Original Article

Comparison of lower limb muscle activation according to horizontal whole-body vibration frequency and knee angle

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ABSTRACT

Whole-body vibration refers to an exercise that stimulates the muscles, using a vibration with an amplitude and power, however, there are few studies that have dealt with fundamental questions such as optimal frequency or body position. This study aims to compare lower limb activation, according to horizontal whole-body vibration frequency and knee flexion angle, in healthy adults. Using 18 healthy adults aged 21–30, this study measured and analysed the activities of the vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA), and gastrocnemius (GCM) muscles, for different horizontal whole-body vibration frequencies (0 Hz, 2 Hz, and 4 Hz) and knee flexion angles (0°, 30°, and 60°), using surface electromyography (sEMG). There was a statistically significant increase in lower limb muscle activation according to horizontal whole-body vibration frequency and knee flexion angle: comparing muscle activation with frequency, the muscle activation of VL, BF, TA, and GCM increased with increase in frequency ($p<0.05$). The muscle activation of VL and TA increased with increase in knee flexion angle ($p<0.05$). In this study, it was observed that for whole-body vibration provided in a horizontal direction, larger the frequency and higher the knee flexion angle,

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greater the lower limb activation. **Keywords:** Whole-body vibration; Muscle activation; Frequency; Knee flexion angle.

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INTRODUCTION

Whole-body vibration refers to an exercise that stimulates the muscles for a certain amount of time, using a vibration with an amplitude and power at a harmless level to the human body (Delecluse et al., 2003). The acquisition of power through whole-body vibration is associated with increased neuromuscular activation during exposure to the vibrations (Lienhard et al., 2014; Ritzmann et al., 2013). There are diverse mechanisms for the increase in lower limb muscle activation, but the major cause is reported to be a stretch reflex response from the activation of muscle spindle and alpha motor neurons, that is, the result of a tonic vibration reflex (Burke et al., 1976; Hagbarth, & Eklund, 1966). A tonic vibration reflex is as follows: if mechanical vibration at a high frequency is applied to the skeletal muscle, reflection occurs in group Ia fibres, which brings about muscle contraction in the pathway like that of an H wave, and while vibration is applied, continuous reflexive muscle contraction occurs, when the antagonist is relaxed (Korean Nurses Academy Society, 1996). In other words, through this tonic vibration reflex, the reflexive muscle is contracted and the function of the neuromuscular system improves.

The factors affecting muscle activation during whole-body vibration are vibration frequency (Cardinale, & Lim, 2003; Cochrane et al., 2009), amplitude (Marıin et al., 2009), additional load (Hazell et al., 2010), vibration type, and body position (Abercromby et al., 2007). Most studies (Cardinale, & Lim, 2003; Cochrane et al., 2009; Di Giminiani et al., 2013; Hazell et al., 2007; Roelants et al., 2006) reported the surface electromyography (sEMG) activity of the lower limb muscles when whole-body vibration was applied, while comparing the difference according to the application. They found that when whole-body vibration was applied, an increase in vibration frequency and amplitude was associated with an increase in lower limb muscle activation, and there was the highest sEMG activation when frequency and amplitude were maximized (Lienhard et al., 2014; Ritzmann et al., 2013). In addition, in a comparison of muscle activation according to knee flexion angles of 10°, 30°, and 60° during whole-body vibration, Ritzmann et al. (2013) reported that larger the knee flexion angle, more the muscle activation, and that muscle activation increased when additional load was applied. In a comparison of the difference according to the application, the side-alternating vibration type showed higher muscle activation than the synchronous vibration type.

