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Original Article

Effects of whole-body vibration with an unstable surface on muscle activation

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Abstract

The current study examined the effects of using an unstable surface during whole-body vibration (WBV) exercise on leg and trunk muscle activity during a static semi-squat. Twenty-eight recreationally active university students completed 4 different test conditions: 1) stable surface with no WBV; 2) unstable surface with no WBV; 3) unstable surface with 30 Hz WBV low amplitude; and 4) unstable surface with 50 Hz WBV low amplitude. Surface electromyography (sEMG) was measured for the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), and multifidus (MF) muscles. Normalized to the stable condition, WBV at 30 Hz and an unstable surface increased EMG in the GM vs the unstable and stable surfaces (~35%; $p<0.05$). VMO EMG decreased in the unstable vs stable condition (~20%), WBV at 30 Hz and an unstable surface increased EMG vs all other conditions (~20-40%; $p<0.05$). MF EMG increased with WBV at 30 Hz (25%; $p<0.05$) vs the stable condition but not vs all other conditions. Using an unstable surface during WBV exposure increases EMG of muscles in the lower extremities and trunk suggesting the combination of an unstable surface combined with WBV may be an effective modality to further increase EMG.

Keywords: Vibration Exercise, Static Semi-squat, Electromyography, Reflex, Balance

Introduction

Recently, there has been a growing interest in the neuromuscular effects of whole-body vibration (WBV) in training[1,2] and rehabilitation settings[3,4]. A WBV platform generates vertical sinusoidal oscillations that elicit reflexive muscle contractions via the tonic vibration reflex (TVR)[5-8]. Exercises performed on ground-based WBV platforms have demonstrated significant increases in lower body muscle activity compared to the same exercise with no WBV[8-16]. The magnitude of the response depends on the amplitude (size of each deflection; measured in mm) and the frequency (number of deflections per second; measured in Hz)[8,15]. Higher vibration frequencies and amplitudes induce a greater muscle activity than lower frequencies and/or amplitudes during a regular isometric-squat during WBV[11,14,15].

The magnitude of the WBV-induced increase in muscle activity during a dynamic squat was demonstrated to be either the same or increased with the addition of an external load (~30% of body mass) compared to an unloaded condition with WBV[12,15]. These results demonstrate the associated increase in skeletal muscle activity with exposure to WBV is not dissipated with the addition of an external load suggesting the potential effectiveness of using external loads with WBV-exercise. However, the addition of external loads to increase the intensity of effort is not always feasible in terms of interest, accessibility, or practicality (i.e. rehabilitation from injuries, cardiovascular diseases, older adults). The use of unstable surfaces has become popular[17] as training with instability can induce similar levels of muscle activation while using less external load[18-20]. However, to our knowledge, no study has researched the neuromuscular changes in lower-limb and trunk muscles using an unstable surface on top of a ground-based WBV platform. Further, the importance of the ratio of vastus medialis oblique to vastus lateralis muscle activity has been noted from a rehabilitation perspective[21-23], yet has not

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been reported with previous WBV literature.

Therefore, the aim of this study was to investigate the effects of using an unstable surface during WBV on leg and trunk muscle activity by means of surface electromyography. The primary hypothesis was that an unstable surface with WBV (independent variables) would increase leg and trunk muscle activity (dependent variables). The secondary hypothesis was that an unstable surface with WBV changes (independent variable) the vastus medialis oblique/vastus lateralis (VMO/VL) muscle ratio (dependent variable).

Methods

Experimental design

To investigate the difference in muscle activation between different conditions, a randomized, crossover experimental design was used for this study. Each subject participated in three laboratory visits in this study (2 familiarization sessions and 1 test session).

Subjects

Twenty-eight undergraduate students (5 women and 23 men) participated in the study (21.7±1.3 years, 176.7±0.3 cm, 74.0±6.4 kg, mean±SD). All participants were recreationally active but none were involved in a systematic training program at the time of data collection or for at least 2 months prior to the study. People suffering from epilepsy, gallstones, kidney stones, neuromuscular or neurodegenerative diseases, stroke, serious heart sicknesses or having an implant, bypass or stent were excluded. Prior to data collection participants were informed of the requirements associated with participation and provided written informed consent. Participants were encouraged to maintain their dietary, sleeping, and drinking habits during participation in the study. The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Exercise Protocol

One week before the testing session, the subjects attended 2 familiarization sessions, which were used to acclimatize subjects with exercise positions as well as the unstable surface and WBV platform.

