Effects of Low-Frequency Whole-Body Vibration on Muscle Activation, Fatigue, and Oxygen Consumption in Healthy Young Adults: A Single-Group Repeated-Measures Controlled Trial

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Context: Whole-body vibration (WBV) training improves muscle strength and balance. Few studies have focused on the effects of WBV frequencies below 30 Hz. We aimed to investigate the effect of low-frequency WBV training on muscle activity, fatigue recovery, and oxygen consumption (VO2). Design: Prospective single-group, repeated-measures study. Methods: In this controlled laboratory setting study, 20 healthy adults (age 23.26 [1.66] y) performed half squats at 0, 4, 6, 8, 12, 16, 20, 24, and 30-Hz WBV. Muscle activity was evaluated using the root mean square and peak electromyography amplitude of 6 muscles (iliocostalis, rectus abdominis, rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius) obtained via surface electromyography. VO2 was measured during the squats using a gas analyzer, and fatigue recovery was evaluated using measurements of lactate after the squats and after a recovery period. Statistical significance was set at P < .05, and analysis of variance was conducted to determine differences in muscle activity, fatigue, recovery, and VO2, with post hoc analyses as appropriate. Results: Of the 6 muscles measured, the muscle activity of the gastrocnemius alone significantly increased from 0 Hz at 4, 8, 12, 16, 24, and 30 Hz based on the root mean square values and at 4, 8, 12, and 30 Hz based on the peak electromyography amplitude values. There were no significant differences in the other muscles. There were no significant differences in VO2 or in lactate levels. Conclusions: Low-frequency WBV during squat exercises significantly increased the activity of the gastrocnemius muscle only at specific frequencies in healthy young adults. Low-frequency WBV is safe and has the potential to increase muscle activity.

Keywords: electromyography, fatigue recovery, muscle activity, vibration frequency

Whole-body vibration (WBV) has been used to improve muscle strength and to promote body mass loss in healthy individuals for the past few decades.1 Furthermore, WBV training (WBVT) has been suggested as a supplement to traditional forms of training for athletes as well as for untrained individuals, including older patients seeking improved strength or recovery.2–4 Vibration frequencies that are affected by several factors, including the type of vibration (oscillation vs vertical), frequency, amplitude, and acceleration. The type of exercise performed during WBVT also plays a role in the efficacy of treatment. Vibration prescriptions are determined by adjusting each component2,3; when the exercise type, amplitude, and frequency of WBVT are adjusted, the effects of the therapy on muscle activity,5–7 oxygen consumption (VO2),8,9 and fatigue recovery differ.10 Frequency is a particularly important component of WBVT as it is proportional to the energy level of the WBV vibration11 and significantly affects the transmission of vibration.12,13 Di Giminiani et al14 reported that frequency is the most important parameter for optimizing WBVT.

Previous studies have reported improvements in muscle function and motor function following WBVT.4 Several studies have investigated the frequency-dependent effects of WBVT; for example, the vastus medialis activity in professional volleyball players was greater at 30 Hz than at 40 or 50 Hz,4 and the knee extensor strength and jump performance of 32 physically active, average 20-year-old men were greater at 50 Hz than at 30 Hz.15 Similarly, when normal adults perform squats with WBV, lower-extremity muscle activity increases as the vibration frequency (acceleration) increases from 20 to 55 Hz.14 In general, high-frequency WBV increases muscle activity and VO2 via a large transfer of energy14,16,17; however, high-frequency WBV also increases the risk of adverse effects, including muscle soreness, excessive fatigue, and paresthesia.18,19 In contrast, low-frequency WBV has been reported to be safer and have less impact on muscle activity than high-frequency WBV because of relatively low energy transfer and reduced acceleration.18 There are few studies regarding muscle activity during low-frequency WBV that comprehensively investigate muscle activation, oxygen intake, and fatigue recovery in low-frequency bands. As the demand for the application of a wider range of vibration frequencies is increasing, it is necessary to investigate the effects of low-frequency WBVT. Therefore, this study aimed to investigate the effect of low frequency (2–30 Hz) WBVT on muscle activity, VO2, and muscle fatigue recovery in untrained, healthy young adults.

