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Original Article

Acute effect of whole-body vibration on electromechanical delay and vertical jump performance

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Abstract

Objectives: To determine if a change in vertical jump performance from acute whole-body vibration can be explained by indirectly assessing spindle sensitivity from electromechanical delay. **Methods**: Using a counter-balanced design, twenty college-aged participants performed whole-body vibration (WBV) and control treatments. WBV included 10 intervals (26 Hz, 3.6 mm) of 60 s in a half-squat followed by 60 s of rest. After 5 intervals, participants rested for 6-minutes before commencing the final 5 intervals. For the control, the exact same protocol of whole-body vibration was performed but without vibration. Electromechanical delay and vertical jump were assessed at baseline, during the 6-minute rest period and immediately after whole-body vibration and control. **Results**: There were no differences between treatments, for both electromechanical delay ($F(2, 38)=1.385$, $p=0.263$) and vertical jump ($F(2, 38)=0.040$, $p<0.96$). Whole-body vibration had no effect on vertical jump performance. **Conclusion**: The current whole-body vibration protocol is not effective for acute vertical jump or electromechanical delay enhancement. Also, since there was no effect on electromechanical delay, this suggests that whole-body vibration did not enhance muscle spindle sensitivity for the parameters examined.

Keywords: Gastrocnemius, Muscle Activation, Muscle Spindle Sensitivity

Introduction

Vibration was initially researched using localized high-frequencies as a means to study the actions of muscle spindles[1-3]. Previous research also focused on vibration as a possible occupational hazard[4,5], as an occurrence which could negatively affect athletic performance in certain sport activities[6], and also as a method of rehabilitation for musculoskeletal injuries and conditions[7-10]. The focus of the current literature has centered on examining vibration at lower frequencies to enhancing acute muscular performance[11-14].

The recent positive findings in low-frequency vibration research specific to muscle adaptation has led to studies focused on using vibration as an exercise method; this is referred to as whole-body vibration (WBV) that involves a vibrating platform. The idea of WBV is to utilize the isolated positive effects, such as muscle spindle activation[1,3,15,16] and muscular performance[8,17-19], and apply them to exercise and training for the entire body.

Theoretically, positive results due to WBV are a product of muscle activation[20-23]. WBV is based on the concept of muscle spindle activation and the resulting position feedback and muscle stretch provided by the vibration stimulation[24,25]. An increase in muscle spindle sensitivity could potentially improve the neuromuscular response. The difficulty with WBV and the theory of muscle activation is how to measure these adaptations.

One possibility of measuring muscle spindle sensitivity is from electromechanical delay (EMD), which is defined the lag time between muscle activation and force production[26]. Increased muscle spindle sensitivity due to vibration increases spindle feedback which affects impulse firing to the muscle fiber, essentially priming the fibers for contraction[3]. In other words, enhanced spindle sensitivity results in an increased number of cross bridges, taking up a portion of the slack in the series elastic component and ultimately

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decreasing EMD. Therefore, a decrease in EMD would provide evidence for enhanced muscle spindle sensitivity.

Many studies have utilized the theory of increased muscle activation to explain muscle strength and power responses of muscles due to WBV. Acute responses to WBV have shown significant increases in lower-limb strength[19,27], and lower-limb muscular power[28,29]. Directly following application, WBV has also provided evidence of significant improvements in vertical jump performance[12,18,19,30]. The majority of studies shows that WBV can have a positive influence on muscle strength and power responses, although a few studies have found acute WBV to have either no effect on lower-limb muscular performance[31] or an increase of fatigue and decreased performance[25].

The literature has shown that acute WBV has potential benefits for neuromuscular performance. More research, however, is required to explain the positive WBV findings. Therefore, the purpose of this study was to determine the effect of 10-minutes of WBV on EMD and vertical jump performance. It was hypothesized that WBV would decrease EMD and enhance vertical jump.