However, despite there being many studies of whole-body vibration conducted, there are few studies that have dealt with fundamental questions such as optimal frequency or body position (Abercromby et al., 2007; Hazell et al 2007; Hazell et al., 2010), and there are insufficient studies on the systematic approach to whole-body vibration that can maximize muscle activation. In addition, the vibration currently used in most whole-body vibrations are provided by the side-alternating vibration type or vertical vibration type (Shim et al., 2014). However, according to previous studies, it has been reported that these vibration types cause negative effects such as erythema (Russo et al., 2003), knee pain (Russo et al., 2003), headaches (Rubin et al., 2004) and soreness or itching (Rubin et al., 2004; Roelants et al., 2004). One of the attempts to adapt for this limitation is to provide vibration in a horizontal direction (Shim et al., 2014). However, even now, there have been insufficient studies on whole-body vibration provided in the horizontal direction.

Therefore, this study aims to compare lower limb muscle activation, according to whole-body vibration frequency provided in a horizontal direction, and knee flexion angle in healthy adults.

MATERIAL AND METHODS

Participants

This study recruited subjects through recruitment bulletin boards at Kyungnam University. The selection criteria for subjects were healthy adults aged 21–30 and the exclusion criteria were those with damage to the body or disease, those with a surgical history and those who were taking drugs that might have a negative impact on neuromuscular performance. The number of participants in this study was 18 persons in total (eight males and 10 females). On average, their age, height and weight were 23.78 (1.73) age, 166.00 (7.69) cm and 57.89 (7.96) kg respectively.

Ethical consideration

This study was approved by the Institutional Review Board of Kyungnam University. Experiments were conducted after receiving agreement on research by explaining to the study subjects the purpose and methods of the experiment, precautions, and anticipated side effects sufficiently.

Procedure

For the subjects who participated in this study, basic information such as age, height and weight was collected. Next, lower limb muscle activation for the vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA), and gastrocnemius (GCM) during horizontal whole-body vibration was measured, using sEMG. To standardize muscle activation, based on the electromyography (EMG) value appearing through the maximal voluntary isometric contraction (MVIC) of each muscle, % MVIC was used, which is the value divided by the EMG value of the same muscle appearing through the actual horizontal whole-body vibration. In VL measurement, a knee joint extension was made whilst the subject was sitting straight on a chair, with a 90° hip joint flexion and a 60° knee joint flexion (Albertus-Kajee et al., 2011; Hsu et al., 2006); in BF measurement, a knee joint flexion was made whilst the subject was in the prone position, with a 60° knee joint flexion (Albertus-Kajee et al., 2011); in TA measurement, an ankle joint dorsiflexion was made whilst the subject was in the supine position (Hsu et al., 2006); in GCM measurement, in a one-leg standing position, a load was applied in a vertical direction for ankle joint plantar flexion (Riemann et al., 2011). At this time, resistance was provided in the direction opposite to the muscle contraction, selected to measure MVIC. It was repeated three times for each muscle and the average value was used. Then, muscle activation appearing while the subject was standing on a whole-body vibration machine provided in the horizontal direction was measured. The horizontal whole-body vibration machine (Extream1000; AMH International Co., Ltd., Incheon, Republic of Korea) used in this study provides whole-body vibration in the ranges of an amplitude of 30 mm and a frequency of 1–9 Hz, in the horizontal direction (forward-backward) (Figure 1). On the whole-body vibration machine, the muscle activation appearing according to a total of three frequencies, 0 Hz, 2 Hz, and 4 Hz, and a total of three knee flexion angles, 0°, 30°, and 60° were measured. Three attempts were made for each condition, and whole-body vibration was applied for one minute during each attempt. Using a goniometer before the start, the subjects were asked to stand up on the horizontal whole-body vibration machine while they put on sEMG electrodes, look at the front, pose in the targeted knee flexion angle, and maintain that posture for a minute. At this time, feedback was continuously provided by their side so that they could maintain the targeted knee flexion angle during the experiment. By giving them a break time of five minutes between the sets, muscle fatigue was minimized. The average of the value measured in each set was used as the result value.