Subjects were exposed to 4 different test conditions while performing an isometric half squat on a vibration platform (Pro5 Power plate, Power Plate International Ltd., London, UK). Test conditions included: 1) no vibration stable surface, 2) no vibration unstable surface, 3) 30 Hz WBV with unstable surface, and 4) 50 Hz WBV with unstable surface. Both WBV stimuli utilized the low amplitude platform setting. Hazell et al. (2007) have demonstrated that muscle activity is increased at both low and high amplitude settings[11]. Recently, Caryn and colleagues demonstrated a similar synchronous WBV platform to the one used in this study did not generate greater than 2 mm amplitude at any frequency ranging from 20-50 Hz suggesting that manufacturer settings for amplitude may not be accurate[24]. Therefore, we utilized the low amplitude setting in the present study and measured the platform acceleration (detailed below). After a 5 min standardized warm-up (2.5 min slow jog and dynamic warm up exercises [10 reps of each exercise] pull-backs, butt kicks, knee to chest, squats, and lateral lunges), test conditions were assigned to each participant in a random order and each condition lasted 30 s, with 120 s of rest between each condition to prevent the acute vibration-induced fatigue effect. The isometric semi-squat exercise had subjects stand feet shoulder-width apart at 60° knee flexion (considering 0° as the anatomical position; measured by a goniometer) on the vibration platform. A researcher provided verbal feedback to ensure knee joint angles were maintained during all test conditions. A custom made wobble board was used with movement tilting from side-to-side (15 degrees); the size of the board was 0.45 x 0.60 m (Figure 1). During testing session, subjects wore sports shoes.

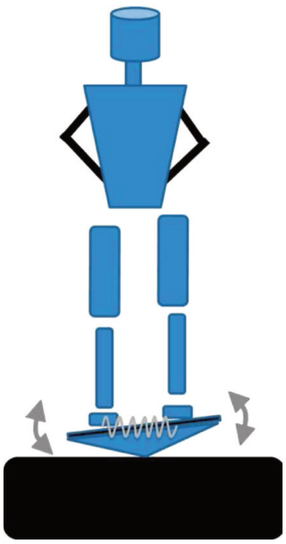

Figure 1. Experimental setup.

The acceleration was measured on both the vibration platform and the unstable surface using two triaxial USB Impact X250-2 accelerometers (Concepts of Gulf Coast Data, LLC. Waveland, MS). The accelerometer was set on high gain (±28 g), resolution of 16 bits, sample rate of 512 Hz, and automatically initialized. Accelerometer data were analyzed using XLR8R software (version 2.1. Gulf Coast Data Concepts, LLC. Waveland, MS). Vibration platform settings included a frequency of 30 Low or 50 Hz Low. The peak to peak vibration amplitudes across the range of subject weights were mean 1.54±0.09 mm (at 30Hz Low) and 1.07±0.08 (at 50Hz Low). The vibration acceleration across the range of subject weight were mean 27.46±0.25 $m \cdot s^{-2}$ (at 30 Hz) and 52.97±0.33 $m \cdot s^{-2}$ (at 50 Hz).

Surface electromyographic activity (EMG)

Muscle activity of the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdo-

	Stable	Unstable	*d*	Unstable 30 Hz	*d*	Unstable 50 Hz	*d*
GM	0.0290±0.0073	0.0306±0.0043[a]	*0.22*	0.0386±0.0085[a]	*1.30*	0.0362±0.0093[a]	*0.98*
VMO	0.0440±0.0167	0.0376±0.0125[b]	*-0.38*	0.0471±0.0143[ac]	*0.18*	0.0402±0.0138	*-0.23*
VL	0.0399±0.0158	0.0355±0.0126	*-0.28*	0.0460±0.0178	*0.39*	0.0401±0.0164	*0.01*
RA	0.0085±0.0013	0.0088±0.0012	*0.26*	0.0092±0.0017	*0.52*	0.0095±0.0033	*0.77*
MF	0.0221±0.0102	0.0236±0.0107	*0.14*	0.0246±0.0088[ac]	*0.25*	0.0241±0.0100	*0.19*

[a] – Significantly greater than stable surface with no WBV.
[b] – Significantly lower than stable surface with no WBV.
[c] – Significantly greater than the unstable surface with no WBV.
[d] – Significantly greater than the unstable surface with 50 Hz WBV.