Materials and Methods

Participants

Twenty healthy college-aged students (13 males and 7 females; mean±SD; height: 175.5±1.02 cm; weight: 72.3±11.2 kg; body mass index: 23.5; age: 22.9±2.2 years) volunteered for the study. The sample size was based on earlier research that reported an improvement of 8% in vertical jump of 2.4 cm ± 3.4 [SD][12]. With α=0.05 and β=0.8, a sample size of 16 was required. To ensure greater statistical power, 20 recreationally active participants completed the study. For purposes of this study. 'recreationally active' was defined as participating in at least 30-minutes of exercise twice per week, not currently involved in any rigorous resistance or athletic training program, and had no lower-limb injuries within the last year. This study was approved by the University Institutional Review Board for Ethics.

All participants signed informed consent and were familiarized with the methods and procedures prior to testing. Each participant was assigned a treatment order using a counterbalance design. At least 2 days following the first treatment and testing, all participants performed the second treatment.

Experimental Procedures

At baseline, participants were tested for involuntary EMD and maximal CMJ. After baseline measurements, participants either performed a 10-minute WBV or control (no WBV). At no less than 2 days following the first treatment, each participant received the alternate treatment.

WBV was performed on a vertical vibration platform (Power Plate North America, Inc., Northbrook, IL). Adhering to the suggested whole-body vibration reporting guidelines[32] vibration was administered at a frequency of 26 Hz and the "high" setting of amplitude. Actual vibration frequency and amplitude was checked and sampled using a Vicon Nexus motion analysis system (Vicon, Denver, USA) and a PCB Piezotronics model 356a11 triaxial accelerometer (PCB Piezotronics Inc., New York, USA) to measure the input vibration to the platform. Thus, the actual frequency was 26 Hz and 3.6 mm amplitude. Participants stood on the vibration platform with their feet hip width apart and they were instructed to feel as if more weight was distributed more towards their heels, in a half-squat (45° knee flexion set by a goniometer), with hands placed on the machine's railing for balance. An elastic band apparatus was positioned under participants' gluteal region, and participants were instructed to keep resistance on the elastic band once the knee angle was set. The WBV protocol was modeled on the study of Bosco, Iacovelli, Tsarpela, Cardinale, Bonifazi, Tihanyi, Viru, De Lorenzo and Viru[18]. However, in piloting testing, participants could not maintain the knee flexion without excessive fatigue. Thus, we adapted the knee angle (45° knee flexion) during the half-squat compared Bosco, Iacovelli, Tsarpela, Cardinale, Bonifazi, Tihanyi, Viru, De Lorenzo and Viru[18] to a knee angle of 100°.

WBV consisted of 60 s intervals, with 60 s of rest between each interval. After 5 bouts of WBV, participants received 6-minutes of rest, which included the second session of testing for EMD and maximal CMJ. Following this, another 5 bouts of WBV were performed, for a total of 10-minutes of WBV. For the control the exact protocol of WBV was performed on the vibration platform, but with no vibration. EMD and CMJ were assessed at baseline (pre-treatment), mid-way through treatment and post-treatment for WBV and control treatments.

Involuntary EMD. This was assessed using a supramaximal percutaneous electrical muscle stimulation (ISOC, BIOPAC Systems Inc., Santa Barbara, CA) of the tibial nerve, similar to the peroneal method used by Mora, Quinteiro-Blondin, Perot, Isabelle, Sylvie and Chantal[33]. A water-based gel was used on the stimulator bar and the stimulation electrode was placed over the tibial nerve, at the posterior aspect of the knee, in the popliteal space. To ensure correct positioning over the tibial nerve, the stimulator was tested and moved until a supramaximal stimulation (maximum m-wave) of the MG was detected. On determining the correct stimulator position, it was then secured to the leg using elastic athletic tape (3M Coban, AR, USA).

Each participant then stood with the right foot on a force plate (AMTI Measurements Group, Watertown, MA) with the heel on a marked position. The left foot was positioned on the floor, to the side of the force plate over a marked spot. Participants then placed hands on a support stand located 30.5 cm in front of toes at the level of the naval and were instructed not to lean on it but use only to maintain balance. Participants were then instructed to relax with weight equally distributed to both legs, with knees extended. Three stimuli were then administered with 30 s of rest between each stimulation.