For lower limb muscle activation, an sEMG TRIGNO Wireless EMG System (Delsys Inc., Natick, MA, USA) was used, and the data of the EMG signals obtained here were processed through EMG Works 4.0 Software. The EMG signals were converted to root mean square (RMS), and to standardize them for an analysis of muscle activation based on the EMG value appearing through the MVIC of each muscle, % MVIC was used in the analysis of the results, which is the value divided by the EMG value of the same muscle appearing through the actual horizontal whole-body vibration. The sites for the attachment of sEMG electrodes are the VL, BF, TA, and GCM, and according to SENIAM guidelines (Hermens et al., 1999), for VL, the electrode was attached to the 2/3 point of the line connecting the anterior superior iliac spine (ASIS) to the side of the knee; for BF, to the 50% point between the ischium and the lateral condyle of the tibia; for TA, to the 1/3 point of the line connecting the end of the fibula to the end of the medial malleolus; and for GCM, to the 1/3 point of the line connecting the fibular head to the calcaneus. Before attaching the sEMG electrodes, the attachment sites were cleaned with rubbing alcohol to minimize skin resistance.

Figure 1. Horizontal whole-body vibration.

Statistical analysis
With the measured data, a statistical analysis was conducted using IBM SPSS Statistics 22.0 (IBM Co., Armonk, NY, USA). An analysis was conducted for a test of normality. For a comparison of muscle activation according to frequency and a comparison of muscle activation according to the knee flexion angle, a Friedman test was conducted. Also, as a post-test, a Wilcoxon signed-rank test was conducted. The statistical significance level was $\alpha=0.05$.

RESULTS

Comparison of muscle activation according to frequency (Hz)
In the comparison of muscle activation according to frequency (Hz), there were statistically significant differences in VL, BF, TA, and GCM at a knee flexion angle of 0° ($p<0.05$). As a result of the post-analysis, there were statistically significant differences in VL and BF at 0 Hz and 4 Hz, and at 2 Hz and 4 Hz ($p<0.05$). There were statistically significant differences in TA and GCM at 0 Hz and 2 Hz, 0 Hz and 4 Hz, and 2 Hz and 4 Hz ($p<0.05$). There were statistically significant differences in VL, BF, TA, and GCM at 30° ($p<0.05$) and as determined by the post-analysis, there were statistically significant differences in VL, BF, TA, and GCM at 0 Hz and 2 Hz, 0 Hz and 4 Hz, and 2 Hz and 4 Hz ($p<0.05$). There were statistically significant differences in VL, BF, TA, and GCM at 60° ($p<0.05$), and as determined by post-analysis, there were statistically significant differences in VL, BF, TA, and GCM at 0 Hz and 4 Hz, and 2 Hz and 4 Hz ($p<0.05$) (Table 1).

Table 1. Comparison of muscle activation according to frequency

		0Hz	2Hz	4Hz	p
0°	Vastus lateralis	24.58 (11.00)[a]	25.30 (10.88)	29.88 (12.22)**, ***	.000
	Biceps Femoris	8.56 (4.15)	8.98 (3.48)	10.47 (3.37)**, ***	.000
	Tibialis Anterior	3.64 (1.97)	4.55 (1.89)*	8.85 (6.36) **,***	.000
	Gastrocnemius	24.233 (19.46)	25.54 (19.66)*	30.00 (20.95) **,***	.000
30°	Vastus lateralis	26.78 (11.81)	28.98 (12.29)*	35.72 (15.61) **,***	.000
	Biceps Femoris	8.19 (3.61)	8.42 (3.51)*	9.91 (3.65) **,***	.000
	Tibialis Anterior	4.80 (3.60)	6.73 (4.45)*	14.35 (7.62) **,***	.001
	Gastrocnemius	24.06 (19.53)	24.61 (19.61)*	29.95 (18.14) **,***	.000
60°	Vastus lateralis	35.96 (13.95)	36.44 (14.62)	42.77 (18.59) **,***	.000
	Biceps Femoris	8.40 (3.71)	8.36 (3.59)	9.65 (3.62) **,***	.000
	Tibialis Anterior	7.76 (6.20)	11.83 (9.49)	15.00 (11.51) **,***	.002
	Gastrocnemius	24.68 (19.31)	24.96 (19.14)	27.24 (19.28) **,***	.000

