Original Article

Analysis of trunk and lower extremity electromyographic activity in horizontal whole-body vibration

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ABSTRACT

Whole-Body Vibration (WBV) has been extensively investigated as a widely used training tool. However, previous studies mostly applied the WBV on synchronous or side alternating vibration platform devices. The present study was aimed to investigate the electromyographic activity of trunk and lower-extremity muscles as one stands on a flat floor, and during horizontal whole-body vibration (WBV). This was a comparative cross-sectional study. Sixteen healthy adults participated in the study. The electromyographic activity of the trunk and lower extremity muscles was collected while the participants stood on either a flat floor or a WBV device moving horizontally. Electromyography (EMG) was used to record the activity of trunk and lower extremity muscles (erector spinae, rectus abdominalis, rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius). The rectus femoris, tibialis anterior, and gastrocnemius muscles showed significantly higher muscle activation on the horizontal WBV device than on the flat floor ($p<0.05$). In particular, the electromyographic activity of Lt. rectus femoris (23.0 vs 14.3), Rt. rectus femoris (32.7 vs 15.1), Lt. tibiailis anterior (19.0 vs 9.8) Rt. tibiailis anterior (17.8 vs 7.9), and of the Lt. gastrocnemius (41.5 vs 15.7), Rt. gastrocnemius (32.7 vs 13.0) increased on the horizontal WBV device than on the flat floor. The muscle activity of the rectus femoris, tibialis anterior, and gastrocnemius muscles proved to be higher when the participants stood on the WBV device vibrating in a horizontal direction than on the flat floor. Further studies need to investigate the clinical applicability of horizontal WBV. **Key words:** WHOLE-BODY VIBRATION, ELECTROMYOGRAPHIC ACTIVITY, HORIAONTAL DIRECTION.

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INTRODUCTION

Whole-Body Vibration (WBV) has been extensively investigated as a widely used training tool (Kurt & Pekünlü, 2015). A WBV device delivers vibration to the whole body on a synchronous vibration platform or side alternating vibration platform (Cardinale & Wakeling, 2005; Rauch et al., 2010). The vibration stimulus provided by the WBV device has been reported to induce cyclic, isolated, and isometric maximal voluntary contractions (MVCs) and promote a neuromuscular response, which varies with several variables such as frequency, amplitude, acceleration, and duration (Cardinale & Erskine, 2008; Rittweger, 2010). Thus, it has been suggested that the vibration stimulus can contribute to high levels of reflex sensitivity, motor neuron excitability, stiffer muscle-tendon units, and betterment of body movement functions for task performance (Bullock et al., 2008; Delecluse et al., 2005).

A previous study compared the difference in electromyographic muscle activity between a group of healthy adults taking both isometric exercise and WBV on a vertical vibrating platform (a synchronous device) and another group taking the isometric exercise only, and reported that the former showed the most significant improvement in hand grasp strength (Dallas et al., 2013; Kurt & Pekünlü, 2015) . applied a vertical vibrating platform to athletes in a squat position of isolated and isometric contractions, and reported a significant improvement in the squat jump in contrast to the control group. They also applied WBV to healthy adults on a vertical vibrating platform to determine an effect on neuromuscular activity responses for the duration of static standing, where the postural stability varied with the pelvic position and the frequency of the platform. They reported a statistically significant improvement in the muscle activity of the erector spinae, rectus abdominis, external oblique, gluteus maximus, rectus femoris, semitendinosus, and gastrocnemius muscles (Kim & Seo, 2015).

During the WBV, the muscles were influenced by biomechanical parameters such as vibration frequency, amplitude, and duration, as well as by exercise parameters such as synchronous and side alternating vibration, and the exercise position (Abercromby et al., 2007a; Roelants et al., 2006). Regarding the effects of varying vibration frequencies in static standing on the activity of trunk muscles, higher frequencies compared to lower frequencies led to a significant increase in the activity of trunk muscles (Kim & Seo, 2015). Moreover, in view of the difference in acceleration (poses a risk) of delivering the WBV to the head between synchronous and side alternating vibration platform devices, the acceleration proved significantly higher in the WBV on synchronous vibration platform devices than on the side alternating vibration platform devices position (Abercromby et al., 2007a; Abercromby et al., 2007b) . That is, the human body can be affected by existing WBV depending on various parameters such as frequency, amplitude, acceleration, and duration. In the same vein, excessive WBV on synchronous and side alternating vibration platform devices could exert adverse effects on the human body (Cardinale & Erskine, 2010).

When the horizontal WBV was applied while the participants stood with their feet apart, the horizontal vibration caused an antero-posterior weight bearing (Baker & Mansfield, 2010; Griffin & Hayward, 1994), and an increase in muscle activity to maintain the position, which exerted positive effects on the improvement of stability. Likewise, the horizontal WBV may have positive effects on the body, including muscle activation. Previous studies mostly applied the WBV on synchronous or side alternating vibration platform devices. Few studies have investigated the effects of horizontal WBV on muscle activity or stability.