Methods

Design

This single-center, prospective, single-group, repeated-measures study was conducted at the rehabilitation center of a national university hospital. We investigated how muscle activity and
VO₂ change according to each subdivided frequency below 30 Hz while performing squat exercises with low-frequency WBV. Therefore, the independent variable was defined as the vibration frequency, and the dependent variables were muscle activity, measured with electromyography (EMG), and VO₂, measured with a gas analyzer during exercise. In addition, to investigate the effect of low-frequency WBV on fatigue recovery, 2 lactate measurements were taken immediately after exercise and after 20 minutes of rest on WBV. Therefore, the independent variable was defined as the vibration frequency below 30 Hz, and the dependent variable was set as “the amount of change in lactate before and after rest.”

**Subjects**

Subjects were recruited among individuals who were willing to participate in clinical trials by posting recruitment notices on the bulletin boards of national universities and hospitals. All subjects provided written informed consent for their participation in this study. The subjects were healthy adults aged 20–29 years with no cognitive decline and no communication limitations (mini-mental state exam scores >24). Regarding the participant’s physical activity level, the subjects were neither trained nor physically vigorous. As per the enrollment criteria, the enrolled subjects performed high-intensity exercise (weight training, spinning, jumping, and others) less than once a week. Before enrolling participants, each WBV frequency was applied for approximately 1 minute (approximately 10 min for all measured frequencies). The research staff investigated dizziness, itchy skin, nausea, and nonspecific discomfort, and subjects with dizziness or discomfort were excluded. Subjects with musculoskeletal disorders or injuries within 6 months of the study, those who were pregnant, and those with neurological disorders, such as central nervous system disorders, were excluded from the study. In addition, the ability of the participants to perform the squat appropriately with feedback from the research staff was checked. Twenty participants were enrolled; however, since one participant dropped out, 19 (11 women and 8 men) participants aged 22–28 years (mean age [SD]: 23.26 [SD] y) were analyzed for this study between July 4, 2019 and August 2, 2019.

This study was approved by the institutional review board of Jeonbuk National University Hospital (approval number: CUIH 2019-03-043-002) and was registered at the Clinical Research Information Service of the Centers for Disease Control and Prevention (registration number: KCT0004832).

**Procedures**

Participants had 10 visits, 1 visit per day for 10 consecutive days, with a 2-day interval between visits 5 and 6. A frequency type was applied for each visit in increasing order as follows: ground, 0, 4, 6, 8, 12, 16, 20, 24, and 30 Hz.

Each subject performed 5 squat sets (one set is defined as 20 squats in 1 min) on a vibratory platform at each WBVT frequency. The squats performed at 0 Hz served as a control. Each set was separated by a 2-minute rest period. During the third set of squat exercises for each frequency, VO₂ and muscle activity were measured using a gas analyzer and surface EMG, respectively (Figure 1). We measured oxygen intake and EMG in the third set as it may be performed with better posture than the previous sets because of sufficient warm-up and repetitive performance of the squats. Besides, the possibility of inappropriate performance due to energy depletion is lower than in the following sets.

Lactate was measured at 2 time points: at the time point immediately after the end of the 5 sets of exercise sessions and at the time of vibration rest for 20 minutes; the change in lactate was evaluated (Figure 1).

**Interventions**

**Vibration.** The sound wave vibration generator (model: SW-VHBS; Sonicworld Co., Ltd.), a device that transmits sound wave vibrations to the human body as vertical vibrations, was used in this study. The vibration parameters (acceleration, amplitude, duration, and type of vibration) were determined according to the recommendations of the International Society of Musculoskeletal and Neuronal Interactions.¹¹ The vibration duration was 13 minutes per session (5 min for 5 sets of squats + rest intervals of 2 minutes each between sets) at an amplitude of 5 mm (Figure 1). As acceleration is defined as the product of angular frequency (ω) squared and amplitude (A) (acceleration ∝ A × ω²), where A is converted from millimeters to meters and ω is the product of 2π and vibration frequency,¹¹ acceleration is a frequency-dependent variable in this protocol because amplitude is fixed at 5 mm. The same frequency of vibrations was applied during the squat exercises and during the 20-minute postexercise rest period (rest on WBV session), during which the subjects sat on a chair with their feet on the vibration plate (Figure 1).

