Original Article

The addition of synchronous whole-body vibration to battling rope exercise increases skeletal muscle activity

P.J. Marín[1,2], M.T. García-Gutiérrez[1,2], M.E. Da Silva-Grigoletto[3], T.J. Hazell[4]

[1]Laboratory of Physiology, European University Miguel de Cervantes, Valladolid, Spain; [2]CyMO Research Institute, Valladolid, Spain; [3]Department of Physical Education, Universidade Federal de Sergipe, Brazil; [4]Department of Kinesiology & Physical Education, Wilfrid Laurier University, Waterloo, ON, Canada

Abstract

Objectives: To evaluate the effects of performing battling rope exercise with and without the addition of whole-body vibration (WBV) on muscle activity of the leg, trunk, and upper body. **Methods:** Twenty-eight recreationally active university students completed 20-s of battling rope undulation for 6 separate conditions: 1) alternating arm motion no WBV -Alt_NoWBV; 2) alternating arm motion 30 Hz low amplitude WBV -Alt_30 Hz-L; 3) alternating arm motion 50 Hz high amplitude -Alt_50 Hz-H; 4) double arm motion no WBV -Double_NoWBV; 5) double arm motion 30Hz low amplitude WBV -Double_30Hz-L; 6) double arm motion 50 `Hz high amplitude -Double_50 Hz-H. Electromyography (EMG) was measured for the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), multifidus (MF), biceps brachii (BB), and triceps brachii (TB) muscles. **Results:** The double arm motion during undulation resulted in greater ($p<0.05$) muscle activity in the VMO, VL, RA, and MF muscles while the GM was more active during the alternating arm motion. WBV at 50Hz increased EMG in all muscles measured vs NoWBV and the 30 Hz condition. **Conclusion:** These results are the first to demonstrate that the exercise stimulus of performing battling rope exercise can be augmented by completing the exercise while being exposed to WBV from a ground-based platform.

Keywords: Battle Ropes, Undulation Training, Electromyography, Reflex, Vibration Exercise

Introduction

Performing body mass resistive exercises on a whole-body vibration (WBV) platform has become an increasingly popular training modality. The vertical oscillations generated via the ground based platform induce short and rapid changes in skeletal muscle fiber length[1-3], which stimulate reflexive muscle contractions increasing skeletal muscle activity[3-12]. The magnitude of these increases in skeletal muscle activity measured via electromyography (EMG) is dependent on the characteristics of the WBV stimulus (amplitude, size of each deflection; frequency, number of deflections per second) with higher frequencies and amplitude inducing greater muscle activity[6,10,13].

The enhanced skeletal muscle activity increases the metabolic muscle demand as evidenced by increases in oxygen consumption/energy expenditure due to the WBV exposure[14-17], though the magnitude of this increased demand is much less than traditional resistance training[7]. Nevertheless, the potential for the WBV stimulus to augment different exercises being performed on the WBV platform is intriguing, as many researchers and health professionals have sought methods to further increase the training stimulus using WBV platforms.

Recently, we have shown the addition of an unstable surface[18] increased lower body muscle EMG suggesting that exercises performed on the WBV platform could be augmented with exposure to the WBV stimulus. The use of battling ropes is a training modality gaining interest in the fitness industry[19]. Battling rope training has participants vigorously undulate heavy ropes (9-15 m in length and 3-5 cm in diameter) that encircle a fixed object. This undulation creates a series of waves for a set interval typically ranging from 10-30 s. This type of training is a vigorous upper-body exercise resulting in an in-
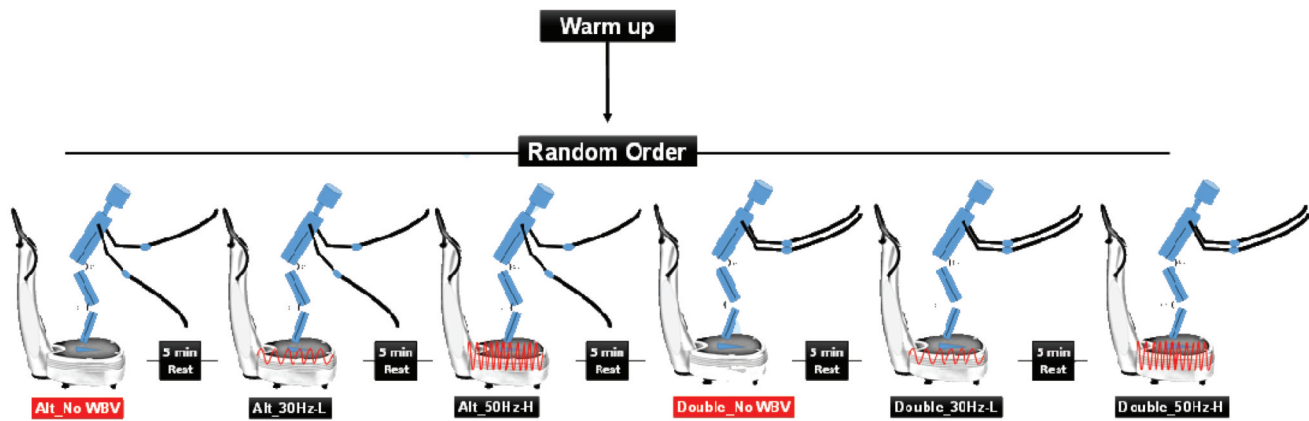
Figure 1. Experiment setup.