During stimulation, muscle activation from the MG was

measured using surface electromyography (EMG) (MP150, BIOPAC Systems, Inc., Santa Barbara, CA). The skin of each participant's right leg of the MG, medial malleolus, and the posterior aspect of the knee were shaved if needed and cleaned with isopropyl alcohol. Two pre-gelled Ag-AgCl electrodes (Type Blue Sensor POOS, Medicotest, Ølstykke, Denmark) were placed on the medial head of the MG, parallel to the muscle fibers and 2 cm superior the distal end. The ground electrode was placed on the medial malleolus. EMG was measured using the Biopac MP100 system (BIOPAC Systems Inc., Santa Barbara, CA). Signals were amplified (TEL100M, BIOPAC Systems Inc., Santa Barbara, CA) from disposable, pre-gelled Ag-AgCl electrodes. The EMG measurements were collected at 1000 Hz. The input impedance of the amplifier was 1.0 megaohm, with a common mode rejection ratio of 90 dB, high and low pass filters of 20 and 400 Hz, a signal to noise ratio of 70 dB, and a gain of 1000. Raw EMG signals were processed using a root mean square algorithm with a 5 msec moving window. The plantar flexion moment was measured using the force plate. Vertical ground reaction force, detected on the force plate, represented the force induced by stimulation and timing of the movement. A specifically designed software program on Microsoft Visual Basic (Microsoft, Portland, Oregon) was used to identify the onset of muscle activity and force to calculate EMD. EMD was calculated from the time EMG first detected stimulation to the time a force was observed (±2 SD).

Vertical Counter-Movement Jump. For each time interval (baseline, mid-treatment, and post-treatment) participants performed 3 maximal vertical CMJ with their hands on their hips and jump as high as possible. The depth of the jump was self-selected. Each CMJ was performed on a force plate (AMTI Measurements Group, Watertown, MA) and the force was collected at 1000 Hz during each jump. An analog to digital conversion card (Keithley 3100, Keithley Instuments Inc., Cleavland, OH) combined with Microsoft Visual Basic (Microsoft, Portland, Oregon) provided the vertical force. Flight time was calculated using the time when force was below 20 N.

Jump height was estimated using the following equation:

$$\text{CMJ height} = \tfrac{1}{2}\, g * [t / 2]^2$$

Where g is the gravitational acceleration for the site of data collection, estimated at 9.797 m/s^2, t= time in air[34]. From the 3 maximal CMJ the maximal height was used for comparisons. This method of determining vertical jump has been found to be both very reliable and valid[35].

Statistical Analysis

The average EMD and maximal CMJ height from each time interval of WBV and control treatments was used for data analysis. Descriptive statistics of treatment means and standard deviations were calculated for both the control and WBV EMD and CMJ results. Means were normalized to baseline and reported as a percent change (Table 1). A (2 treatments x 3 time intervals) repeated measures factorial ANOVA was used to detect differences between treatments over time for both EMD and CMJ using the SPSS (version 11.5 Chicago, IL, USA). The significance level was set at $p \leq 0.05$.

Table 1. Normalized Percentage (mean ± SD) of EMD in Control and WBV.

Time	Control	WBV
Baseline	0.00 ± 0.00	0.00 ± 0.00
Mid-Treatment	-5.88 ± 16.46	-0.39 ± 11.49
Post-Treatment	-5.20 ± 12.26	0.10 ± 6.63

Table 2. Normalized Percentage (mean ± SD) of Vertical Counter-Movement Jump in Control and WBV.

Time	Control	WBV
Baseline	0.00 ± 0.00	0.00 ± 0.00
Mid-Treatment	-3.98 ± 3.21	-4.23 ± 2.72
Post-Treatment	-3.62 ± 4.63	-3.54 ± 4.91

Results

No significant differences were detected in EMD between treatments ($F(2, 38)=1.385$, $p=0.263$). A non-significant decrease in EMD was observed in the mid and post-testing compared to baseline of 5.9% and 5.2% in the control and a 0.4% and 0.1% decrease in WBV (Table 1). No significant differences were detected in CMJ between treatments ($F(2, 38)=0.040$, $p<0.96$). A non-significant 4.0% and 3.6% decrease in CMJ for the control, and 4.2% and 3.5% decrease for WBV of the mid and post-testing compared to baseline (Table 2).

