181–186. [Medline] [CrossRef]
2) Rauch F: Vibration therapy. Dev Med Child Neurol, 2009, 51: 166–168. [Medline] [CrossRef]
3) Choi SJ, Shin WS, Oh BK, et al.: Effect of training with whole body vibration on the sitting balance of stroke patients. J Phys Ther Sci, 2014, 26: 1411–1414. [Medline] [CrossRef]
4) Ritzmann R, Gollhofer A, Kramer A: The influence of vibration type, frequency, body position and additional load on the neuromuscular activity during whole body vibration. Eur J Appl Physiol, 2013, 113: 1–11. [Medline] [CrossRef]
5) Di Giminiani R, Masedu F, Tihanyi J, et al.: The interaction between body position and vibration frequency on acute response to whole body vibration. J Electromyogr Kinesiol, 2013, 23: 245–251. [Medline] [CrossRef]
6) Avelar NC, Ribeiro VG, Mezêncio B, et al.: Influence of the knee flexion on muscle activation and transmissibility during whole body vibration. J Electromyogr Kinesiol, 2013, 23: 844–850. [Medline] [CrossRef]
7) Seo HJ, Kim JW: Analysis of muscle activation related to postural stability according to different frequency of whole body vibration during quiet standing. J Korean Soc Phys Ther, 2013, 25: 316–321.
8) Kim TH, Choi HS: EMG activities trunk and lower extremity muscles included by different intensity of whole body vibration during bridging exercise. Korean Res Soc Phys Ther, 2009, 16: 16–22.
9) Abercromby AF, Amonette WE, Layne CS, et al.: Variation in neuromuscular responses during acute whole-body vibration exercise. Med Sci Sports Exerc, 2007, 39: 1642–1650. [Medline] [CrossRef]
10) Wakeling JM, Nigg BM, Rozitis AI: Muscle activity damps the soft tissue resonance that occurs in response to pulsed and continuous vibrations. J Appl Physiol 1985, 2002, 93: 1093–1103. [Medline]
11) Cardinale M, Lim J: Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. J Strength Cond Res, 2003, 17: 621–624. [Medline]
12) Fritz M: Estimation of spine forces under whole-body vibration by means of a biomechanical model and transfer functions. Aviat Space Environ Med, 1997, 68: 512–519. [Medline]
13) Rahmatalla S, Deshaw J: Predictive discomfort of non-neutral head-neck postures in fore-aft whole-body vibration. Ergonomics, 2011, 54: 263–272. [Medline] [CrossRef]
14) Pollock RD, Woledge RC, Mills KR, et al.: Muscle activity and acceleration during whole body vibration: effect of frequency and amplitude. Clin Biomech (Bristol, Avon), 2010, 25: 840–846. [Medline] [CrossRef]
15) Roelants M, Delecluse C, Verschueren SM: Whole-body-vibration training increases knee-extension strength and speed of movement in older women. J Am Geriatr Soc, 2004, 52: 901–908. [Medline] [CrossRef]
16) Cochrane DJ, Loram ID, Stannard SR, et al.: Changes in joint angle, muscle-tendon complex length, muscle contractile tissue displacement, and modulation of EMG activity during acute whole-body vibration. Muscle Nerve, 2009, 40: 420–429. [Medline] [CrossRef]
17) Rahmatalla S, Liu Y: An active head-neck model in whole-body vibration: vibration magnitude and softening. J Biomech, 2012, 45: 925–930. [Medline] [CrossRef]
18) Shim C, Lee Y, Lee D, et al.: Effect of whole body vibration exercise in the horizontal direction on balance and fear of falling in elderly people: a pilot study. J Phys Ther Sci, 2014, 26: 1083–1086. [Medline] [CrossRef]
19) Donald A: Neumann: Kinesiology of the musculoskelectal system. foundations for physical rehabilitation, 2nd ed. USA: Mosby, 2011.
20) Willson JD, Dougherty CP, Ireland ML, et al.: Core stability and its relationship to lower extremity function and injury. J Am Acad Orthop Surg, 2005, 13: 316–325. [Medline]