The Acute Effect of Whole-Body Low-Frequency Vibration on Countermovement Vertical Jump Performance in College-Aged Men

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Abstract

Lamont, HS, Cramer, JT, Bemben, DA, Shehab, RL, Anderson, MA, and Bemben, MG. The acute effect of whole-body low-frequency vibration on countermovement vertical jump performance in college-aged men. *J Strength Cond Res* 24(x): 000–000, 2010—The purpose of this study was to examine the acute effects of whole-body vibration on jump performance. A total of 21 college-aged men, 18–30 years, recreationally resistance trained, were exposed to a total of 4 different acute whole-body low-frequency vibration (WBLFV) protocols (conditions 1–4), performing 2 protocols per testing session in random order. Exposures were all performed using high-amplitude (peak–peak 4–6 mm) and either 30 or 50 Hz for 30 continuous seconds, or 3 exposures of 10 seconds with 1 minute between exposures. Three countermovement vertical jumps (CMVJs) were performed before vibration (testing phase 1 or Tp1 and J1 the highest of 3 attempts) and at 3 separate time points postvibration (Tp2–4). Jump height (cm), peak power (P_{max}), peak power per kilogram of body mass (P_{max} kg^{-1}), mean power (P_{av}), and mean velocity (V_{av}) were recorded. Repeated measures analysis of variance and analysis of covariance revealed no significant condition (C) or jump (J) differences for CMVJ height (cm) ($p > 0.05$). Analysis of percent change (Δ%) for CMVJ height (cm) revealed a significant Condition × Jump interaction, C4, J3 > C1, J3 ($p = 0.009$, mean diff 4.12%). Analysis of P_{max} and P_{max} kg^{-1} revealed no significant Condition, Jump, or Condition × Jump interaction for the raw data or percent change ($p > 0.05$). Analysis of P_{av} (W) revealed significant differences for Condition ($p = 0.031$) but not for Jump ($p = 0.226$). There was a strong trend toward significance for Condition × Jump interaction ($p = 0.059$). C4 > C3 ($p = 0.043$, mean diff 23.78 W) and C1 ($p = 0.038$, mean diff 32.03 W). Analysis of V_{av} (m·s^{-1}) revealed no significant main effects for Condition or Jump ($p > 0.05$) but found a significant Condition × Jump interaction ($p = 0.007$). C4, J6 > C2, J6 ($p = 0.014$, mean diff 0.05 m·s^{-1}), and C3, J6 ($p = 0.020$, 0.05 m·s^{-1}). WBLFV applied intermittently using 50 Hz appears to be more effective than other protocols using 30 and 50 Hz in facilitating select measures of CMVJ performance over a 17-minute time period post-WBLFV exposure. Practical manipulation of such a WBLFV "dose" may be beneficial to strength and conditioning practitioners wanting to acutely facilitate CMVJ and slow stretch shortening cycle performance while minimizing exposure time.

Key Words stretch shortening cycle, jump performance, postactivation potentiation

Introduction

In addition to traditional resistance training, other techniques have been employed to elicit acute increases in power output, such as maximal voluntary contractions (MVCs) and heavy load dynamic actions (80% or > 1RM) before jumping. Increased jump height, power output, dynamic rates of force development, velocity, and increased neuromuscular efficiency have been reported to arise from the resultant state of "postactivation potentiation" or PAP. Such modalities have been referred to as complex or contrast training within a strength and conditioning setting (1,2,11,12,15,19–22,38,41,43).

Recent studies suggest whole-body low-frequency vibration (WBLFV) may also elicit a PAP response to improve performance (3,6,7,9,10,15,18,23,25,26,30,33,36,40), whereas

