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WHOLE-BODY VIBRATION EFFECT ON MUSCLE ACTIVATIONS: WHICH ONE IS THE MOST EFFECTIVE, LOW FREQUENCY OR HIGH FREQUENCY?

ORIGINAL ARTICLE

ABSTRACT

Purpose: Whole Body Vibration (WBV) is a practice that passively applies mechanical oscillations to an individual from a support surface. The tonic vibration reflex response depends on the vibration localization, frequency, amplitude, and initial length of the muscle, but there is no consensus on what the optimal frequency should be. This study was conducted to examine the activation differences of lower extremity muscles at low and high frequencies during squat exercise on WBV.

Methods: This study involved 16 healthy individuals (Age = 23.66 ± 2.33 years, Body Mass Index = 22.59 ± 3.86 kg/m^2). WBV application was performed on a vertical vibration platform (GLOBUS Physioplate®). Participants performed static half-squats on WBV for 20 seconds under vibrating (20 Hz and 60 Hz; 2-3 mm amplitude) conditions. An 8-channel Electromyography (EMG) Noraxon MiniDTS system was used to measure the activation of the Gluteus Medius (GMed), Gluteus Maximus (GMax), Vastus Lateralis (VL), and Vastus Medialis (VM) muscles.

Results: It was observed that there was a difference between the two frequencies for the activation of the VM, VL, and GMed muscles (p = 0.004, 0.001, 0.002, respectively). Vibration frequencies of GMed, VL, and VM muscle activities at high frequency were increased compared to low frequency. GMax did not show any statistically significant change between the two vibration conditions (p=0.013).

Conclusions: Physiotherapists and trainers should prefer high frequencies in WBV applications, especially when they need to improve the neuromuscular response in the quadriceps and gluteus medius muscles.

Keywords: Electromyography, Frequency, Lower Extremity, Whole Body Vibration

TÜM VÜCUT VİBRASYONUN KAS AKTİVASYONLARINA ETKİSİ: HANGİSİ EN ETKİLİ, DÜŞÜK FREKANS MI YÜKSEK FREKANS MI?

ARAŞTIRMA MAKALESİ

ÖZ

Amaç: Tüm Vücut Vibrasyon (TVV), kişiye bir destek yüzeyinden pasif olarak mekanik salınımlar uygular. Tonik vibrasyon refleksi yanıtı, vibrasyon lokalizasyonuna, frekansına, amplitüdüne ve kasın başlangıç uzunluğuna bağlıdır, ancak optimal frekansın ne olması gerektiği konusunda bir fikir birliği yoktur. Bu çalışma, TVV'de yapılan squat egzersizi sırasında alt ekstremite kaslarının düşük ve yüksek frekanslardaki aktivasyon farklılıklarını incelemek amacıyla yapılmıştır.

Yöntem: Bu çalışmaya 16 sağlıklı birey dahil edildi (Yaş = 23,66 ± 2,33 yıl, Vücut Kitle İndeksi = 22,59 ± 3,86 kg/m^2). TVV uygulaması, vertikal vibrasyon platformunda (GLOBUS Physioplate®) gerçekleştirildi. Katılımcılar düşük amplitüdte (2-3 mm) 20 Hz ve 60 Hz'lik vibrasyon durumlarında TVV üzerinde 20 saniye boyunca statik half-squat yaptılar. Gluteus Medius (GMed), Gluteus Maximus (GMax), Vastus Lateralis (VL) ve Vastus Medialis (VM) kaslarının aktivasyonunu ölçmek için 8 kanallı Elektromiyografi (EMG) Noraxon MiniDTS sistemi kullanıldı.

Sonuçlar: VM, VL, GMed kaslarının aktivasyonu için iki frekans arasında fark olduğu gözlendi (sırasıyla p = 0,004; 0,001; 0,002). Çalışmamız, yüksek frekanstaki GMed, VL ve VM kas aktivitelerinin titreşim frekanslarının düşük frekansa göre arttığını göstermektedir. Gmax kas aktivitesinde iki frekans arasında istatistiksel olarak anlamlı bir fark bulunmadı (p=0,013).

Tartışma: Fizyoterapistler ve antrenörler TVV uygulamalarında, özellikle quadriceps ve gluteus medius kaslarında nöromusküler yanıtı geliştirmeye ihtiyaç duyduklarında yüksek frekansları tercih etmelidirler.