Discussion

The purpose of this study was to determine if an increase in CMJ from acute WBV could be explained by measuring EMD as an estimate of spindle sensitivity. The results of this study reported no significant difference in EMD between WBV and control. In earlier work using the same EMD method as the present study, researchers concluded that peroneus longus EMD could be used as an indirect method for assessing muscle stiffness; reporting that a decrease in EMD was a product of spindle sensitivity due to greater stiffness around the joint[33]. In effect, a decrease in EMD would indicate an increase in muscle spindle sensitivity and muscle activation. When muscles are vibrated, it has been theorized that spindle sensitivity is enhanced and muscle stiffness increases to damp the vibration[24]. The increased stiffness and change in muscle spindle sensitivity, increases the muscle's α-motoneuron activity and the number of actin-

myosin cross-bridges. Therefore, since cross bridges have already been formed the time necessary to take up slack in the series elastic component may be significantly reduced, decreasing the overall time between activation and force development[36].

Several studies have attributed improvements in muscle performance due to WBV, to increased muscle spindle sensitivity and the feedback system[19,37]. However, in the current study there was no change in EMD following WBV, indicating, no increased muscle spindle sensitivity. In earlier studies, the acute effect of WBV on EMD remains unclear. After an acute bout of WBV soleus EMD was significantly reduced by 15.6% (20 Hz, 5 mm)[38], while others have reported no change in EMD of vastus lateralis (26 Hz, 6 mm)[39], vastus medialis and vastus lateralis (26 Hz) and peroneus longus[40]. The lack of EMD response following WBV in the current study, may be due to the duration of the experimental protocol that could have elicited fatigue, mainly in the control treatment. The majority of the participants reported WBV having a relaxing effect while the control participants provided feedback that fatigue started to set in during the static half-squat. While not significant, the control exhibited, a mid- and post-treatment decrease of 5.9% and 5.2% in EMD compared to baseline, while WBV contributed 0.4% and 0.1% decrease in EMD compared to baseline. It is plausible that the muscle spindle or EMD coexisted with fatigue of the muscle. When large motor units begin to fatigue, muscle spindles initiate a feedback contribution to decrease activation rates and reduce the muscle's loss of force during the contraction[41]. Hortobagyi, Lambert and Kroll[42] reported that CMJ performance following fatigue, participants compensated for fatigue by enhancing muscle spindle sensitivity. In another study, fatigue and 3-minute of rest decreased EMD, indicating that the fatigue effect may persist for a long period[43]. Further, the contribution of MG to CMJ performance may be a factor in addressing the present EMD result. Previous research reported that the lower-limb percentage contribution for CMJ performance were[30,42], 28% for the hip, knee and ankle, respectively[44]. It is plausible that MG EMD may not be indicative of lower-limb response to WBV and future research should assess the implications of using MG EMD.

In contrast to previous findings[12,17,30,31,45] current findings reported no significant increase in CMJ following acute WBV. The disparity between results appears to be the variability of WBV parameters (vibration frequency, amplitude and duration) and the use of different vibration platforms. It is still unknown what the optimal acute WBV parameters are for enhancing CMJ. Another explanation for the non-significant differences between treatments may exist with the knee flexion angle. From our pilot work participants were unable to tolerate 1-minute bouts in a deeper squat as described by previous research[17]; therefore, we prescribed a less aggressive knee flexion angle. The knee can attenuate vibration transmission[46], with knee angles smaller than 180° (knee extension=180°) damping mechanical vibration before reaching the hip[47]. This may be a factor in optimizing hip joint moment and consequently CMJ performance. In considering the limitations of the current study examined the effect of a single WBV exposure. The covariate of sex (male, female) was not analyze due to the unequal sample of males and females. However, the group is representative of recreationally active participants, but future studies should investigate other populations and a greater range of vibration frequencies and amplitudes could be examined. The strength the present study provided an investigation to determining a potential WBV mechanism and related performance.

In conclusion, our findings suggest acute WBV has no effect on EMD and does not enhance CMJ performance. Future work may focus on an optimal training protocol, including WBV duration, frequency, and amplitude, that might have beneficial effects. Additional research is required to determine the applicability and reliability of EMD in measuring muscle spindle sensitivity.

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