tense metabolic workout[20], even greater than several traditional resistance training movements such as squatting, lunges, and deadlifts[21]. As previous research using WBV has demonstrated the addition of WBV to a static and dynamic squat increases both skeletal muscle activity and metabolism, whether the addition of WBV to battling rope exercise augments these effects is effective unknown. Further, there is much interest in the health and fitness realm in time-efficient training. Therefore, the aim of this study was to combine the upper body effects of battling rope exercise with the lower body effects of WBV exposure to evaluate the skeletal muscle activity of battling rope exercise with and without the addition of WBV. Surface electromyography (EMG) was measured in muscles the lower body (vastus lateralis, vastus medialis oblique, gastrocnemius), trunk (multifidus, rectus abdominus) and upper body (biceps brachii, triceps brachii). We hypothesized that the addition of WBV to battling rope exercise would result in an increase in skeletal muscle EMG for all muscles evaluated.

Materials and methods

Experimental design

To investigate the difference in muscle activation between different conditions, a randomized, crossover experimental design was used for this study (all conditions placed in a box, and were picked one by one for each participant). Each participant completed three laboratory sessions in this study (2 familiarization and 1 test session). The experimental protocol began with electrode placement, followed by a standardized warm-up consisting of a 2-min slow jog and 5 dynamic warm-up exercises (10 reps of each exercise for butt kicks, knee to chest, squats, lateral lunges, and inch worms). The test session then had each participant complete one 20-s set of battling rope undulation (Figure 1) for 6 separate conditions followed by 5-min of rest. All sets were performed on the WBV platform and in random order where the 6 different conditions (Figure 1) were: 1) Alternating arm motion no WBV - Alt_NoWBV; 2) Alternating arm

motion 30 Hz low amplitude WBV - Alt_30 Hz-L; 3) Alternating arm motion 50 Hz high amplitude - Alt_50 Hz-H; 4) Double arm motion no WBV - Double_NoWBV; 5) Double arm motion 30 Hz low amplitude WBV - Double_30 Hz-L; 6) Double arm motion 50 Hz high amplitude - Double_50 Hz-H).

Participants

Twenty-eight undergraduate students (5 female; 23 male) participated in the study (21.7±1.3 y; 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 for at least 2 months prior to data collection. People suffering from epilepsy, gallstones, kidney stones, neuromuscular or neurodegenerative diseases, stroke, serious heart sicknesses or having an implant, bypass or stent were excluded (3 in total, 1 female). 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 (both familiarization trials and experimental session). The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Battling rope exercise

All participants used a nylon rope 15 m long, weighing 11.2 kg, and 3.8 cm in diameter (O'Live Fitness, Aerobic & Fitness SL, Barcelona, Spain). The rope was anchored at the base of a post, resulting in the participant holding 7.5 m of rope in each hand. Participants began in an athletic position on vibration platform; feet shoulder width apart, knees flexed to 30° with their trunk flexed forward to approximately 45° (Figure 1). These angles were measured via goniometer at the beginning of the bout and participants were asked to maintain these angles during the bout. Participants held the ends of the rope with a neutral grip, with the arms straight and relaxed at their side.

During the alternating arm motion, participants moved their arms up and down in an asynchronous (alternating) fashion (i.e. right arm first, then as right arm was returning to the starting position the left arm began; Figure 1). When performing the double arm motion, participants moved both arms up and down synchronously (at the same time) continuously (Figure 1). Participants were instructed to move their arms as fast as possible and were coached to use minimal lower body and trunk movement as to generate the waves primarily through shoulder flexion when raising the ropes, and shoulder extension when crashing the ropes to the floor. Participants were instructed to have their entire foot in constant contact with the platform with feet spaced shoulder wide apart. All participants maintained a 30°-knee flexion during the exercise.

Vibration equipment

The vibration stimulus consisted of commercial platform (Power Plate® Next Generation pro 5, Power Plate North America, Northbrook, IL, USA) that produced synchronous (uniform) tri-planar oscillations[22]. The acceleration of the vertical sinusoidal oscillations (z-axis) was measured using a uniaxial accelerometer in accordance with ISO2954 (Vibration meter VT-6360, Hong Kong, China). Vibration platform settings included a frequency of 50 Hz with the peak-to-peak displacement of 2.51 mm (High) or a frequency of 30 Hz with peak-to-peak displacement of 1.15 mm (Low). Measured accelerations were 100.6 ± 0.24 m·s^{-2} (at 50 Hz) and 20.44 ± 0.34 m·s^{-2} (at 30 Hz). During all conditions, subjects wore the same athletic shoes to standardize the damping of the vibration because of the footwear[8].