Anahtar Kelimeler: Elektromyografi, Frekans, Alt Ekstremite, Tüm Vücut Vibrasyon

INTRODUCTION

Whole body vibration (WBV) is an exercise modality that can be used by applying indirect mechanical oscillations from the support surface to the target muscle (1). During the WBV exercise, the vibration is transmitted through the kinetic chain depending on the body position, and its energy is absorbed by the activated muscle (1,2). It has been shown that WBV exercises have a similar effect with strengthening and plyometric training on muscle activation, strength, and performance. For this reason, it has been applied to increase the effectiveness of the exercises in sports and rehabilitation programs and has become an important research topic in recent years (3,4).

The traditional theory explaining the possible mechanism of action of vibration stimulation is that as vibration produces rapid and short changes in the length of the muscular-tendon complex, it increases the activation of the terminations of the muscle spindle, creating a tonic vibration reflex (TVR) in the muscle (5). TVR results in increased muscle activation, contraction, and synchronization of the motor unit (6). TVR response depends on the localization of vibration, its frequency, amplitude, and the initial length of the muscle (5). Therefore, in studies with WBV, the effect of these parameters on the TVR response has commonly been investigated (3,5,6). Studies have shown that acute WBV generally provides higher EMG activation responses compared to no-vibration conditions (7-14). However, there are also studies that show the opposite results. Also, the effect of differences in vibration frequency on muscle activity is contradictory (15,16). Many studies include different exercise parameters (type of vibration platform, duration, and volume of exercises), vibration frequency, amplitude, and joint angles in order to evaluate the EMG activation of the lower extremities (7-16). Since various parameters are used in the studies and no consistent results are produced, the optimal vibration frequency remains uncertain (5). Thus, creating a WBV protocol for each type of exercise and target muscle would be a sensible approach.

The squat is a type of exercise that is commonly used in the strengthening and motor control exercises of the lower extremities and has become an essential part of hip and knee training programs (17). The primary muscle acting on the knee during squat exercise is the quadriceps femoris. Gluteus maximus (GMax) is a potent hip extensor and stabilizer, contracting eccentrically to inspect going down during squats and contracting concentrically to overcome external resistance when going up (18,19). Gluteus Medius (GMed) has a key role in providing pelvis and knee stabilization during the squat (20). There are many studies investigating the effect of vibration on the activity of the quadriceps muscles during squat exercise. However, there is no consensus in the related literature regarding the available information on the frequency at which the Vastus Medialis (VM) and Vastus Lateralis (VL) muscles are activated at a higher level during static half-squat exercises in the WBV application. Also, a limited number of studies were found for the GMax muscle, while no studies were found for the GMed muscle. Therefore, this study was conducted to investigate the effect of vibration frequency on lower extremity muscles (GMed, GMax, VL, VM) activations during static half-squat exercise.

METHODS

Participants

The study was approved by Gazi University Ethics Committee (Date: 14.07.2020, Number: 91610558-604.01.02, Research Code Number: 2020-374). After the participants were informed about the purpose and procedure of the study, an informed consent form was signed. Healthy volunteers between the ages of 18-30 were included in the study (Table 1). Individuals with any orthopaedics or neurological disorders that would affect their ability to exercise were not included. The study was completed with 16 individuals who agreed to participate in the study.

Experimental Design

The study design was determined as a single group and repeated measurement. The dependent variables were activation of lower extremity muscles (GMax, GMed, VM, and VL), while the independent variable was vibration frequency (20 Hz (low) and 60 Hz (high). In addition, evaluation was made in the static squat position in the vibration-free condition. Moreover, one day was allocated to each subject in the experiments.

Procedures

Whole Body Vibration Protocol

A vertical vibration platform (GLOBUS Physioplate®) was used for WBV application. The subjects were asked to stand barefoot on the platform and maintain the static half-squat posture for 20 seconds under vibration-free and vibrating (20 Hz and 60 Hz; at 2-3 mm amplitude) conditions (9). The adverse effects of vibration on the human body occur below 20 Hz and above 60 Hz frequencies (3). For this reason, 20 Hz for low frequency and 60 Hz for high frequency were preferred. Simultaneous EMG measurement was performed to examine changes in muscle activation under different vibration conditions. Each of the three vibration conditions was performed twice. The subjects took a 2-minute rest between trials (21). The starting frequency for each participant was determined by randomization, and WBV frequencies were not told to the participants. Participants were asked to hold the handrail of the device and extend their arms straight. In addition, the participants were instructed to keep their trunk position upright, and their shanks were nearly vertical, preventing the knee joint from going over the toes. Using a universal goniometer, a physiotherapist measured the joint angle to keep 90° flexion angles (22) and ensured that the participants' body positions were maintained (23). This study preferred a 90° half-squat because the hip extensor torque peaks at 90° and angles above 90° are unreliable (19).