Thus, the present study was aimed to investigate the electromyographic activity of trunk and lower-extremity muscles as one stands on a flat floor, and during horizontal whole-body vibration (WBV).

MATERIAL AND METHODS

Participants

Sixteen healthy adults participated in the present study. A public notice was posted on the University's bulletin board to recruit participants. The inclusion criteria were as follows: 1) healthy adults aged 20–30 years, 2) those who did not have any health issues that could hinder their participation in the WBV training program (e.g. diabetes, epilepsy, metabolic disease, and neuromuscular disease), and 3) those who had not done any strenuous activities or taken caffeine or alcohol within the last 24 hours before participating in the experiment. Sixteen out of 18 volunteers were selected as per the criteria. Demographically, the 16 participants (8 men and 8 women) were on average, 25.5 ± 0.97 years old, 169.06 ± 9.24 cm in height, and 65.5 ± 14.07 kg in weight.

The participants voluntarily signed the informed consent upon being fully informed of the study objective and methods. The objective and procedure of this study were approved by the Institutional Review Committee of Kyungnam University.

Design and procedure

This was a comparative cross-sectional study. The participants were interviewed for general demographic information such as age, sex, height, and weight. Then, electromyography (EMG) was used to measure the maximal voluntary contraction (MVIC) of trunk and lower extremity muscles including erector spinae (ES), rectus abdominis (RA), biceps femoris (BF), rectus femoris (RF), gastrocnemius (GCM), and tibialis anterior (TA). To minimize muscle fatigue, the participants had a 30-minute break after the measurement of MVC and before the measurement of the muscle activities of the trunk and lower extremity, while they were standing on a flat floor and receiving the horizontal WBV. The participants stood on the floor bare feet. To minimize the variables attributable to postural sway, the participants were asked to place their feet on spots marked by the author while staring at a point marked on the wall. They were asked to remain standing on the floor for 1 minute, while the EMG measured the muscle activities of the trunk and lower extremity muscles. The participants also stood on the platform of the horizontal WBV device with their feet placed on spots marked on the device while staring at a point on the wall (Figure 1). Previous study reports that the muscle activity could vary with knee angles (Perchthaler et al., 2013), the participants in the present study were asked to extend their knees by maintaining the knee joint angles at 0° while standing. Then, a research assistant attached a goniometer to the lateral skin of the tibiofemoral joint to see if the angle was maintained. In addition, to prevent the risk of a fall while the WBV was applied, the assistant supervised the process. The horizontal WBV was applied for 1 minute, followed by EMG to measure muscle activity. To minimize muscle fatigue, a 5-minute break was given to the participants before the horizontal WBV, upon completion of the standing position on the floor.

The WBV device used in this study (Extream 1000; AMH International Inc., Incheon, Republic of Korea) was designed to vibrate horizontally at 30-mm antero-posterior amplitude and 1–9-Hz frequency. The horizontal WBV was applied to the s participants at a frequency of 6 Hz so that they felt comfortable in an antero-posterior direction.

Figure 1. WBV device moving horizontally

Electromyographic analysis

To determine the muscle activities of the trunk and lower extremity, a surface electromyograph (Trigno™ Wireless EMG, Delsys, USA) was used. This system involves small wireless EMG sensors and an integrated amplifier. The EMG electrodes were attached to each of the muscles including ES, RA, BF, RF, GCM, and TA as per the SENIAM guideline (Perchthaler et al., 2015). The EMG electrodes were cleaned with sand paper and alcohol before being attached to the muscle belly. As for the upper and lower erector spinae (UES/LES), the electrodes for the UES were placed at a two-finger width, lateral from the process spinous of L1. Those for the LES were placed at one-finger width, medial from the line from the posterior spina iliaca, superior to the lowest point of the lower rib at the level of L2. To see the upper and lower rectus abdominis (URA/LRA), the electrodes for the URA were placed 2–3 cm lateral from the midline on the second segment of the muscle, whilst those for the LRA were placed 2–3 cm lateral from the midline on the fourth segment of the muscles, or 2 cm inferior to the umbilicus if the fourth segment could not be palpated. As for the rectus femoris of the lower extremity, the electrodes were placed halfway on the line from the anterior spina iliaca superior to the superior part of the patella, whereas those for the biceps femoris (BF) were placed halfway on the line between the ischial tuberosity and the lateral epicondyle of the tibia. The electrodes for the gastrocnemius (GCM) were mostly placed on the most prominent bulge of the muscle, whereas those for the tibialis anterior (TA) were placed at one-third of the line between the tip of the fibula and the tip of the medial malleolus. The EMG electrodes were secured to the skin with tape for the data to be collected accurately under postural sway on the horizontal WBV device.