**Squat Exercises.** Subjects performed half squats on the vibration plate with bare feet. Each set of squats included 20 squats per minute (1 squat every 3 s). A metronome was used to pace the subjects. To perform a half squat, the subject extended at the waist and flexed the knee joint to 90°. Each half squat included a 1-second isometric phase during which the thigh remained parallel to the floor in a static posture. Both arms were extended forward to help the subject maintain balance (Figure 1). Five sets of half squats were performed at each frequency of WBV, with a 2-minute vibration-free interval separating each set. During the rest interval, subjects stood on the vibration plate. Before each session, familiarization was done by performing the squat posture under the assigned frequency of WBV for approximately 10 minutes. During familiarization, the research staff evaluated and gave feedback on the appropriateness of the squat position and suitable appropriate interval between repetitions. After sufficient rest (30–60 min), the main session started.

**Outcome Measurements**

**Primary Outcome.** The primary outcome was the total area of the root mean square (RMS) at each frequency, measured via EMG, as RMS reflects muscle activity. A NORAXON Portable Lab EMG system (Noraxon) was used in this study with the bandpass type of filter (low 20 Hz and high 500 Hz) using Finite Impulse Response filtering. The RMS smoothing was 100 milliseconds, and the sampling rate was 1000 Hz. After the skin was prepped with alcohol and electrolyte gel, surface Ag/AgCl dual electrodes (4 × 2.2 cm, interelectrode distance of 2 cm; Noraxon Dual Electrode, Noraxon) were placed longitudinally on 6 target muscles: the iliocostalis, rectus abdominis, rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and gastrocnemius medialis (mGCM). The attachment location of the iliocostalis was approximately 4 finger widths from the spinous process at the L2–L3 level, where the lowest part of the rib is palpable. In the case of the RA, the target was the muscle mass just above the umbilicus among the muscles.
of several segments. The electrode attachment position was 2 finger widths lateral and 2 finger widths superior to the umbilicus. The BF electrode was located at the midpoint of a line between the fibular head and the ischial tuberosity. The TA electrode was located 4 finger widths below the tibial tuberosity and one finger width lateral to the tibial crest. The RF electrode was located on the anterior aspect of the thigh, midway between the superior border of the patella and the anterior superior iliac spine. The mGCM electrode was located one hand width (5 finger widths) below the popliteal crease on the medial mass of the calf.20

A researcher with anatomical knowledge specified the attachment locations, which were marked with a semipermanent marker so that the electrodes could be attached at the same location each time.

The EMG measurements were obtained during the 1-second isometric phase of 14 squats during the third set for each frequency. The first 3 and last 3 squats of the set were excluded from the EMG measurements. The average of the obtained 14 EMG measurements was analyzed. We performed data normalization to minimize the effect of the subjects’ individual characteristics, such as age, sex, size of the muscle section, and skin thickness.21 A reference voluntary contraction normalization process was adopted to check the percentage of activation according to each vibration frequency using the nonvibration stimulus as a reference value, that is, vibration frequency versus no vibration (0 Hz).22

Secondary Outcomes. The secondary outcomes of this study included peak EMG amplitude, VO2, and lactate.

The peak EMG amplitude was based on the same EMG data as the RMS discussed in the primary outcome. The peak EMG amplitude was analyzed as the average of the peak EMG amplitude of each round from EMG data obtained from 14 squats except for the first 3 times and last 3 times in one set (total 20 repetitions), as in RMS. In addition, the peak amplitude was also normalized to the reference voluntary contraction.

