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What is the Optimal Frequency for Ankle Muscles During Whole-Body Vibration Exercises?

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ABSTRACT

Usage of the whole-body vibration (WBV) is effective in preventing the ankle injuries caused by increasing neuromuscular activity. The aim of this study was to investigate effective frequencies for neuromuscular activity of ankle muscles. A single-group, repeated-measures study design was used. Twenty-three healthy subjects (age 23.91±3.07, BMI 22.66±3.39) participated in this study. This study investigated the effects of WBV on the EMG responses of the Tibialis Anterior (TA), Peroneus Longus (PL), Gastrocnemius Medial (GM) and Lateral heads (GL). The muscle activity was measured with an 8-channel EMG Noraxon MiniDTS system (Noraxon, USA, Inc, Scottsdale, AZ) during 0, 20, 40 and 60 Hz of vibration. The Physio Plate® vibration platform (Physio Plate®, Domino S.R.L, San Vendemiano, Italy) was used to deliver mechanical vibration. Compared with no vibration condition; EMG activity of all ankle muscles were significantly increased from at 60 Hz (123 % in TA, 64 % in PL, 53 % in GM, 77 % in GL) ($p<0.01$). At 40 Hz of vibration frequency, EMG responses of GM and GL was significantly increased (27 % and 53%, respectively) ($p<0.01$). Only GL was significantly increased of 33 % at 20 Hz ($p<0.01$). It could be concluded that using higher frequencies at whole-body vibration exercises are more effective than lower frequencies on ankle muscles' EMG activities. During squat exercises on the WBV platform, higher frequencies should be used to increase ankle muscle activation.

1. Introduction

Ankle sprains are accepted as the most common sports and physical activity related injuries [35]. An acute ankle sprain causes pain, function loss and economic burden [31]. Moreover, most of the patients with history of ankle sprain tend to repeat their injury [9]. Because of these reasons emphasis should be put on the importance of preventive intervention for the ankle.

Neuromuscular training is one of the popular intervention which is used to prevent ankle sprain and includes challenging the ability of related joints to detect external stimulus and produce desired response to stimulus [10, 31]. Whole-Body Vibration (WBV) trainings take place both in preventive programs and in rehabilitation protocols [22], as neuromuscular training techniques [2, 21] and exercise modality [13].

WBV trainings are exercises performed on a platform that creates an oscillation with certain frequency and amplitude [24]. It is believed that the vibration stimulus can move the muscle spindle to cause stimulation of alpha motor neurons, thereby increasing muscle contraction [19, 26], and motor unit synchronization [14] because muscles try to dampen the vibration effect by recruitment of muscle units through tonic vibration reflex (TVR) which increases observed electromyographic (EMG) activity [38]. TVR is derived from rapid change of the muscle spindle during vibration stimulation results excitation of the neuromuscular system and caused more involuntary contraction. There is evidence that WBV trainings cause the development of various neuromuscular parameters, such as strength, power and balance [22, 25]. It has been reported that WBV training increased muscle strength due to increased neuromuscular activation and similar adaptations to resistance training were observed [1].

In many studies, it has been shown to improve EMG activity of the lower extremity during the application of vibration [1, 5, 11, 24, 27]. To our knowledge no study has investigated which frequency is more effective in these muscles of the ankle joint. EMG activity is related to amplitude and frequency of vibration stimulus, body posture and effect of WBV may change in different body parts [13]. Regarding to the given information, the aim of this study was to compare the responses of the muscles around the ankle to the WBV training at different frequencies in squat position. Thus, it was thought that it would be possible to find the answer which frequencies will be more effective to the muscles around the ankle when using WBV in order to prevent ankle injuries. It was hypothesized that the highest myoelectric activity would be obtained at the highest possible combination of amplitude and frequency [20], because of the number of simultaneously stimulated motor units would be higher, as well as a better synchronization of their stimulation [4].