The EMG signals in the trials, within 30 seconds, and from 16 to 45 seconds were used for the data analysis. The data was processed using standard filtering and rectifying methods. The sampling frequency was 2000 Hz. A 60Hz high-pass filter and a 10Hz low-pass filter were applied (all filters, zero-lag 4th order Butterworth). The root mean square (RMS) was calculated for raw EMG data. The EMG data from each muscle was normalized by calculating the RMS of a 5-second MVC for the muscles. The EMG data collected during the standing on a flat floor and receiving the horizontal WBV were expressed as %MVIC.

Statistical analysis

The SPSS 18.0 was used for statistical analysis. Mean values, standard deviation, or frequency were used to analyze participants' general characteristics. A paired t-test was used to compare the muscle activities measured when the participants were standing on the floor, with that measured upon the application of the horizontal WBV. The statistical significance level was $\alpha<0.05$.

RESULTS

Table 1 shows the summary results of the present study.

The muscle activity of the left erector spinae on the floor and during horizontal WBV was 24.6% MVC and 24.9% MVC, respectively. The difference of 0.3% between the two results was not statistically significant. The muscle activity of the right erector spinae on the floor and during the WBV was 22.7% MVC and 28.3% MVC, respectively. The 5.6% increase in muscle activity during the WBV was not statistically significant.

The muscle activity of the left rectus abdominis was 19.4% MVC and 20.2% MVC on the flat floor and during horizontal WBV, respectively. The difference of 0.8% between the two results was not statistically significant. The muscle activity of the right rectus abdominis was 14.3% MVC and 20.7% MVC on the floor and during WBV, respectively, where the 6.4% increase in muscle activity on the WBV was not statistically significant.

The muscle activity of the left biceps femoris on the floor and during horizontal WBV was 26.3% MVC and 35.9% MVC, respectively, where the difference of 9.6% was not statistically significant. The muscle activity of the right biceps femoris on the floor and during WBC was 22.1% MVC and 30.6% MVC, respectively, where the 8.4% increase in muscle activity on the WBV was not statistically significant.

The muscle activity of the left rectus femoris on the floor and during horizontal WBV was 14.3% MVC and 23.0% MVC, respectively, showing a difference of 8.7%. The muscle activities of the right rectus femoris on the floor and WBV was 15.1% MVC and 32.7% MVC, respectively, showing a 17.6% increase. Statistically significant differences were found in the muscle activities of both the left and right rectus femoris.

The muscle activity of the left gastrocnemius on the floor and during horizontal WBV was 15.7% MVC and 41.5% MVC, respectively, showing a difference of 25.9%. The muscle activity of the right gastrocnemius on the floor and during WBV were 13.0% MVC and 32.7% MVC, respectively, showing a 19.8% increase. Statistically significant differences were found in both the left and right gastrocnemius.

The muscle activity of the left tibialis anterior on the floor and during horizontal WBV was 9.8% MVC and 19.0% MVC, respectively, showing a difference of 9.1%. The muscle activity of the right tibialis anterior on the floor and during WBV was 7.9% MVC and 17.8% MVC, respectively, showing a 9.9% increase. Statistically significant differences were found in both the right and left tibialis anterior.

Table 1. Comparison of trunk and lower extremity electromyographic muscle activity while standing on either a flat floor or a WBV device moving horizontally

		A flat floor	WBV device moving horizontally	Difference
Elector spina (%MVC)	Left	24.6 (21.2)	24.9 (15.7)	+0.3
	right	22.7 (11.8)	28.3 (18.3)	+5.6
Rectus abdominis (%MVC)	Left	19.4 (13.5)	20.2 (13.3)	+0.8
	right	14.3 (9.4)	20.7 (23.3)	+6.4
Biceps femoris (%MVC)	Left	26.3 (15.8)	35.9 (28.3)	+9.6
	right	22.1 (15.4)	30.6 (28.5)	+8.4
Rectus femoris (%MVC)	Left	14.3 (8.4)	23.0 (14.4)	+8.7*
	right	15.1 (9.0)	32.7 (37.3)	+17.6*
Gastrocnemius (%MVC)	Left	15.7 (8.4)	41.5 (23.8)	+25.9*
	right	13.0 (5.6)	32.7 (26.9)	+19.8*
Tibialis anterior (%MVC)	Left	9.8 (9.1)	19.0 (14.6)	+9.1*
	right	7.9 (5.3)	17.8 (18.1)	+9.9*

Values are shown as mean (standard deviation).
*Significant differences were presented as * p<.05.*