*Values (%MVIC) are shown as mean (standard deviation). Significant differences between 0Hz and 2Hz were presented as * (p < 0.05), Significant differences between 0Hz and 4Hz were presented as * (p < 0.05), Significant differences between 2Hz and 4Hz were presented as ** (p< 0.05).*

Comparison of muscle activation according to knee flexion angle

Table 2. Comparison of muscle activation according to knee flexion angle

		0°	30°	60°	p
0Hz	Vastus lateralis	24.58 (11.00)[a]	26.78 (11.81)*	35.96 (13.95)*,**	.000
	Biceps Femoris	8.56 (4.15)	8.19 (3.61)	8.40 (3.71)	.119
	Tibialis Anterior	3.64 (1.97)	4.80 (3.60)	7.76 (6.20)*,**	.006
	Gastrocnemius	24.23 (19.46)	24.06 (19.53)	24.68 (19.31)*	.042
2Hz	Vastus lateralis	25.30 (10.88)	28.98 (12.29)*	36.44 (14.62)*,**	.000
	Biceps Femoris	8.98 (3.48)	8.42 (3.51)	8.36 (3.59)	.607
	Tibialis Anterior	4.55 (1.89)	6.73 (4.45)	11.83 (9.49)*,**	.056
	Gastrocnemius	25.54 (19.66)	24.61 (19.61)*	24.96 (19.14)	.115
4Hz	Vastus lateralis	29.88 (12.22)	35.72 (15.61)*	42.77 (18.59)*,**	.000
	Biceps Femoris	10.47 (3.37)	9.91 (3.65)	9.65 (3.62)	.115
	Tibialis Anterior	8.85 (6.36)	14.35 (7.62)*	15.00 (11.510*	.034
	Gastrocnemius	30.00 (20.95)	29.95 (18.14)	27.24 (19.28)*	.249

*Values (%MVIC) are shown as mean (standard deviation). Significant differences between 0° and 30° were presented as * (p < 0.05), Significant differences between 0° and 60° were presented as * (p < 0.05), Significant differences between 30° and 60° were presented as ** (p < 0.05).*

In the comparison of muscle activation according to knee flexion angle, there were statistically significant differences in VL, TA and GCM at a frequency of 0 Hz (p<0.05) and as a result of the post-analysis, there were statistically significant differences in VL at 0° and 30°, 0° and 60°, and 30° and 60° (p<0.05); in TA at 0° and 60°, and 30° and 60° (p<0.05) and in GCM at 0° and 60° (p<0.05). There was no statistically significant difference in BF (p>0.05). There was a statistically significant difference in VL at 2 Hz (p<0.05) and as determined by the post-analysis, there were statistically significant differences in VL at 0° and 30°, 0° and 60°, and 30° and 60° (p<0.05). There were no statistically significant differences in BF, TA and GCM (p>0.05). There was a statistically significant difference in VL and TA at 4 Hz (p<0.05), and as a result of the post-analysis, there were statistically significant differences in VL at 0° and 30°, 0° and 60°, and 30° and 60° (p<0.05); there were statistically significant differences in TA at 0° and 30°, and 0° and 60° (p<0.05). There were no statistically significant differences in BF and GCM (p>0.05) (Table 2).