3. Method

3.1. Participants

Twenty-three healthy individuals (age 23.91±3.07, height 171.56±11.11, weight 67.45±16.12, BMI 22.66±3.39) were included in this study. The exclusion criteria included epilepsy, pregnancy, cardiovascular diseases, diabetes, tumors, implants, recent fractures, musculoskeletal disorders and severe delayed onset of muscle soreness in leg muscles.

The protocol for the study was approved by the ethic committee of Gazi University. The subjects were aware of the purpose of the study and all the subjects signed an informed consent form before participation.

3.2. Materials

Whole-Body Vibration protocol

Vibration stimulus was applied with a GLOBUS Physio Plate® that oscillates vertically up and down. The subjects were asked to assume isometric two legs deep squat position for the following conditions: no vibration (0 Hz), 20 Hz, 40 Hz, and 60 Hz at 2 –3 mm amplitude. The subjects performed 2 trials and each trial lasted 20 seconds in every vibration condition. Two minutes of rest period was given between each trial. The order of the trials for each subject was randomized (via a random number integer table was generated at random.org) across the frequencies and the WBV frequency were not verbally informed to participants. Proper feet position was marked for each subject in first trial. Arms were placed in horizontally extended position and hand grasping on handrail of the WBV device. At the same time, participants maintained their trunk position as upright as possible. A physical therapist measured knee joint angle to keep 90^0 [8] and 26^0 ankle dorsal flexion angle by using the universal goniometer and ensured the maintenance of the body position of participants (Figure 1).

Figure 1. Positioning of the squat exercise on the vibration platform

EMG

The muscle activity was measured with an 8-channel EMG Noraxon MiniDTS system (Noraxon, USA, Inc, Scottsdale, AZ). Unit specifications contain a common-mode rejection ratio (CMRR) was greater than 100dB and input impedance was greater than 100 Mohm. Sampling rate for EMG data was 1500 Hz per channel. The EMG signal of muscles was recorded using the bipolar Ag/AgCl surface electrodes (Noraxon, USA, Inc, Scottsdale, AZ) with a center-to-center interelectrode distance of 20 mm. Before the electrode placement, the skin was prepared to minimize skin impedance by cleaning the area with 70% isopropyl alcohol solution and body hair was shaved. EMG activity of all subjects was measured at the TA, PL, GM and GL of the dominant leg during all of the trials. The surface electrodes were placed parallel to the muscle fiber direction on dominant sides of the body;

Tibialis anterior – 1/3 on the line between the tip of the fibula and the tip of the medial malleolus; peroneus longus – 25% on the line between the tip of the head of the fibula to the tip of the lateral malleolus; gastrocnemius medialis – on the most prominent bulge of the muscle; and gastrocnemius lateralis – 1/3 of the line between the head of the fibula and the heel) [12, 29, 34]. All electrodes were fixed by double-sided tape to guarantee that they remain stable throughout the session and the cables were carefully fixed by tape to the skin.

During data collection, the EMG signals were visually checked against the possibility of artifacts. The EMG signals were processed and analyzed with MR 3.12 software (Noraxon, USA, Inc, Scottsdale, AZ). For data analysis the middle 10s of the test condition were chosen (from 5 s to 15 s) was evaluated. First, the raw EMG signals were band-pass filtered [33] between 15 and 500 Hz [5]. The raw EMG data were smoothed by means of a moving root-mean-square (RMS) (time window 100 ms) [5, 16].

3.3. Procedure

A single-group, repeated-measures study design was used to investigate the effects of WBV on the EMG responses of the ankle muscles. The independent variables were vibration frequency (no vibration, 20 Hz, 40 Hz and 60 Hz) while the dependent variables were the activities of four ankle muscles (TA, PL, GM and GL). Muscle activity was assessed during isometric squat position with 90^0 knee flexion in two different exercise conditions. For each subject, the experiment was performed on one day.