A Querk CPET (COSMED) device was used to measure VO2 as a means of evaluating aerobic function, including VO2. VO2 was measured for 40 seconds, excluding the first and last 10 seconds of the third set. Based on the VO2 over 40 seconds, the mean VO2 (VO2 per minute) was assigned as a variable.

Subjects’ lactate levels were measured immediately after completion of the squat exercises and again after a 20-minute rest on WBV (resting with exposure to same frequency vibration as the exercise session) to evaluate the recovery of muscle fatigue. Accutrend Plus (Roche Diagnostics, GmbH) blood analysis was performed using blood (32 μg) obtained from the subjects’ fingers. As lactate reflects the degree of fatigue,23 the amount of lactate reduction between, immediately after the exercises, and after the rest on WBV session was used to measure the fatigue reduction effect.

Statistical Analyses

All statistical analyses were performed using SPSS for Windows (version 24.0). A repeated-measures analysis of variance was performed to compare the primary and secondary outcome variables for each frequency. Data that were not normally distributed were analyzed using the Friedman test. Statistical significance was set at $P < .05$.

Variables that were found to be significantly different in the repeated-measures analysis of variance underwent a post hoc analysis using a paired t test. Data that were not normally distributed were analyzed using the Wilcoxon signed-rank test. The Bonferroni correction method was used to adjust for the comparisons of the 8 time periods. The effect size was calculated using partial eta squared.
Results

Subjects
Of the 20 subjects enrolled in this study, one was excluded because of a refusal to exercise. Therefore, the final analysis includes data from 19 subjects (Figure 2). There were no reports of abnormal or spontaneous adverse events in this study.

Primary Outcome
Among the measured RMS values of the 6 muscles, the BF ($P = .013$, $\eta^2_p = .185$) and mGCM ($P < .001$, $\eta^2_p = .180$) muscles alone were significantly different between the vibration frequencies (Figure 3 and see Supplementary Table S1 [available online]). The post hoc analysis revealed a statistically significant increase in the RMS of the mGCM at 4, 8, 12, 16, 24, and 30 Hz ($P < .001$, $P = .008$, $P = .003$, $P = .016$, and $P = .008$, respectively) compared with 0 Hz; however, there were no significant differences at 6 and 20 Hz ($P = .208$ and $P = .064$, respectively) (Figure 3 and see Supplementary Table S2 [available online]). Regarding the post hoc analysis of the RMS of the BF, there was no statistical significance for any of the frequencies compared with 0 Hz (Figure 3 and see Supplementary Table S2 [available online]).

Secondary Outcomes
Regarding the peak EMG amplitude, the BF ($P = .011$, $\eta^2_p = .164$), TA ($P = .013$, $\eta^2_p = .123$) and mGCM ($P < .001$, $\eta^2_p = .245$) alone showed a statistically significant difference among the 6 muscles (Figure 4 and see Supplementary Table S3 [available online]).

The post hoc analysis revealed that the peak EMG amplitude of the mGCM muscle at frequencies of 4, 8, 12, and 30 Hz was significantly increased compared with that at 0 Hz ($P = .040$, $P = .032$, $P = .016$, and $P = .024$, respectively; Figure 4 and see Supplementary Table S4 [available online]). Regarding the post hoc analysis of the peak EMG amplitudes of the BF and TA, there was no statistical significance between all the evaluated frequencies and 0 Hz (Figure 4 and see Supplementary Table S4 [available online]).

Discussion
This study investigated the effect of a single bout of low-frequency WBVT on muscle activity, fatigue recovery, and VO$_2$ in untrained young adults. In this study, the mGCM muscle had significantly increased muscle activity at specific low-frequency WBVT compared with the muscle activity measured while no vibrations were used during exercise. The VO$_2$ and lactate reduction were not significantly different compared with 0 Hz for low-frequency WBVT analyzed in this study.