Surface electromyographic activity (EMG)

Muscle activity of the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), multifidus muscle (MF) muscles, biceps brachialis (BB), and triceps brachialis (TB) were measured using EMG[4,7,8,23,24] on the dominant limb. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes were placed over the midbelly of the muscle parallel to the direction of the fibers according to recommendations by the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) using adhesive double sided tape[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) and 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, MA, USA). EMG data was averaged by root mean square (EMGrms) in order to obtain averaged amplitude of the EMG signal. EMGrms were calculated together for eccentric and concentric phases. Moreover, in order to obtain average frequency the signal was averaged
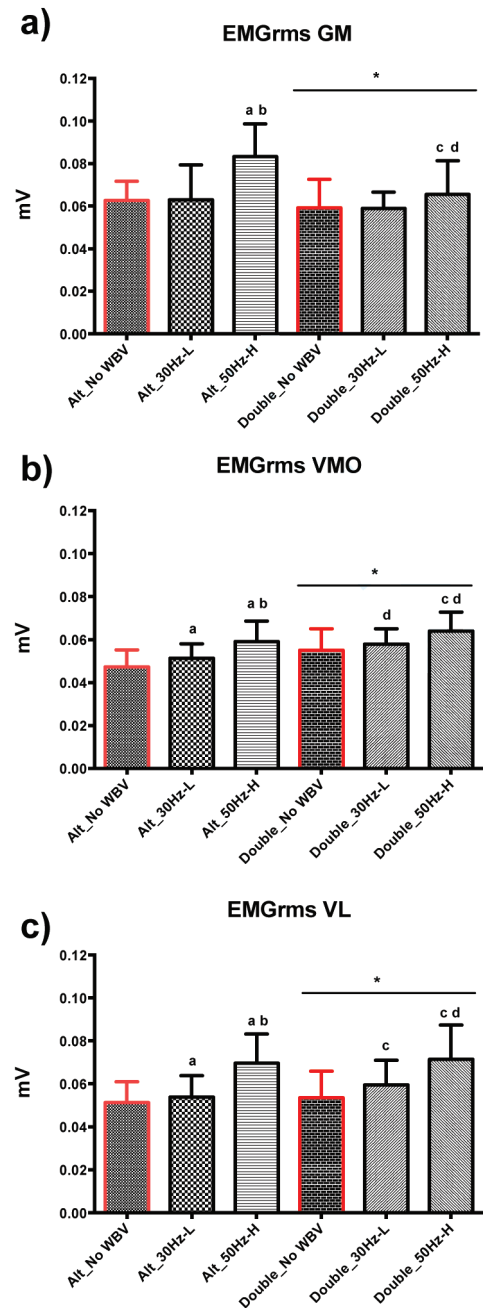
Figure 2. EMGrms activity of the (a) gastrocnemius medialis (GM), (b) vastus medialis oblique (VMO), and (c) vastus lateralis (VL), during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [b] Significantly different than Alt_30 Hz-L condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). [d] Significantly different than Double_30 Hz-L condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.01$) (n=28).

by median frequency (EMGmdf) which is a valid measure of the frequency shift associated with muscle fatigue[26]. For data analysis only 15 s of the test conditions were utilized (from 2.5 s to 17.5 s).

	GM	VMO	VL	RA	MF	BB	TB
Alt_No WBV	106.8±32.1	78.6±17.1	80.8±14.3	48.9±15.6	57.4±10.6	68.9±10.3	70.1±11.7
Alt_30Hz-L	100.0±29.2	74.8ª±18.9	76.3±15.4	47.9±15.1	58.3±11.1	68.0±10.7	69.3±12.9
Alt_50Hz-H	103.4±31.6	75.5±16.7	73.8ª±16.2	48.3±14.0	60.0±8.8	67.5±11.0	69.8±11.8
Double_No WBV	100.0**±32.1	79.6±16.5	79.0±11.9	48.9±10.9	63.9**±13.5	68.4±13.7	66.9*±15.4
Double_30Hz-L	95.7**±28.2	75.7ᵇ±19.3	74.1±13.4	46.5±11.5	61.2**±13.5	67.1±12.1	66.9*±15.9
Double_50Hz-H	98.2**±28.4	77.3±17.2	72.7ᵇ±13.6	45.9±10.1	62.3**±12.0	65.8±12.4	68.3*±12.8

a Significantly different than Alt_No condition (p<0.05). b Significantly different than Double_No motion (p<0.05). c Significantly different than Double_NO WBV condition (p<0.05). *Difference from alternate motion at the same condition (p<0.05). ** Difference from alternate motion at the same condition (p<0.01) (n=28).

Table 1. EMG median frequency (Hz) activity of the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), multifidus (MF), biceps brachii (BB), and triceps brachii (TB) muscles during 6 experimental conditions.

Arm movements

Frequency of arm movements were measured using a three-axis accelerometer (TrigoTM Wireless System, Delsys Inc., Boston, MA, USA) taped to the wrist of the dominant arm (Figure 5a). The output of the accelerometer allowed synchronization with EMG. Raw accelerometer signals were sampled at 148 Hz and stored on a laptop and data analysis was performed using specific software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, MA, USA). The frequencies of arm oscillations were recorded for each 20-s exercise condition in the y-axis (anterior/posterior), z-axis (up/down), and x-axis (side/side).

Heart rate

Heart rate average and maximum (beats per min) was recorded beat to beat with a heart rate monitor (Polar RS400, Polar Electro Oy, Kempele, Finland).