Table 1. Mean ± SD and effects sizes (*d*) of electromyography root-mean-square activity (mV) of gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), and multifidus muscle (MF). (n=28).

minis (RA), and multifidus muscle (MF) muscles were measured using EMG. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes (inter-electrode distance=10 mm) were placed over the mid-belly of the muscle parallel to the direction of the fibres according to recommendations by the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles)[25].

The double differential technique was used to detect myoelectric raw signals. The surface electrodes were connected to a 16-bit AD converter (TrigoTM Wireless System, Delsys Inc., Boston, MA, USA). Raw EMG signals were pre-amplified close to the electrodes (signal bandwidth of 20-450 Hz), sampled at 4000 Hz, and stored on a laptop. EMG data analysis was performed using specific software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA) which calculated the root mean square (rms)[26,27]. For data analysis only 20s of the test condition were utilized (from 5s to 25s). The EMG values for each test condition were normalized relative to the stable without WBV, which was used as 100%.

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 18.0 (SPSS Inc, Chicago, IL) and significance level was set at P≤0.05. Values are expressed as mean±SD. All the measures were normally distributed, as determined by the Shapiro-Wilk test. Sphericity was tested by the Greenhouse-Geisser method. One-way analysis of variance (ANOVA) with repeated measures were performed for all muscles evaluated (GM, VL, VMO, VMO/VL, RA, MF; dependent variables) to assess the main effects of the conditions (stable surface, unstable surface, unstable surface with 30 Hz WBV, unstable surface with 50 Hz WBV; independent variables). A Bonferroni post hoc test was used in all pairwise comparisons when a significant result was found. Effects sizes were measured by Cohen's *d* for comparison between stable vs. unstable treatments to determine the magnitude of an effect independent of sample size. The intraclass correlation coefficients were calculated for each dependent variable to determine test-retest reliability. The intraclass correlation coefficients for EMGrms were greater than 0.93 (GM=0.95; VMO=0.93; VL=0.94; RA=0.93; MF=0.95)

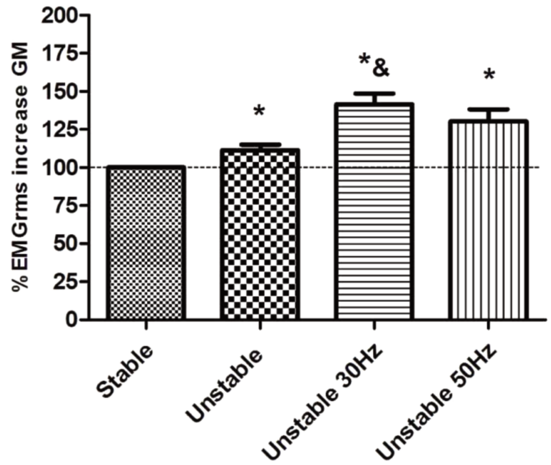

Figure 2. Percent increase of EMGrms of the gastrocnemius medialis (GM) above stable condition during 3 experimental conditions. *Significantly different than stable condition (*P*<0.05). & Significantly different than unstable condition (*P*<0.05). (n=28).

Results

Gastrocnemius medialis muscle

Performing an isometric half squat in the no vibration unstable surface condition increased GM EMGrms 5.5% vs no vibration stable surface condition ($p<0.05$; Table 1). The addition of 30 Hz and 50 Hz WBV to the unstable surface condition increased EMGrms 33.0% and 24.8%, respectively; vs the no vibration stable surface condition ($p<0.05$; Table 1). There were no other differences for GM EMGrms ($p>0.05$)

Normalizing muscle activity to the no vibration stable surface condition, performing the half squat with the no vibration unstable surface increased %EMGrms 17% ($p<0.05$) vs the no vibration stable surface condition (Figure 2). The addition of