Previous studies have investigated the effects of WBVT, including the effects on muscle activity. Vibration frequency has been reported as the WBVT component with the most potential to be the main decisive factor of the effects of WBVT. However, there are few studies regarding the effects of low-frequency WBVT. Therefore, this study aimed to evaluate the effects of low-frequency WBVT on muscle activity, VO$_2$, and fatigue recovery.

Three mechanisms exist for improving muscle function during low-frequency WBVT: the tonic vibration reflex, the muscle tuning mechanism, and increased muscle perfusion. All these mechanisms are affected by vibration frequency. First, the tonic vibration reflex exists as a result of the mechanism that activates Ia-afferent fibers through vibrational stimulation of the muscle spindle. Aside from neuromuscular spindles, such as muscle spindles and Golgi tendon organs, vibration sensory input to skin or joints increases presynaptic inhibition transmitted to the Ia-afferent fibers responsible for antagonistic movement. Reducing the activity of the antagonist and increasing the activity of the agonist of the target muscle can be accomplished using vibration therapy during exercise, and the overall process is affected by vibration frequency. Second, the muscle tuning mechanism is based on the muscles’ adaptive responses to reduce the harmful effects caused by vibration resonance. Each individual has different viscoelastic characteristics because of their unique body composition. Therefore, each individual has their resonance frequency. In addition, each exercise posture has different resonance frequencies owing to several variables, including joint angle, range of motion, and target muscle. During WBVT, muscles respond in the direction of minimizing the resonance at this specific frequency, which may lead to an increase in muscle activity. Third, as the last possible mechanism, increased muscle perfusion due to vibration appears to be a mechanism of increased muscle activity. Vibration may have a direct effect on the vascular system, which may be specific to the vibration frequency. Low-frequency vibrations have been reported to increase skin blood flow, whereas high-frequency vibrations decrease skin blood flow. In muscle blood flow, there have also been reports of increasing effects in low-frequency vibrations. Taking into account the direct effect of vibration on blood vessels, the increase in perfusion may be a primary effect, rather than a secondary change derived from muscle activation.

There were no significant differences in lactate reduction ($P = .308$) after the vibration at any WBVT frequency (see Supplementary Table S5 [available online]). The lactate level tended to be decreased after all WBVT frequencies compared with that at 0 Hz, except for lactate reduction measured after WBVT at 8 Hz (Figure 5A).

There were no significant differences in VO$_2$ ($P = .509$) between the frequencies of WBVT (see Supplementary Table S6 [available online] and Figure 5B).
Previous studies demonstrated a larger increase in perfusion in low-frequency vibration, and it can be considered as a mechanism of increasing muscle activity in this study on low-frequency vibrational exercise.

In this study, a significant increase in muscle activity was observed in the mGCM at specific frequencies. The RMS of the EMG data was significantly increased at 4, 8, 12, 16, 24, and 30 Hz (Figure 3 and see Supplementary Table S2), and the peak amplitude of EMG was significantly increased at 4, 8, 12, and 30 Hz compared with no vibrations. An overall tendency of muscle activity increase was observed in the RMS, with peak EMG amplitude measurements in the mGCM (Figure 4 and see Supplementary Table S4).

Muscles close to the WBV diaphragm (such as the mGCM and TA) are expected to be affected more by the vibration than muscles that are far from the WBV diaphragm (such as the RF or BF). WBVT maximizes the exercise effect using additional gravity energy through vibration; thus, the shorter the transmission distance, the easier it is to transfer additional energy. In previous studies in which squat exercises were performed on a WBV platform, vibrations were found to primarily affect the distal lower extremities rather than the proximal ones. It was also reported that vibration was relatively less transmitted to the lumbar muscle than the distal muscles. In addition, the postural effects of the specific squat exercises used in this study may account for the muscle-specific findings. First, knee flexion further reduced the transmission of vibrations to muscles far from the diaphragm, including the RF and BF. Second, the main muscle used in the squat exercise is the quadriceps muscle. In a quadriceps muscle that has already been sufficiently contracted, small additional stretching of the muscle by vibration causes an eccentric contraction. Thus, it may cancel out the effects of additional contraction by tonic vibration (stretch reflex) due to the action of the Golgi tendon reflex. Third, in the isometric phase of the squat posture, the mGCM associated with the Achilles tendon appears to be more affected by WBV than the TA. As the mGCM was activated through the tonic vibration reflex, activation by the vibration of TA would have been at least partially canceled out, as a result of the reciprocal inhibitory reaction against the TA as the mGCM antagonist.