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 20.0 (SPSS Inc, Chicago, IL, USA). The normality of the data was checked and subsequently confirmed with the Shapiro-Wilk test. Dependent variables (EMG for each muscle, arm movements in all 3 axes, and heart rate) were evaluated with a repeated measures analysis of variance (ANOVA) on motion x condition. When a significant F-value was achieved, pairwise comparisons were performed using the Bonferroni post hoc procedure. The level of significance was fixed at $p \leq 0.05$. To determine test-retest reliability, intra-class correlation coefficients (ICC's) were calculated for heart rate and arm movements in all 3 axes collected during the familiarization sessions. ICC's were greater than 0.92 indicating a high level of reproducibility in assessing the dependent variables was achieved. Values are expressed as mean±SD and effects sizes were measured by partial Eta square (η^2) to determine the magnitude of the effect independent of sample size.

Results

Gastrocnemius medialis (GM) muscle

A motion x condition interaction effect was noted for GM (p=0.001; η^2=0.358; see Figure 2a). A main effect of the motion was observed indicating a significantly increased EMGrms GM activity during the alternating arm condition compared to double arm motion (p=0.001; η^2=0.461). A main effect of the condition was noted indicating that significantly increased EMGrms GM activity during 50 Hz-H compared to NoWBV and 30 Hz-L (p=0.001; η^2=0.680).

For EMGmdf in the GC (Table 1), during the alternating arm motion the 30 Hz-L stimulus resulted in a lower (p<0.05) EMGmdf vs 50 Hz-H and NoWBV. The 50 Hz-H was also lower than NoWBV. There were no differences during the double arm motion.

### Vastus medialis oblique (VMO) and vastus lateralis (VL) muscles

A motion x condition interaction effect was detected for VMO (p=0.030; η^2=0.122; see Figure 2b) and VL (p=0.005; η^2=0.176; see Figure 2c). A main effect of the motion was observed indicating that significantly increased EMGrms VMO (p=0.001; η^2=0.649) and VL (p=0.002; η^2=0.294) activity during double compared to alternating arm motion. A main effect of the condition was noted indicating that significantly increased EMGrms VMO (p=0.001; η^2=0.827) and VL (p=0.001; η^2=0.805) activity during 50 Hz-H compared to NoWBV and 30 Hz-L, as well 30 Hz-L compared to NoWBV (p<0.001).

For EMGmdf in the VMO (Table 1), the alternating arm motion during 30Hz-L resulted in a lower (p<0.05) EMGmdf vs NoWBV. During the double arm motion, the 30 Hz-L condition was lower than the NoWBV condition. For the VL, the 50 Hz-H was lower (p<0.05) vs NoWBV and during both the alternating and double arm motions.

Rectus abdominis (RA) and multifidus (MF) muscles

A motion x condition interaction effect was detected for RA (p=0.001; η^2=0.610; see Figure 3a). However, there was no significant motion x condition interaction effect for MF