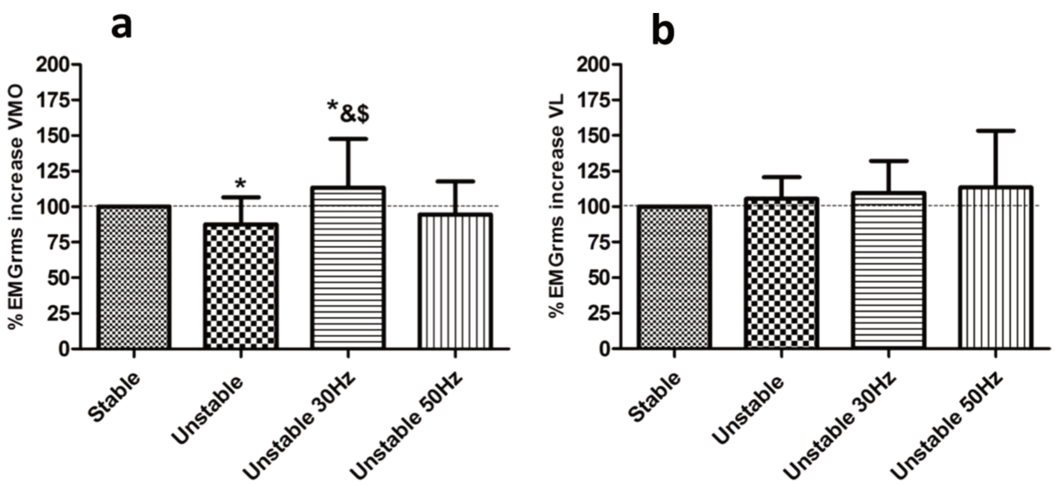

Figure 3. Percent increase of EMGrms of the (a) vastus medialis oblique (VMO) and (b) vastus lateralis (VL) above stable condition during 3 experimental conditions. *Significantly different than stable condition ($P<0.05$). & Significantly different than unstable condition ($P<0.05$). $ Significantly different than unstable 50 Hz ($P<0.05$). (n=28).

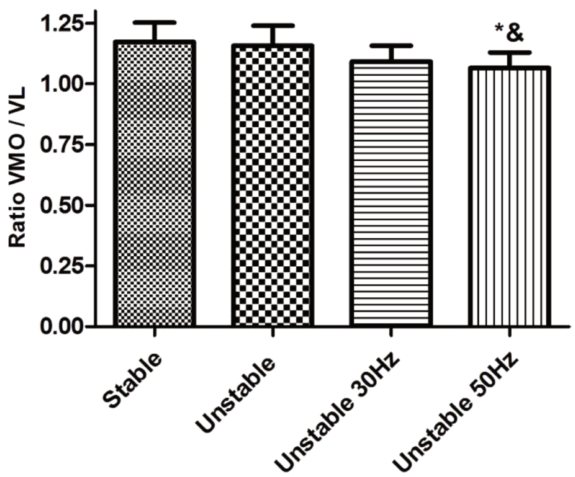

Figure 4. The EMG ratio between vastus medialis oblique and vastus lateralis (VMO/VL). *Significantly different than stable condition ($P<0.05$). & Significantly different than unstable condition ($P<0.05$). (n=28).

30 Hz WBV increased %EMGrms 48% ($p<0.05$) vs the no vibration stable surface condition (Figure 2) and 31% ($p<0.05$) vs the no vibration unstable surface condition (Figure 2). The 50 Hz WBV unstable surface condition increased %EMGrms (26%; $p<0.05$) vs the no vibration stable surface condition (Figure 2).

Vastus medialis oblique and vastus lateralis muscles

Performing the half squat in the no vibration unstable surface condition decreased VMO EMGrms activity by 14.5% vs the stable surface condition ($p<0.05$; Table 1). The addition of 30 Hz WBV to the unstable surface condition increased EMGrms 7.1% vs the no vibration stable surface condition ($p<0.05$) and 25.3% vs the no vibration unstable surface condition ($p<0.05$; Table 1). There were no differences in VL muscle activity across conditions ($p>0.05$; Table 1).