Statistical analysis

SPSS 23.0 was used for the statistical analysis. The Kolmogorov-Smirnov test was carried out to determine whether parametric and non-parametric tests should be used. Friedman test was used to carry out the $sEMG_{RMS}$ data comparisons of each frequency of WBV (no vibration, 20 Hz, 40 Hz, 60 Hz). The level of significance of $p<0.05$ was chosen. To compare the difference of $sEMG_{RMS}$ value between frequencies, the Wilcoxon signed ranked test was used. The type 1 error was adjusted using Bonferroni's correction, which resulted in level of significance of $p<0.0083$.

4. Results

Median and interquartile range values were showed in table 1. Figure 2 illustrates the $sEMG_{RMS}$ value during whole-body vibration exercise with no vibration and vibration with different frequencies. The $sEMG_{RMS}$ activity of the tibialis anterior and peroneus longus significantly increased at 60 Hz as compared with no vibration (respectively $p=0.0013$, $p<0.0001$). Peroneus longus also has significantly greater muscle activity at 60 Hz compared to 20 and 40 Hz (respectively, $p=0.0008$, $p=0.0004$). All vibration frequencies (20, 40 and 60 Hz) were enhanced muscle activity of the gastrocnemius lateral head (respectively $p=0.0015$, $p=0.0002$, $p<0.0001$). Gastrocnemius medial head muscle activity increased 40 and 60 Hz as compared with no vibration (respectively $p=0.0035$, $p<0.0001$). $sEMG_{RMS}$ values was significantly increased at 60 Hz compare with 20 Hz ($p= 0.0075$) in gastrocnemius medial head. The most remarkable result was significant increase in the sEMG activity of all muscles at 60 Hz compare with no vibration.

Table 1. Median and IQR for the $sEMG_{RMS}$ values at the different applied vibration frequencies

	No Vibration	20 Hz	40 Hz	60 Hz	p
	Median (IQR) (µV)	Median (IQR) (µV)	Median (IQR) (µV)	Median (IQR) (µV)	
Tibialis Anterior	13.7 (6.62-32.65)	18.25 (13-51.75)	17.35 (12.22-51.21)	35.5 (18.3-73.9)	0.000*
Peroneus Longus	17.95 (13.79-28.4)	19.75 (14.05-35.15)	27.26 (17.9-30.7)	35.85 (21.8-47.9)	0.000*
Gastrocnemius (Lateral Head)	11.80 (8.58-14.35)	14.93 (9.82-22.15)	15.65 (12.5-25.8)	20.4 (15.2-28.75)	0.000*
Gastrocnemius (Medial Head)	12.36 (10.33-15.7)	17.95 (11.6-27.1)	21.65 (11.1-32.1)	24.7 (16.55-34.6)	0.000*