DISCUSSION

Whole-body vibration is a way of stimulating muscles over a certain time using vibration, amplitude and power at harmless levels (Delecluse et al., 2003). The factors affecting muscle activation during vibration are vibration frequency (Cardinale, & Lim, 2003, Cochrane et al., 2009), amplitude (Marıin et al., 2009), additional load (Hazell et al., 2010), vibration type and body position (Abercromby et al., 2007). This study investigated the impact of whole-body vibration of the type providing vibration in the horizontal direction according to frequency (0 Hz, 2 Hz and 4 Hz) and knee flexion angle (0°, 30°, 60°) on lower limb muscle activation in healthy adults. As a result, it was found that when the muscle activation was compared according to frequency, there were statistically significant increases in VL, BF, TA, and GCM with an increase in the frequency, at the knee flexion angles of 0°, 30°, and 60°. In addition, when muscle activation with an increase in knee flexion angle was compared, there was a statistically significant increase in VL with an increase in the knee flexion angle at the frequencies 0 Hz, 2 Hz, and 4 Hz. There was a statistically significant increase in TA at 0 Hz and 4 Hz with an increase in knee flexion angle. Consequently, it was noted that while applying whole-body vibration, higher the frequency and larger the knee flexion angle, greater is the lower limb muscle activation.

Lienhard et al. (2014) reported that when they compared vertical vibration type whole-body vibration at the frequencies 25 Hz and 40 Hz in healthy adults, muscle activation in GCM significantly increased at 40 Hz. Whilst Lienhard et al. (2014) showed that when vertical vibration type whole-body vibration was applied, the muscle activation in GCM increased at a high frequency, in this study the muscle activation significantly increased in VL, BF, TA and GCM at a high frequency. It is believed that whole-body vibration in the horizontal vibration type moving forward and backward requires more lower limb muscle activation than the vertical vibration type. According to previous studies (Cochrane et al, 2009; Ritzmann et al., 2010), during whole-body vibration muscle/tendon units increase and the increase in muscle/tendon units induces the activation, depending on the frequency of the muscle spindle; this induces the stretch reflex that can be detected in EMG signals. As a result, the increase in EMG activation due to the increased frequency of whole-body vibration can be said to be caused by the increase in the number of stretch reflex reactions (Ritzmann et al., 2013). In addition, Ritzmann et al. (2013) reported that when they applied side-alternating vibration type whole-body vibration to 18 healthy adults, knee extension and TA muscle activation was the highest when the knee flexion angle was at 60°. Similar to preceding studies, in this study when the knee flexion angle was 60°, muscle activation was the highest in VL and TA, and the larger the knee flexion angle, the more is the muscle activation required for lower limb anterior muscles VL and TA. According to the muscles' anatomical function, the gradually increased knee flexion causes voluntary contraction of the rectus femoris and vastus medialis to generate the high power that compensates for the increased joint torque (Kooistra et al., 2006; Pincivero et al., 2004). In addition, the size of the stretch reflex amplitude is related to the amount of voluntary activation (Bedingham, & Tatton, 1984). Based on the aforementioned two aspects, it is believed that the increased knee flexion angle during whole-body vibration results in increased knee extensor muscle activation and the increased stimulation of Ia afferent fibre causes greater nerve root reaction (Abercromby et al., 2007). Based on the results of this study, it was noted that the horizontal whole-body vibration requires further lower limb muscle activation at a high frequency and an increased knee flexion angle and this would be the basic data on how horizontal whole-body vibration could be used in exercise or rehabilitation.

However, there are a few limitations to this study. First of all, since the whole-body vibration was applied for a very short time, it was not possible to find out the effect of its application for a long time. Additionally, since this study dealt with healthy adults in their 20s only, it is difficult to generalize the results of this study due to the limitation of age and the small number of subjects. Moreover, since this study did not directly compare vertical whole-body vibration with side-alternating whole-body vibration, which direction of vibration could be more effective and safer was not suggested. Therefore, it would be necessary to conduct higher quality follow-up studies that compensate for these limitations.

CONCLUSION

This study compared lower limb muscle activation, according to horizontal whole-body vibration frequency and knee flexion angle, in healthy adults. As a result, it was noted that larger the frequency and knee flexion angle, more is the lower limb muscle activation. Therefore, the appropriate setting of knee flexion angle and frequency for horizontal whole-body vibration would be used as guidelines for implementing a more effective exercise program.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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