Normalizing muscle activity to the no vibration stable surface condition, performing the half squat in the no vibration unstable surface condition decreased VMO %EMGrms 15% ($p<0.05$) vs the no vibration stable surface condition (Figure 3a). The addition of 30 Hz WBV to the unstable surface condition increased %EMGrms 20% ($p<0.05$) vs the stable surface no WBV condition, 35% ($p<0.05$) vs the unstable surface no WBV condition, and 23% ($p<0.05$) vs the unstable surface 50 Hz WBV condition (Figure 3a). There were no differences in VL %EMGrms ($p>0.05$; Figure 3b).

There was as 8.7% decrease ($p<0.05$) in the VMO:VL ratio with the 50 Hz WBV unstable surface condition vs the no vibration stable surface condition and a 7.8% decrease ($p<0.05$) vs the no vibration unstable surface condition (Figure 4).

Rectus abdominis muscle and multifidus muscle

Performing a half squat in the no vibration unstable surface condition with and without WBV did not affect RA EMGrms activity ($p>0.05$). The MF %EMGrms was not affected by the no vibration unstable surface condition ($p>0.05$) though the addition of the 30 Hz WBV increased %EMGrms 11.3% ($p<0.05$) vs the no vibration stable surface condition and 4.2% vs the no vibration unstable surface condition ($p<0.05$).

Normalizing muscle activity to the stable surface condition, there were no differences across conditions for the RA muscle ($p>0.05$). The addition of 30 Hz and 50 Hz WBV to the no vibration unstable surface condition increased %EMGrms 30% and 25% ($p<0.05$), respectively, vs the stable surface no WBV condition (Figure 5).

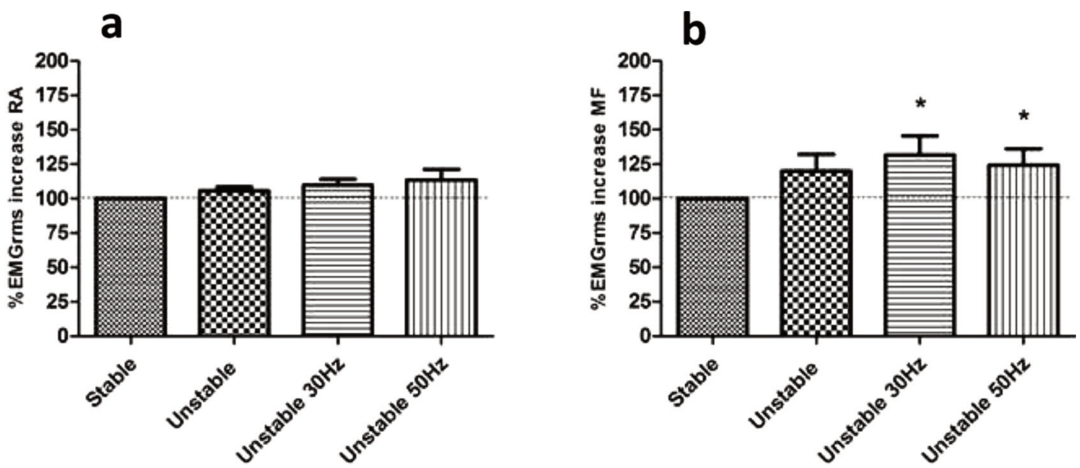

Figure 5. Percent increase of EMGrms of the (a) rectus abdominis (RA) and (b) multifidus muscle (MF) above stable condition during 3 experimental conditions *Significantly different than stable condition ($p<0.05$). (n=28).

Discussion

The present study evaluated the effects of performing an isometric half squat on stable and unstable surfaces during exposure to two different WBV frequencies (30 and 50 Hz) at low amplitude. The primary finding is the addition of WBV in combination with an unstable surface increased skeletal muscle activity of the GM and VMO of the lower leg and the MF of the lower back with no effect on the VL or RA muscles. Interestingly, performing a static half squat on an unstable surface decreased muscle activity in the VMO compared to the stable surface condition. These results suggest isometric squatting on an unstable surface while exposed to WBV increases skeletal muscle EMG in several muscles evaluated. To our knowledge, this is the first study analyzing the effects of WBV on skeletal muscle activity while performing a half squat on an unstable surface. It should be noted that the low amplitude setting at the two different WBV frequencies (30 vs 50 Hz) employed actually resulted in different amplitudes (1.54 mm in the 30 Hz condition vs 1.07 mm in the 50 Hz condition) demonstrating the importance of measuring WBV platform oscillation characteristics to ensure the WBV stimuli being used[24].