EMG Measurements

An 8-channel EMG Noraxon MiniDTS system (Noraxon, USA, Inc, Scottsdale, AZ) was used to assess the activation of the VM, VL, GMed, and GMax muscles. Unit specifications include a common-mode rejection ratio (CMRR) greater than 100dB and input impedance greater than 100 Mohm. The sampling rate for EMG data was 1500 Hz per channel. EMG measurement was performed with bipolar Ag/AgCl surface electrodes (Noraxon, USA, Inc, Scottsdale, AZ) with a center-to-center distance of 20 mm. Before placing electrodes to reduce skin impedance, the skin was cleaned with a 70% alcohol solution and body hair was removed (21). During all trials, the participants' EMG activity was recorded from their dominant leg. The surface electrodes were aligned in the direction of the muscle fibers (13). A clinical expert put the electrodes on the areas of interest, following the SENIAM project instructions (24). All electrodes were taped to the skin with double-sided tape to ensure that they stayed steady during the session, and the cables were taped to the skin with care.

The EMG signals were processed with MR 3.12 software (Noraxon, USA, Inc, Scottsdale, AZ) and then analyzed. For the data analysis, the middle 10 seconds of the test duration (from 5 seconds to 15 seconds) was chosen. First, the raw EMG signals were band-pass filtered (25) between 15 and 500 Hz. The raw EMG data were smoothed using a moving root-mean-square (RMS) filter (time window 100 ms) (26).

The baseline EMG activity was recorded at the beginning during static half-squat (knee flexion angle was 90°) without vibration (13). Then, the values were normalized to the muscle activities obtained during the no vibration according to the following formula:

vibration conditions/no vibration * 100.

Statistical Analysis

Statistical Package for Social Science (SPSS) version 23.0 (IBM Corp., Armonk, NY, 2015) was used for the statistical analysis. Descriptive analyses are presented as mean ± standard deviation. Bonferroni corrected Wilcoxon signed-rank test was used to examine the changes in muscle activities at different frequencies. The significance level was set at 0.0125. Post-hoc power analysis was conducted. The achieved power is 0.99 according to the G*Power analysis, the effect size of Cohen's d = 1.56 with alpha = 0.0125, and two-tailed (n = 16) in a Wilcoxon signed rank test (matched pairs).

RESULTS

Normalized mean values and standard deviations are shown for the no vibration condition. VM, VL, GMed muscle activities significantly increased under the high frequency vibration condition compared to low frequency (p = 0.004, 0.001, 0.002, respectively; Table 2 and Figure 1). GMax did not

Table 1. The Demographic Information of the Participants

	Participants (n=16) (Mean ± SD)
Age (years)	23.66 ± 2.33
Height (cm)	174.00 ± 12.00
Body weight (kg)	69.78 ± 28.85
Body Mass Index (kg/m^2)	22.59 ± 3.86

SD: Standard Deviation

Table 2. Neuromuscular Activity of the Muscles Between Low and High Vibration Frequencies (Normalized to the No Vibration Condition)

	Low Frequency (%) (Mean ± SD)	High Frequency (%) (Mean ± SD)	Changes in Muscle Activity (%) (Mean ± SD)	Z	p
VM	119.46 ± 19.02	142.42 ± 24.74	22.96 ± 24.42	**-2.844**	**0.004***
VL	112.12 ± 18.14	142.22 ± 22.86	30.10 ± 19.17	**-3.309**	**0.001***
GMed	143.69 ± 33.00	189.84 ± 38.68	46.15 ± 42.22	**-3.103**	**0.002***
GMax	152.45 ± 30.80	194.52 ± 52.04	42.06 ± 56.93	**-2.482**	**0.013**

VM: Vastus Medialis, VL: Vastus Lateralis, GMed: Gluteus Medius, GMax: Gluteus Maximus, SD: standard deviation, *p<0.0125

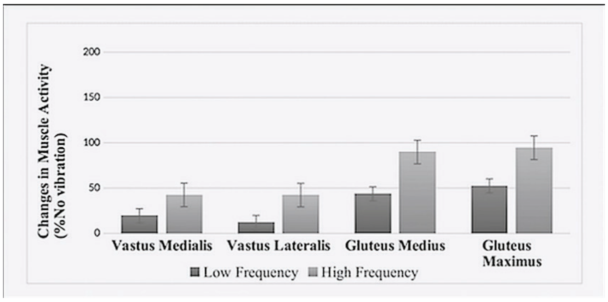

Figure 1. The mean and standard errors of normalized values to the no vibration condition neuromuscular activity in knee and hip muscles during Whole Body Vibration in response to the low and high frequencies.

show any statistically significant change between the two vibration conditions (p=0.013).