*p<0.05, difference of four groups; IQR: interquartile range

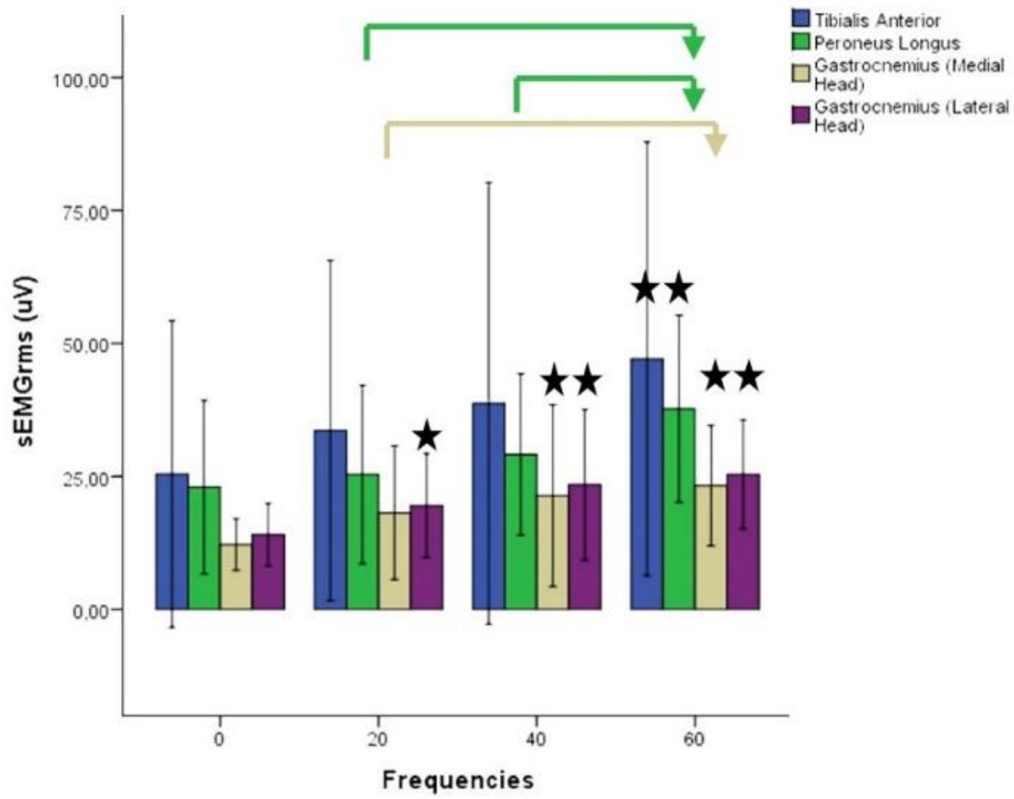

Figure 2. Means and SD (Colorful Box and thin line, respectively) for the $sEMG_{RMS}$ values at the no vibration and different vibration frequencies. The asterisks indicate significantly greater values compared with the no vibration values ($p<0.0083$). The significant differences of $sEMG_{RMS}$ values compared with between vibration frequencies was symbolized with the arrows ($p<0.0083$).

5. Discussion and Conclusion

The study was supported by Gazi University Projects of Scientific Investigation (BAP).

This study aimed to analyze the muscle activation of the ankle muscles at different frequencies during the squat exercise performed on the whole-body vibration. According to the results of our study; sEMG median values increase of 123% in TA, and 64% increase in PL were observed at 60 Hz compared with no vibration. GM muscle activity was also increased at 40 and 60 Hz as compared with no vibration (respectively 27% and 53%). In addition, at all vibration frequencies (20, 40 and 60 Hz) GL muscle activity was increased (respectively 33%, 53% and %77) compared with no vibration. These results support our hypothesis. However, the effects of different frequencies on EMG during the WBV was remained incompletely understood and was continued to be a matter of debate among researchers.

Similar to our study, there are several study which found that higher frequencies of vibration increase sEMG activity of ankle muscles. Roelants et al.[30] analyzed Gastrocnemius muscle activity during high squat (125^0 knee flexion), low squat (90^0 knee flexion), and 1-legged squat. The results showed that during all exercises compared with the no vibration muscle activities were significantly increased during WBV at 35 Hz in all muscles (respectively; high squat: 301%; low squat: 134%; one-legged: 360%). Pollock and collagenous [23] recorded EMG signals of TA and GL muscles during 15^0 knee flexion at 5, 10, 15, 20, 25 and 30 Hz frequencies. They found using of higher frequencies and amplitudes of vibration was optimal WBV protocol for increasing muscle activity. In addition; Duc et al.[8] found that $sEMG_{RMS}$ ratios of GM were significantly higher at 50 and 60 Hz compared with 20Hz, whereas those of TA remains unchanged during two different flexed body positions (60° knee flexion; 90° knee flexion). Lienhard et al.[17] investigated soleus (SOL) and GL muscle activity at 0, 25, 30, 35, 40 Hz frequency during 70^0 squat exercises. They showed that the SOL and the GL showed significantly higher $sEMG_{RMS}$ during WBV for all vibration frequencies than no vibration. In addition, only the highest vibration frequency (40 Hz) caused an enhancement in muscle activity compared to the lowest frequency (25 Hz) in the GL.