EMGrms RA

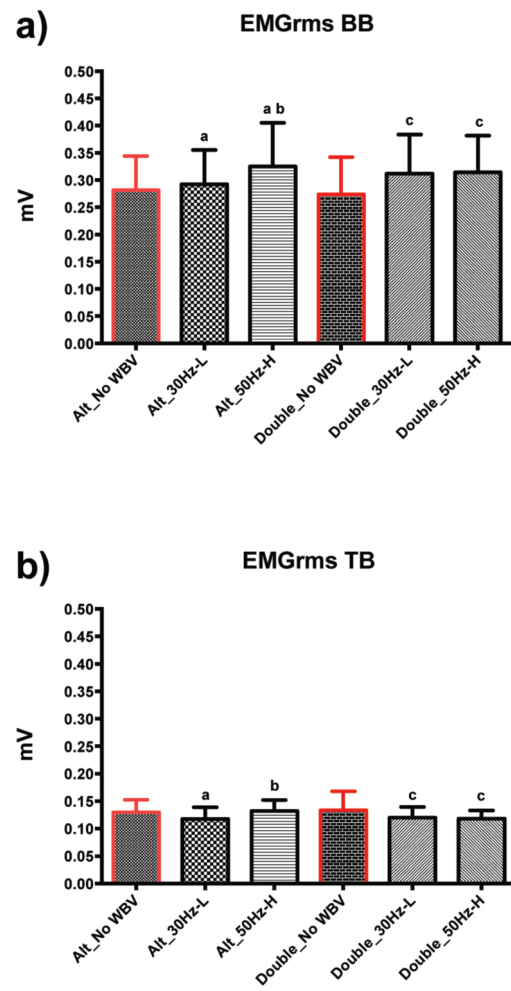**a) EMGrms BB**

EMGrms MF

b) EMGrms TB
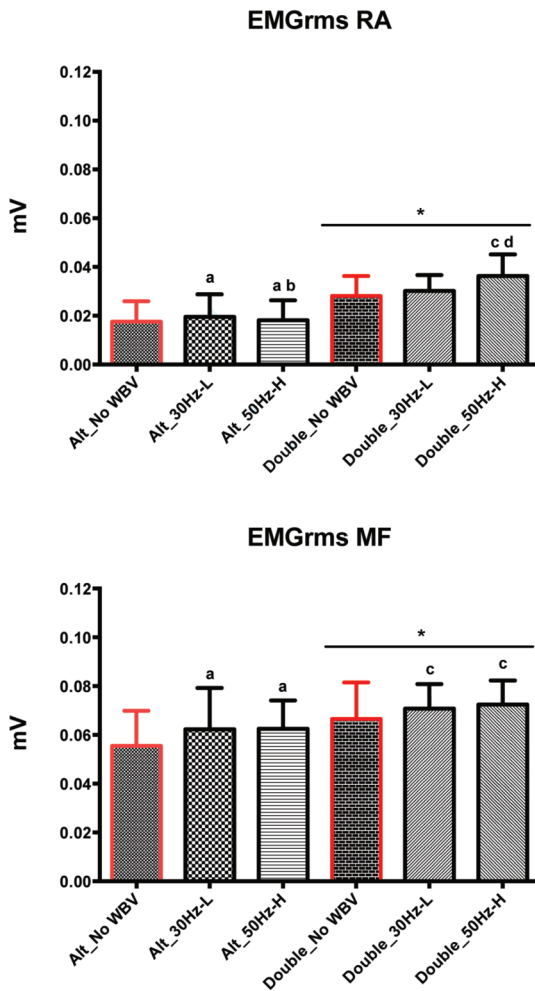
Figure 3. EMGrms activity of the rectus abdominis (RA), and multifidus (MF) muscles during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.01$) (n=28).
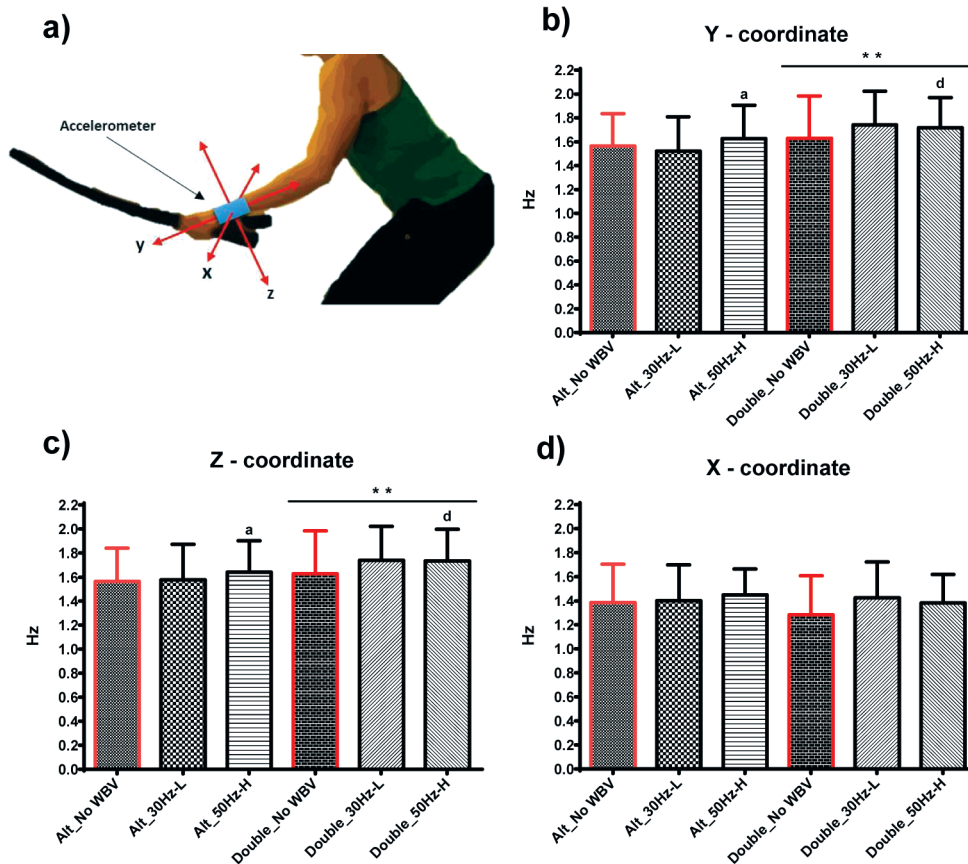
Figure 4. EMGrms activity of the biceps brachii (BB) and triceps brachii (TB) muscles during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [b] Significantly different than Alt_30 Hz-L condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$) (n=28).

($p>0.05$; $\eta^2=0.003$; see Figure 3b). A main effect of the motion was observed indicating that significantly increased EMGrms RA ($p=0.001$; $\eta^2=0.839$) and MF ($p=0.001$; $\eta^2=0.737$) activity during double compared to alternating arm motion. A main effect of the condition was noted indicating that EMGrms RA ($p=0.001$; $\eta^2=0.600$) and MF ($p=0.001$; $\eta^2=0.354$) activity were increased during 50 Hz-H vs NoWBV and 30 Hz-L, as well 30 Hz-L compared to NoWBV ($p<0.001$).

There were no differences in EMGmdf in the RA (Table 1). For the MF, the alternating arm motion NoWBV condition was lower ($p<0.05$) vs both WBV conditions, and the 30 Hz-L was also lower vs the 50 Hz-H condition.