The WBVT results in an increased muscle load compared with conventional exercise. In particular, this additional muscle load can cause muscle soreness, preventing training from continuing. Therefore, recovery may be more important than after conventional exercise, which is even more important for untrained people than for athletes. Rapid energy consumption due to additionally activated muscles by WBV increases metabolic stress, and more lactic acid and hydrogen ions are released as waste products owing to increased muscle activity. Previous studies have reported that the recovery of muscle fatigue from low-frequency vibrations below 20 Hz is associated with increased blood flow during low-frequency vibration at rest. In a similar context, low-frequency vibration is expected to reduce muscle pain by increasing lymph and blood perfusion of muscles causing to wash out wastes products, and by affecting the sensory nervous system. Several previous studies regarding low-frequency WBVT and muscle fatigue have been conducted; however, the results were somewhat confusing. One
study showed that it is effective (10 Hz),\textsuperscript{10} while another study showed that is not effective (20 Hz)\textsuperscript{8} or that there is no significant effect in the early phase on muscle recovery but effective after 48 hours (12 Hz).\textsuperscript{41} In this study, no statistically significant lactate reduction was observed during the rest on WBV sessions; however, the amount of lactate reduction at all frequencies except 8 Hz was higher in rest on WBV than during no vibration (Figure 5A). In addition, considering Kosar et al.’s\textsuperscript{40} study, which showed improvement in muscle soreness at 12 Hz, it can be estimated that WBV had a beneficial effect on recovery.

Figure 4 — The peak amplitude of the EMG data obtained for each muscle at each vibration frequency. The EMG signal (peak amplitude) was normalized to 0 Hz as a reference and converted to a percentage of the RVC. Data are presented as mean values with SD. The translucent horizontal bar indicates RVC 100%. EMG indicates electromyography; RMS, root mean square; RVC, reference voluntary contraction. The asterisks indicate significant increases in peak amplitude-RVC (in percentage) during whole-body vibration. *P < .05, muscles with significantly different frequencies compared to Peak amplitude-RVC of 0 Hz. †P < .05, significantly different frequency compared with the Peak amplitude-RVC of 0 Hz within each muscle.

Figure 5 — Lactate and oxygen consumption during whole-body vibration therapy. (A) The lactate reduction from immediately after exercise to after a 20-minute vibration session with no exercise was not significantly different between vibration frequencies. The translucent horizontal bar represents the lactate reduction at 0 Hz and shows that lactate reduction is increased compared with that at 0 Hz at all vibration frequencies except for 8 Hz. (B) The oxygen consumption during the third set of exercises was not significantly different between vibration frequencies. Data are presented as mean values. The bars represent the SD. VO2 indicates oxygen consumption.
The WBVT has been reported to have a beneficial effect on the improvement of metabolic syndrome based on the increase in total oxygen intake for 24 hours, increase in muscle mass, suppression of adipogenesis, decrease in body fat, and modification of hormones, such as growth hormone. Metabolic syndrome is closely related to high blood pressure, diabetes, and obesity. In relation to metabolic syndrome, we hypothesized that WBVT would favor weight loss by increasing the exercise effect more than conventional training, causing additional VO2 and additional fat oxidation.

However, in this study, low-frequency WBVT did not show a significant difference in VO2 compared with exercises performed without vibration. Altogether, the beneficial effect of WBVT on metabolic syndrome is nonimmediate VO2 (recovery phase or delayed phase) through fat burning for energy recovery and through the modification of hormones, such as insulin-like growth factor-1, growth hormone, and insulin.