DISCUSSION

This study investigated the effect of static half-squat exercise performed at low (20 Hz) and high (60 Hz) frequencies in WBV on EMG activity of the lower limb muscles. It was found that high vibration frequency was more effective on muscle activation responses than low frequency in VM, VL, and GMed. There was no statistically significant change in GMax muscles.

The effects of different vibration frequencies applied during various exercises on muscle activities have often been investigated (8,10,11,14). Most of the studies have shown that adding vibration to exercise increases the EMG activities of the VM and VL muscles (11,12,14). In our study, increasing the vibration frequency led to an improved EMG activity of the VM and VL muscles. There are studies that support our findings (10,11,21). Krol et al. investigated the effects of amplitude (2-4 mm) and frequency (20, 40, and 60 Hz) on VL and VM activity in female participants only. It was determined that the highest muscle activation was seen when the frequency and amplitude were set at 60 Hz and 4 mm, respectively (21). Perchthaler et al. also recorded EMG signals of VL and VM muscles during the squat with different knee flexion angles at 6, 12, 18, 24, and 30 Hz frequencies. They similarly demonstrated that an optimal WBV protocol is achieved with higher frequency (10). These results indicated that even low level of changes in vibration frequency causes a significant increase in the muscle activity. The vibration increases the activation of the muscle spindle and creates a TVR in the muscle (27). This response is more elicited at higher vibration frequencies, resulting in an increased EMG activity (28). The WBV with high frequencies also contributes to a large number of simultaneously stimulated motor units and this results in a higher muscle activation (18,24). Although most of the studies showed significant improvement in the muscle activities by increasing the frequency, some studies have controversial results. Cardinale and Lim (2003) investigated different frequencies (30, 40 and 50 Hz.) during isometric half-squat exercise in professional women volleyball players. The higher muscle activity was shown during the lowest vibration frequency (7). Borges et al. (2017) compared VL muscle activity during half-squat exercise under no vibration and two different vibration conditions (30 and 50 Hz.) in 40 healthy women (29). Their results showed that muscle activity increased in vibration conditions but there were no significant differences between the two vibration conditions. The reason for these inconsistent results in the literature may be the highly variable demographics of population and vibration parameters (frequency, amplitude, duration). Due to the variety of parameters, it is very difficult to determine the optimal frequency for each muscle. Therefore, related studies should be specific to each muscle, exercise, and population.

Although there are many studies in the literature assessed the response of the quadriceps muscle activity to WBV during the squat, there are limited studies investigating the gluteal muscles (22,30-33). In our study, GMax muscle activity was not affected by the changes of frequency. Zaidell et al. (31) evaluated the effect of 20, 25, and 30 Hz vibration frequencies on GMax EMG activity during the squat (30°) and standing position. Muscle activity during the squat increased with WBV compared to the no-vibration condition. However, similar to our results, vibration frequency did not affect GMax muscle activity. The vibration energy produced by the WBV device decreased while transmitting through the body. Vibration energy is damped by muscles and joints as it is transmitting through the body (22,31). For this reason, it is thought that the muscles closer to WBV platform may show higher activation than the muscles far from the platform. Zaidell et al. (31) stated that higher frequencies or deeper squat angles may be effective in inducing the activity of the GMax muscle located distal to the platform. In our study, higher frequency (60 Hz) and deeper squat angle (90 degrees) were used. However, there was no significant difference between the low and high frequency of vibration in GMax activity. It has been reported that increasing the knee angle (>30degree) during the squat decreases the vibration energy transmitted to the proximal body part (hip and head region) as the knee muscles may absorb more energy. This may explain the results showing a statistically significant difference between high and low frequencies (27). In addition, the duration of exposure to vibration may affect the activation response. Longer exposure to vibration may be required to elicit the tonic vibration reflex in the GMax muscle (1). Pollock and colleagues recorded EMG signals of GMax muscle during 15° knee flexion at different low frequencies (5, 10, 15, 20, 25, and 30). Similar to our results, they found that GMax muscle activation did not change with frequency. The reason for this result may be the preferred vibration frequencies that are very close to each other (30). Liu et al. (32) investigated the effect of body positions during different squat tasks (static, static with elastic band loading, and dynamic squat) and amplitude of the vibration on muscular activity in GMax in middle aged and older women. They showed that there were no differences between vibration and no vibration conditions during static squat in GMax muscles. WBV does not affect gluteus maximus activity in different squat tasks. On the contrary, Duck et al. (22) showed that high frequencies (50 and 60 Hz) result in higher EMG responses in GMax than low frequencies (20 Hz). Kim and Seo investigated the change of GMax muscle activation with different vibration frequencies (0, 10, 20 Hz) and different pelvic positions (neutral, anterior, and posterior pelvic tilt) when standing still. The results showed that higher frequencies (20 Hz) and the use of posterior pelvic tilt during WBV improved GMax activation (33).