Biceps brachii (BB) and triceps brachii (TB) muscles

A motion x condition interaction effect was detected for BB ($p=0.001$; $\eta^2=0.213$; see Figure 4a) and TT ($p=0.001$;

$\eta^2=0.287$; see Figure 4b). There was no significant main effect of the motion for BB ($p>0.05$; $\eta^2=0.031$) and TB ($p>0.05$; $\eta^2=0.001$). A main effect of the condition was noted indicating that significantly increased EMGrms for BB ($p=0.001$; $\eta^2=0.603$) and significantly decreased for TB ($p=0.001$; $\eta^2=0.369$) activity during 50 Hz-H compared to NoWBV and 30 Hz-L, as well 30 Hz-L compared to NoWBV ($p<0.001$).

There were no differences in EMGmdf in the BB (Table 1). For the TB, the double arm motion resulted in lower EMGmdf ($p<0.05$) than the alternating arm motion in the same condition.

Arm movements

There was no significant motion x condition interaction effect for the *y-coordinate* during battle rope exercise ($p>0.05$; $\eta^2=0.038$; Figure 5b). A main effect of motion was noted indicating that significantly increased frequency of arm movements

Figure 5. Arm motion (a) frequencies during 6 experimental conditions in the (b) y-coordinate, (c) z-coordinate, and (d) x-coordinate. [a] Significantly different than Alt_No condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.01$) (n=28).

in the *x-coordinate* (anterior/posterior) during the double arm motion vs the alternating arm motion ($p=0.001$; $\eta^2=0.465$). A main effect of the condition was also noted indicating significantly increased frequency of arm movements in the *y-coordinate* during 50 Hz-H compared to NoWBV ($p=0.020$; $\eta^2=0.138$).

There was no significant motion x condition interaction effect ($p>0.05$; $\eta^2=0.050$; Figure 5c). A main effect of motion was noted indicating that significantly increased frequency of arm movements in the *z-coordinate* (up and down) during the double arm motion compared to the alternating arm motion ($p=0.001$; $\eta^2=0.338$). A main effect of the condition was also noted indicating significantly increased frequency of arm movements in the *z-coordinate* during 50 Hz-H compared to NoWBV ($p=0.020$; $\eta^2=0.132$).

There was no significant motion x condition interaction effect for the *x-coordinate* ($p>0.05$; $\eta^2=0.034$; Figure 5d). There was no significant main effect of motion ($p>0.05$; $\eta^2=0.028$) or condition ($p>0.05$; $\eta^2=0.069$).
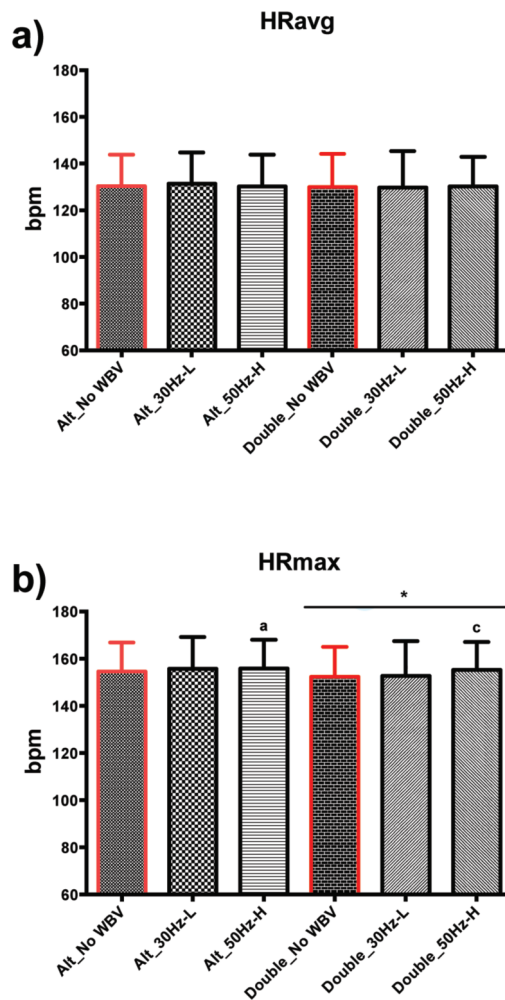
Heart rate

There was no significant motion x condition interaction effect of average heart rate ($p>0.05$; $\eta^2=0.012$; Figure 6a) and

there were no main effects of motion ($p>0.05$; $\eta^2=0.015$) or condition ($p>0.05$; $\eta^2=0.002$) on average heart rate. There was no significant motion x condition interaction effect on maximum heart rate attained ($p>0.05$; $\eta^2=0.038$). A main effect of motion was noted indicating significantly lower maximum heart rates during the double arm motion vs the alternating arm motion within the same condition ($p=0.048$; $\eta^2=0.137$). A main effect for condition was also noted where the maximum heart rate achieved during the 50 Hz-H condition was greater compared to the NoWBV condition ($p=0.027$; $\eta^2=0.125$; Figure 6b).

Discussion

The current study evaluated the effects of performing battle rope exercise with two different WBV stimuli (30 Hz low vs 50 Hz high). The primary finding is the addition of WBV to battle rope exercise results in an increase in skeletal muscle activity in the lower leg (gastrocnemius), upper leg (vastus medialis oblique and vastus lateralis), trunk (rectus abdominus and multifidus), and arms (biceps brachii and triceps brachii). These results demonstrate that the exercise stimulus of performing battling rope exercise (undulation training) can be

HRavg

HRmax

Figure 6. Beats per minute (bpm) heart rate average (a) and maximum (b) during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.05$) (n=28).

augmented by completing the exercise while being exposed to WBV from a ground-based platform.