Performing an isometric half squat on an unstable surface increased GM muscle activity compared to an unstable surface, which was increased with the addition of WBV (30 Hz). The increase in GM muscle activity on the unstable surface likely represent the increased needs of the GM to maintain the half squat position[17-20] while the further increase with WBV exposure results from an increased skeletal muscle reflexive response via the mechanical vibration oscillations[5,6,8]. While the muscle activity response appeared greater in with the 30 Hz condition compared to the 50 Hz condition, this could be due to the decrease in amplitude generated by the platform.

The current results suggest that WBV did not significantly increase VL muscle activity while performing a half squat on an unstable surface, contrary to most WBV muscle activity literature[9,11,12,28], though in line with a recent study[29]. However, in this study subjects held on to the handlebars while on the vibration platform and did not perform a body weight squat. The lack of an increase in VL muscle activity with WBV is likely due to the physical demands of adding the unstable surface to the half squat with WBV placing more emphasis on other synergistic muscles rather than the VL. However, the variability in the VL muscle activity response may have prevented detection of a significant increase due to a Type II error.

In terms of the VMO muscle activity, the addition of the unstable surface actually decreased muscle activity compared to the stable condition, though the addition of the 30 Hz WBV increased muscle activity vs both no vibration conditions, similar to previous work[16]. With the decrease in amplitude in the 50 Hz condition vs. 30 Hz (1.54 mm vs. 1.07 mm) it is possible that the combination of a higher frequency, slightly lower amplitude, and an unstable surface is not as strenuous to the VMO muscle as the 30 Hz condition. The VMO counteracts the lateral pull of the patella and has thus been found to provide stabilization of the knee in extension[30,31]. The lower VMO:VL ratio during the unstable surface to the half squat with 50 Hz WBV suggests higher intensity WBV stimuli in combination with an unstable surface alters this ratio. This may be detrimental as there may be a need to strengthen the VMO:VL ratio to counterbalance VL activity during normal activities[21-23]. We speculate that the unstable surface with 50 Hz WBV decreased knee stabilization in extension due to the increase in frequency (from 30 to 50 Hz) or the non-intended decrease in amplitude (1.54 to 1.07 mm).

To our current knowledge this is the first study to measure abdominal (RA) and lower back (MF) muscle activity during WBV with an unstable surface. While there was no effect on RA muscle activity in any condition, the current results demonstrate a significant increase in MF muscle activity with both

WBV conditions. These results suggest that the combination of WBV and an unstable surface is enough of a stimulus to increase lower back muscle activity to maintain balance/posture during the half squat.

Despite the randomized, crossover experimental design and the relatively large number of subjects (n=28) there was still several limitations. The main limitation to the present study was the experimental platform employed generated different amplitudes in the 30 Hz condition (1.54 mm) compared to the higher 50 Hz condition (1.07 mm) despite the same low amplitude setting. As a result we cannot differentiate whether the WBV effects are due to the frequency or the slightly differing amplitude. Several studies have demonstrated skeletal muscle activity is enhanced with increased frequency and amplitude for both synchronous WBV[11-13] as well as side alternating WBV[32,33]. Future work should address the effects of utilizing an unstable surface with WBV exposure of more combinations of frequency and amplitude to determine the most effective WBV exposure to use in this exercise setting. The present data should also be interpreted with some caution as we also only utilized a single isometric exercise in recreationally active university aged students and did not include a WBV and stable surface condition.

Conclusion

In conclusion, the results of this study demonstrate that performing a static half squat on an unstable surface during WBV results in significant increases in muscles in the calf, quadriceps, and lower back. These increases in skeletal muscle EMG were greater in the 30 Hz condition compared to the 50 Hz condition suggesting greater WBV accelerations are not necessary to further increase muscle activity in the muscles evaluated. Furthermore, the current results demonstrate for the first time that WBV exercise on an unstable surface attached to the WBV platform increases skeletal muscle activity and affects muscles in the lower back.

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