Although there are studies evaluating VM, VL, and GMax muscle activities during squat exercises with different knee angles and vibration parameters, no study has been found on the GMed muscle activity during squat exercises with vibration condition. Only the study by Aguilera-Castells et al. assessed the response of the GMed muscle to vibration of 30 and 40 Hz during the suspended lunge and Bulgarian squat exercises (34). Their results demonstrated that there was a statistical difference between no vibration and vibration conditions but no statistically significant difference between the two vibration frequencies. However, our study showed that increased vibration frequency improved neuromuscular responses in GMed. Differences in the activation responses of the Gmed muscle were observed in the two studies. There may be many reasons for this difference (population selection, exercise type, amount of vibration and amplitude). In our study, two vibration frequencies (vibration 20 or 60 Hz and 2 mm of amplitude) are compared during squat exercise in a mixed group of men and women. However, in the study of Aguielera Castells et al., 2 different vibration frequencies were applied (vibration 30 or 40 Hz and 4 mm of amplitude) during bulgarian squat and suspended lunge exercises only to men. There might not have been a difference in the activation response of the Gmed muscle due to the fact that they chose 2 frequencies very close to each other in their studies. In addition, the exercises used in the studies differ from each other. Since each muscle's contribution rate and response to each exercise are different, it might have given different responses to different frequencies. In addition, the difference in the selected population and amplitude in both studies might have affected the results. The gluteal muscles have a key role in improving athletic performance, preventing and rehabilitating lower extremity injuries (35). For this reason, determining the optimal WBV frequency for the gluteal muscles is important for the correct training of these muscles. More studies are needed to assess the gluteal muscle activities with WBV.

In raw EMG data, sharp peaks of the power spectrum are observed during WBV exercises. Some authors point out that accurate EMG measurement is difficult to obtain due to motion artifacts occurring during WBV exercises and the exact activation level cannot be determined. For this reason, notch filter of vibration frequency and its harmonics is used in some studies (29). As the neuromuscular response to vibration frequency has been shown to contribute more than motion artifacts, no additional filter is suggested (36,37).

The vibration stimulus in the WBV device used in the study was applied only vertically up and down with 2–3 mm amplitude, excluding other oscillations and amplitudes. In addition, the effect of multiple WBV sessions was not examined in this study. Our research was completed with one-time evaluation results. The fact that the long-term training effect was not evaluated is a limitation of this study. WBV studies should be performed in different populations and with more participants and, if possible, with long-term interventions.

As a result of this study, the effect of high vibration frequency on VM, VL, and Gmed muscles was found to be higher compared to low vibration frequency. It has been determined that 60 Hz frequency is more appropriate to maximize VM, VL, and Gmed muscle activation responses in WBV application. Physiotherapists who incorporate WBV into their programs in training lower extremity rehabilitation can optimize their training programs. Moreover, EMG recordings can be a tool to individualize training protocols for WBV. In this way, maximal neuromuscular development can be achieved by determining the optimal frequency specific to the individual.

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Conflict of Interest: The authors report no conflict of interest.

Ethical Approval: The study was approved by Gazi University Ethics Committee (Date: 14.07.2020, Number: 91610558-604.01.02, Research Code Number: 2020-374).

Author Contributions: ZBE: Collection of data, interpretation of data, drafted manuscript, literature review; OBT: Collection of data, analysis and interpretation of data; GC: Collection of data, interpretation of data, drafted manuscript; SSK: Study design, critical revision of manuscript; NK: Study design, critical revision of manuscript; NAG: Study design, critical revision of manuscript.

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