Battle rope exercise using the alternating arm motion resulted in an increased muscle activity response in the GM of the lower leg compared to the double arm motion suggesting more stabilization in the lower leg is necessary when undulating the battle ropes asynchronously. With the addition of WBV, the 50 Hz stimulus increased muscle activity to a greater extent than the 30 Hz and NoWBV stimuli, while 30 Hz was also greater than NoWBV. This increased in skeletal muscle EMG is a result of the increases skeletal muscle reflexive response via the mechanical vibration oscillations[1-3]. Similar to our previous work, performing different types of exercise on a WBV platform augments the skeletal muscle EMG response[18].

The combination of battle rope exercise and WBV also increased muscle activity in the upper leg (VMO and VL) and

trunk muscles (RA & MF). While the double arm motion resulted in greater muscle activity in the upper leg and trunk compared to the alternating arm technique, this response was reversed in the lower leg (GM). These results suggest different muscle activation patterns across the different battle rope undulation protocols. In response to WBV, all muscles had increased skeletal muscle activity in response to WBV compared to NoWBV, while the higher magnitude WBV stimulus (50 Hz, high amplitude) was also higher compared to the lower magnitude WBV condition (30 Hz, low amplitude). These results are inline with previous research demonstrating a WBV-induced increase in skeletal muscle activity[3-8,10,11,13,18,27], and these responses being greater with a higher magnitude (acceleration) stimulus. The increased activation in the MF muscle is similar to our previous study using WBV and an unstable surface[18] though our increase in RA is a novel result of the addition of WBV to battle rope exercise.

In the upper arms (BB and TB), there was no difference between the muscle activity elicited during alternating arm or double arm motions. This is perhaps not surprising as the arms are directly involved in undulating the ropes, whether the movement is asynchronously (alternating) or synchronously (double arm). The addition of WBV still resulted in an increased muscle activity response in the BB with the 50 Hz condition having the greatest EMG. However, the addition of WBV actually resulted in a decrease in TB muscle activity. This suggests that WBV via a ground based platform can alter upper arm muscle activity during upper body exercise (battle rope undulation) which is in line with previous work evaluating upper body EMG during WBV in older adults[9]. Further, the increase in BB and decrease TB EMG suggests a decrease in co-activation of the elbow extensor (TB) while activation of the elbow flexor (BB) is increased (which could affect speed of arm movements discussed below).

While surface EMG has been used quite commonly to measure the muscles response to WBV, it can provide more information than how active the muscle is. The median frequency of the EMG signal divides the frequency spectrum into two equal halves and a shift to lower frequencies are associated with muscle fatigue[26]. The GM and TB muscles had lower EMGmdf during the double arm motion compared to the alternating arm motion suggesting the synchronous undulation exercise protocol was the most fatiguing for these muscles. However, the MF muscle was lower during the alternating arm motion vs the double arm motion. The current results also demonstrate that the different muscles are differentially affected by the different WBV exposures. In the VMO the 30 Hz condition resulted in lower EMGmdf during both motions compared to the NoWBV condition suggesting the 30 Hz condition may result in the most muscle fatigue in the VMO, perhaps due to less reflexive muscle contractions as compared to the 50 Hz condition. However, in the VL muscle, the 50 Hz condition resulted in a lower median frequency compared to NoWBV suggesting a different activation pattern than the VMO in the upper leg. These EMGmdf results suggest that the condition that results in the greatest muscle activity response

generally has decreased EMGmdf suggesting the occurrence of muscle fatigue.

The frequency of arm movements was more rapid in both the z and y coordinates during the double arm motion compared to the alternating arm motion. Further, the frequency of arm movements was further increased with the addition of the 50 Hz WBV condition vs the NoWBV condition. This increase in arm speed movements with the application of WBV could be due to improved coactivation (increase BB and decreased TB EMG) with WBV exposure allowing a less inhibited arm motion. Further, as the 50 Hz WBV condition had the highest muscle activity for all muscles, except the TB, this data could suggest a benefit to performance (faster arm motion) as there is more active muscle to overcome the weight/resistance of the battling rope. While speculative, the increased EMG with WBV suggests increased cross bridge activity and force production to move an object of the same mass (battle ropes). As the force is increased then it seems possible that the movement velocity would also increase as participants are intending to move the ropes as fast as possible.

There was no difference in average heart rate between alternating arm or double arm motion in the present study. However, maximal heart rate attained during exercise was increased during the 50 Hz condition vs NoWBV in both the alternating arm and double arm motion. Further the maximal heart rates attained during the double arm motion were decreased compared to the alternating arm motion within the same condition. It is presently unclear how peak heart rates attained could be different across conditions without any change in average heart rate, however as peak heart rates were likely attained at the end of each bout, the increase in peak heart rate was likely not attained for a long enough duration to affect average heart rate. Further research exploring these possibilities would be of interest.