As opposed to these results, Di Giminiani and collagenous investigated the EMG_{RMS} activities in the GL at different frequencies and positions. Their results indicate that lower frequencies of vibration (25–35 Hz) resulted in maximal activation of GL (averaged values of four body positions) than higher frequencies [6]. They suggested that ankle muscles were highly influenced by body position therefore, the different body positions may be affected the findings. We used

The present study was found that the highest muscle activity was occurred at 60 Hz for all the ankle muscles. Stretches of muscles and tendons during whole-body vibration exercises induce a frequency-dependent activation of the muscle spindles and thus elicit stretch reflex response. Increasing in EMG activity was caused by higher number of stretch reflex responses that occur during whole-body vibration [27]. The measurement was carried out during squat with ~26^0 dorsal flexion. As this lengthening of the plantar flexors cause the sensitivity of the spindles [6], EMG activation was substantially affected by this position. Muscle activity of gastrocnemius lateral heads showed statistically increasing at all vibration condition while there was increasing gastrocnemius medial head's activity at both 40 and 60 Hz. However, peroneus longus and tibialis anterior muscles activity increased only at 60 Hz compared with no vibration condition. Schoenfeld et al. demonstrate that increasing of the knee flexion cause greater activity of the gastrocnemius during squat [32]. The results of this study support this hypothesis. Additionally, the amount of voluntary background activation is influenced on the size of the stretch reflex amplitude [27]. Gastrocnemius, tibialis anterior and peroneus longus muscles is contracted simultaneously during the deep squat. Dionisio et al. emphasize that the Center of Pressure (COP) moving to heel in squat position compared with the upright position and tibialis anterior was more activated during the squat as a result of to avoid falling backward [7]. Grasping the hand at the device may decreased the backward force and inhibit tibialis anterior in this study.

Vibrations may cause different responses to these different muscles, leading to different muscle fiber type distributions. Histological studies have shown that the ratio of type-1 fiber is 72.7-73.4% for TA, 62.5% for PL, 50.8% for GM and 43.5-50.3% for GL.[15] According to this information, the ratio of type-1 muscle fibers is higher than that of TA and PL muscles being active at higher frequencies; GM and GL muscles, which have a lower ratio of type-1 muscle fibers, were found to be active even at lower frequencies. Resting membrane potentials of type-2 fibers, also called fast-twitch muscle fibers, are more positive than type-1 fibers [36], and therefore easier to ignite may have caused changes in muscle activation of GM and GL muscles to start at lower frequencies. In the same direction, muscle activity of GL was started to statistically increasing at 20 Hz and GM at 40 Hz while activity of TA and PL was increased at 60 Hz in present study.

In raw EMG data, the sharp peaks in power spectrum are observed during the WBV exercises. Some authors emphasize that the measurements of the TVR and muscle activation is difficult to give an exact quantification of EMG activity because of the motion artifacts during WBV exercises and they used notch filter vibration frequencies and its harmonics [3, 18]. It was demonstrated that the neuromuscular response to the vibration frequency is contributes more than motion artifacts. Therefore, no additional filter is suggested [28, 37]

As we didn't evaluate maximum voluntary contraction (MVC) of the ankle muscles, we couldn't know which proportion of these muscles were active and we did not use different knee and ankle joint degrees. These are the limitations of this study.

In literature, no study has been done to determine the optimal frequency of TA, PL, GM and GL muscles at 20, 40, 60 Hz frequencies focusing on the surrounding muscles of the ankle in 90^0 knee flexion. The present study demonstrated that high-frequency WBV was more effective than low frequency in TA, PL, GL and GM. The high frequencies should be preferred on whole body vibration to increase the neuromuscular response in the ankle. Based on the results of the present investigation, physical therapists and sports trainers may be able to optimize training programs by using the WBV training.

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