DISCUSSION

The present study investigated the muscle activity of the trunk and lower extremity when participants were standing on a flat floor versus a horizontal WBV device. The WBV device used here was designed to adjust the vibration levels from 5 to 40, in line with the frequency of vibration. The frequencies at the lowest (5) and highest (40) vibration levels were 1 Hz and 9 Hz, respectively. Previous studies investigated the acceleration delivered to the head, depending on different frequencies and knee joint angles, when the WBV was applied to participants while standing on synchronous vibration platform devices, and found that a frequency of not more than 30 Hz and a knee angle of no more than 40° could reduce the injury of soft tissues in the head to the greatest extent (Caryn et al., 2014). Therefore, the present study was performed using a frequency lower than the abovementioned level to prevent any injury to soft tissues and thus make the participants feel comfortable, and applied the set frequency equally to all participants to determine the muscle activities of the trunk and lower extremity. In short, the muscle activity of the rectus femoris, gastrocnemius, and tibialis anterior muscles significantly increased on the horizontal WBV device, compared with that on the flat floor.

A previous study on the muscle activities of the trunk and neck when the WBV (on synchronous vibration platform devices) was applied with varying knee angles reported that the muscle activities of the trunk significantly increased in a group that received both isometric exercise and WBV compared with the other group that received the isometric exercise only (Perchthaler et al., 2013). Yet, the muscle activity of the trunk during horizontal WBV did not significantly increase compared to that during standing on the flat floor. The difference between the two studies may be attributable to the antero-posterior postural sway caused by the horizontal WBV applied in this study, where the ankle or hip joint strategies were intensely used to maintain the posture. Previous studies have reported that muscle activities could vary with the direction of WBV platform devices (i.e. synchronous or side alternating vibration platform devices) or with postural and joint positions (Abercromby et al., 2007a; Roelants et al., 2006). Notably, Rittweger (2010) reported that different amounts of WBV would be delivered to each segment of the body from the distal to the proximal direction on side alternating vibration platform devices due to the anatomical structure of our body, with 85%, 8%, and 2% of the root mean square vibrations being delivered to the ankle joint, knee joint, and hip joint, respectively. That the WBV delivered to the body differs from the distal to the proximal direction seems to explain the significant activities of the ankle and hip joint muscles found in this study.

The most significant difference was in the gastrocnemius muscle activity during horizontal WBV compared to that when standing on the flat floor, followed by that in the tibialis anterior muscle and the rectus femoris muscle. The horizontal WBV occurs on the sagittal plane (van Nes et al., 2004). That is, the gastrocnemius and tibialis anterior muscles are subject to cyclic contractions as both are primary muscles to maintain balance by reducing the postural sway that increases on the antero-posterior platform of the horizontal WBV device (Perchthaler et al., 2015). In addition, according to a previous study, the synchronous and side alternating vibration platform devices used for the WBV, induced isolated and isometric MVC of muscles (Rittweger, 2010). To recap, the significant activities of the gastrocnemius and tibialis anterior muscles may be translated as an effort to reduce the postural sway caused by the horizontal WBV used in this study.

In the present study, the rectus femoris muscle showed a significant difference in the levels of muscle activity on the two surfaces, whereas the biceps femoris muscle did not. Perchthaler, Horstmann and Grau (2013) reported that when knee angles and frequencies of WBV varied, the activities of the rectus femoris and biceps femoris muscles increased as the knee angles became smaller, or as the knee flexion became greater. In particular, they reported that the activity of the rectus femoris muscle increased more significantly than that of the biceps femoris muscle as the knee angles became smaller, which was attributed to the effects of muscle length and preactivation (Perchthaler et al., 2013). The effects of vibration increase as the muscle shortens and the preactivation increases. The rectus femoris muscle showed a higher level of activity than did the biceps femoris muscle because the distance between the biceps femoris muscle and the vibration platform was shorter, and the preactivation was lower. This may account for the significantly higher activity of the rectus femoris muscle than that of the biceps femoris muscle in this study.

Yet, the present study has a few limitations. First, to collect the EMG data on the WBV in a horizontal direction, participants' knee extensions were measured with a standard goniometer relatively subjectively, which may have exerted negative effects on the accuracy of the data. Second, the small sample size hinders the generalization of the present findings. Finally, the frequency of the horizontal WBV, which was set at a comfortable level, was equally applied to all participants. Yet, the muscle activity levels needed to maintain the posture may have varied with the individual difference in the intensity of vibrations felt.

CONCLUSION

The present study highlighted the significantly high muscle activities of the rectus femoris, gastrocnemius, and tibialis anterior muscles during horizontal WBV compared with those when standing on the flat floor. Hence, the horizontal WBV used in this study may serve to exert positive effects on the neuromuscular activity of the lower extremity as a means of exercise, which needs to be verified by conducting a further study while rectifying the foregoing limitations.

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