In summary, this is the first study to examine the muscle activity response to battle rope exercise performed on a ground-based WBV platform. The current results demonstrate that the muscle activity response while performing battle rope (undulation) exercise can be augmented when the exercise is performed on a ground-based WBV platform. This increase in skeletal muscle activity in the lower leg (gastrocnemius), upper leg (vastus medialis oblique and vastus lateralis), trunk (rectus abdominus and multifidus), and arms (biceps brachii) is caused by an increased skeletal muscle reflexive response via the mechanical vibration oscillations. These increases in muscle EMG were greater with the increased WBV stimuli (50 Hz-H vs 30 Hz-L). For most muscles measured (VMO, VL, RA, MF) the double arm undulation technique resulted in increased skeletal muscle activity compared to the alternating arm motion. However, the GM muscle had increased muscle activity during the alternating arm motion, and EMG was not different between motions for the upper body (BB and TB). In conclusion, these results demonstrate that the exercise stimulus of performing battling rope exercise (undulation training) can be augmented by completing the exercise on a ground-based WBV platform.

References

1. Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003;31:3-7.

2. Hagbarth KE, Eklund G. Tonic vibration reflexes (TVR) in spasticity. Brain Res 1966;2:201-3.

3. Ritzmann R, Kramer A, Gruber M, Gollhofer A, Taube W. EMG activity during whole body vibration: motion artifacts or stretch reflexes? Eur J Appl Physiol 2010; 110:143-51.

4. Abercromby AF, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Variation in neuromuscular responses during acute whole-body vibration exercise. Med Sci Sports Exerc 2007;39:1642-50.

5. Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. J Strength Cond Res 2003;17:621-4.

6. Hazell TJ, Jakobi JM, Kenno KA. The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. Appl Physiol Nutr Metab 2007;32:1156-63.

7. Hazell TJ, Kenno KA, Jakobi JM. Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. J Strength Cond Res 2010;24:1860-5.

8. Marin PJ, Bunker D, Rhea MR, Ayllon FN. Neuromuscular activity during whole-body vibration of different amplitudes and footwear conditions: implications for prescription of vibratory stimulation. J Strength Cond Res 2009;23:2311-6.

9. Marin PJ, Herrero AJ, Garcia-Lopez D, et al. Acute effects of whole-body vibration on neuromuscular responses in older individuals: implications for prescription of vibratory stimulation. J Strength Cond Res 2012;26:232-9.

10. Ritzmann R, Gollhofer A, Kramer A. The influence of vibration type, frequency, body position and additional load on the neuromuscular activity during whole body vibration. Eur J Appl Physiol 2013;113:1-11.

11. Roelants M, Verschueren SM, Delecluse C, Levin O, Stijnen V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. J Strength Cond Res 2006;20:124-9.

12. Osawa Y, Oguma Y. Effects of resistance training with whole-body vibration on muscle fitness in untrained adults. Scand J Med Sci Sports 2013;23:84-95.

13. Marin PJ, Santos-Lozano A, Santin-Medeiros F, et al. Whole-body vibration increases upper and lower body muscle activity in older adults: potential use of vibration accessories. J Electromyogr Kinesiol 2012;22:456-62.

14. Da Silva ME, Fernandez JM, Castillo E, et al. Influence

of vibration training on energy expenditure in active men. Journal of strength and conditioning research / National Strength & Conditioning Association 2007;21:470-5.

15. Hazell TJ, Lemon PW. Synchronous whole-body vibration increases VO(2) during and following acute exercise. Eur J Appl Physiol 2012;112:413-20.

16. Rittweger J, Schiessl H, Felsenberg D. Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. Eur J Appl Physiol 2001;86:169-73.

17. Rittweger J, Ehrig J, Just K, Mutschelknauss M, Kirsch KA, Felsenberg D. Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. International journal of sports medicine 2002;23:428-32.

18. Marin PJ, Hazell TJ. Effects of whole-body vibration with an unstable surface on muscle activation. J Musculoskelet Neuronal Interact 2014;14:213-9.

19. Martino M, Dawes J. Battling ropes: A dynamic training tool for the tactical athlete. J Aust Strength Cond 2012; 20:52-7.

20. Fountaine CJ, Schmidt BJ. Metabolic Cost of Rope Training. J Strength Cond Res 2013.

21. Ratamess NA, Rosenberg JG, Klei S, et al. Comparison of the Acute Metabolic Responses to Traditional Resistance, Body-Weight, and Battling Rope Exercises. J Strength Cond Res 2014.

22. Rauch F, Sievanen H, Boonen S, et al. Reporting whole-body vibration intervention studies: recommendations of the International Society of Musculoskeletal and Neuronal Interactions. J Musculoskelet Neuronal Interact 2010;10:193-8.

23. Avelar NC, Ribeiro VG, Mezencio B, et al. Influence of the knee flexion on muscle activation and transmissibility during whole body vibration. J Electromyogr Kinesiol 2013;23:844-50.

24. Walker S, Peltonen H, Avela J, Hakkinen K. Kinetic and electromyographic analysis of single repetition constant and variable resistance leg press actions. J Electromyogr Kinesiol 2011;21:262-9.

25. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000;10:361-74.

26. Stulen FB, DeLuca CJ. Frequency parameters of the myoelectric signal as a measure of muscle conduction velocity. IEEE transactions on bio-medical engineering 1981;28:515-23.

27. Marin PJ, Hazell TJ, Garcia-Gutierrez MT, Cochrane DJ. Acute unilateral leg vibration exercise improves contralateral neuromuscular performance. J Musculoskelet Neuronal Interact 2014;14:58-67.