One area of potential concern is the safety of WBV. Although little is known regarding the side effects of short-term WBVT, some forms of vibration (such as long-term occupational exposures) lead to adverse effects, including lower back pain, sciatica, dizziness, disturbances in proprioception, and motion sickness. According to Nigg et al’s argument, there are physiological resonance vibrations that may have a detrimental effect on the body, and muscle activation to avoid this effect is the main flow of the “muscle tuning mechanism.” Rittweger argued that vibration resonance may have a harmful effect even in WBVT, and in particular, this effect may appear at 5 Hz in the trunk and below 20 Hz in the lower extremities; thus, caution should be taken in WBVT. Munera also reported that vibration resonance of the lower-extremities appeared below 20 Hz. However, studies focusing on the safety of low-frequency WBVT have not yet been conducted.

In this study, one subject was excluded because of the burden of performing the squat exercises. None of the remaining 19 subjects complained of specific side effects. These findings suggest that there are few side effects of low-frequency WBVT, especially as previous studies have reported that untrained subjects are more susceptible to side effects than trained subjects. Furthermore, WBVT appears to reduce the muscle damage caused by conventional training through various mechanisms, including the warm-up effect and modulation of muscle fiber activations that decrease muscle damage. The recruitment ratio of slow-twitch muscle fibers increases when vibration is used, and contraction–excitation coupling is promoted owing to the increase in background tension through muscle spindle activation.

This study is not without limitations. First, the number of subjects in this study is small. In addition, the participants of this study were untrained young people; hence, extrapolation may be difficult for people of different age groups or people with different levels of physical activity. Because the subject’s sex was not considered, and height, weight, and body mass index were not investigated, we did not analyze median variables, such as gender or body mass. The second limitation is the absence of randomization of the frequencies at each visit. In this study, fixed WBV frequencies were used for sequential visits. Therefore, the results of muscle activity, muscle fatigue, and oxygen intake may have been affected by the learning effect in untrained people not used to the squat posture. However, the participants had sufficient opportunity to practice the squat posture with feedback from the research staff at every visit (familiarization about 1 h before training) and at the screening (visit 1). Moreover, measurements were taken during the third set of squats to allow enough time for the participants to achieve the proper squat posture. As a result, we believe that the learning effect was minimized as squats were performed with the proper posture. Third, the 2-day interval between visits 5 and 6 may have affected the results. However, we argue that as the participants were young, recovery might not require more than 1 day; thus, the impact of the interval on the results would not have been significant. Besides, we conducted a comparative analysis using each single session of WBV. Fourth, only one type of exercise was performed, and only one vibration component was adjusted. Further research with a larger sample size is needed to determine the effects of exercise motion, exercise duration, and vibration components on muscle activity and VO2. In addition, this study measured lactate to analyze muscle fatigue. Future studies should include additional methods to analyze muscle fatigue (such as creatinine kinase, blood urea nitrogen, or phosphatase) and should test these levels closer to the target muscle.

Low-frequency WBVT is known to deliver relatively low energy; therefore, there are few side effects. For this reason, its accessibility to untrained subjects is favorable, but no comprehensive, detailed frequency-based study regarding its effects on muscle activity, VO2, or fatigue recovery has been conducted. In this study, we found that a single bout of low-frequency WBVT increased muscle activity only in the mGCM among 6 muscles of the lower extremities measured during squat exercise. Regarding VO2 and fatigue recovery, despite increased mGCM activation, there was no significant difference between low-frequency WBV (<30 Hz) and no vibrations (0 Hz).

Conclusions

A single bout of low-frequency WBVT significantly increased the activity of the mGCM alone at specific low frequencies of vibration in healthy, untrained, young adults. Oxygen intake and muscle fatigue were not affected by low-frequency WBVT in this study. Our results suggest that low-frequency WBVT is safe and has the potential to increase muscle activity. Further studies on the detailed low-frequency WBVT protocol are needed.

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