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others report no change or decrements (postactivation depression [PAD]) (4,13,17,24,28,29,39) in performance. Whole-body low-frequency vibration has been reported to stimulate mono and polysynaptic reflex pathways triggering a "tonic vibration reflex" or TVR. The TVR arises as a net response to increased afferent input from sensory receptors that include type 1a and type 2 muscle spindle afferents, Miessner and Pacinian corpuscles, Ruffini nerve endings, Renshaw cells, golgi-like receptors and tendon organs (GTO), and type 3, type 4 afferents. An upregulation in musculotendinous stiffness is initially (within 3 seconds) seen while standing on a WBLFV platform, resulting in high oscillatory accelerations within the targeted musculature (3,6, 7,9,10,15,16,18,23,25,26,30,33,36,40). The resultant increased reflex activation of Alpha motor neurons leads to increased motor unit activation, firing frequency, and possible synchronization of higher threshold motor units. The residual effects of WBLFV exposure may last up to 20 minutes or longer depending upon frequency, amplitude, exposure time, and platform type used. WBLFV may also enhance performance via other mechanisms, such as increased myosin light chain (MLC) phosphorylation, reciprocal inhibition of antagonistic musculature, type 2 afferent feedback, neuromuscular efficiency, or intramuscular temperature (3,6,7,9,10, 13,14,17,18,25,26,28–30,33,36,37). Early work revealed, during vibration exposure to the muscle, that stretch and Hoffman reflexes were partially inhibited because of presynaptic inhibition at type 1a afferents (11,37). After vibration removal, the stretch reflex recovered beyond baseline within 100 seconds indicating a potentiated response (8,35,45). The H-reflex saw greater relative depression but recovered to baseline within 2 minutes. Other work has shown increasing vibration amplitude, but not frequency, leads to greater relative depression of H-reflex magnitude during the Achilles tendon reflex (8,35).

Recent research using WBLFV by Armstrong et al. (4) looked at H-reflex activity after a 1-minute bout of WBLFV at 40 Hz, low (2–4 mm peak–peak) amplitude in college-aged men and women. H-reflex activity was measured at 30-second intervals for 30 minutes after WBLFV. Significant depression was seen post-WBLFV for all subjects during the first minute, followed by 4 distinctive patterns of recovery, suggesting high, between-subject variability based upon their physiological make-up and training status.

Hopkins et al. (24) found no significant facilitation of patella tendon stretch reflex latencies, electromyography (EMG) activity, or force output within the quadriceps immediately after, or 30 minutes post-WBLFV applied for 5, 1-minute bouts (1-minute rest between bouts) at 26 Hz while subjects stood in a standardized squat position.

Adams et al. (3) and Ronnestad et al. (40) examined the effects of frequency, amplitude, mode, and exposure time on countermovement vertical jumps (CMVJs) and squat jumps (SQJs). Adams et al. (3) found higher frequencies worked best with higher amplitudes using Power Plate® with previously untrained men and women. A 50-Hz condition with high amplitude (4–6 mm peak–peak) was significantly different from a 40-Hz, high-amplitude condition ($p < 0.05$) for %Δ in CMVJ P_{max}, 1 minute post-WBLFV. No significant differences were seen for exposure time (30, 45, or 60 seconds) suggesting as little as 30 seconds of WBLFV can improve CMVJ P_{max}. Ronnestad et al. (40) looked at WBLFV applied at 20, 35, and 50 Hz (3-mm peak–peak amplitude) upon CMVJs and SQJs performed on a WBLFV platform, in untrained and recreationally trained men and women. The greatest increase in P_{av} was seen using 50 Hz during the SQJ for trained and untrained compared with no WBLFV ($p < 0.01$). Only untrained subjects saw significant improvement in CMVJ P_{av} with WBLFV ($p < 0.05$) with 50 Hz significantly better than 35 Hz in untrained subjects ($p < 0.05$). Although experimental differences exist between these studies, both report improvements using 50 Hz with untrained and trained men and women.

Recent concerns over chronic exposure to WBLFV have been raised, with potential damage to internal organs, the spinal column and the retina highlighted (3,26,33). With this in mind, using the "least effective dose" of WBLFV during acute applications would appear to be important, not only to facilitate performance but also to reduce the potential for possible vibration-induced injury. The optimal combination of frequency, amplitude, duration, and platform type is still a subject of debate with positive results seen with frequencies ranging 6–50 Hz, low and high amplitudes, and varying platform types (3,6,7,9,10,15,18,23,25,26,30,33,36,40). The CMVJ assesses power, using a slow stretch shortening cycle (SSC) that is reliant upon reflex activation (medium latency loop, M2 and M3), and potential energy storage within the series elastic component of the musculature within the lower extremities. If WBLFV does lead to reflex potentiation, increased jump height and power output would be expected.

Therefore, the purpose of the study was to compare WBLFV applied acutely, for a total duration of no more than 30 seconds: for 30 continuous seconds, or intermittently for 3 bouts of 10 seconds using a frequency of 30 or 50 Hz all at high amplitude (4–6 mm peak–peak), and their effects on CMVJ performance over a 17-minute period.

Methods

Experimental Approach to the Problem

The current study was designed to investigate possible performance-enhancing effects of 4 distinct WBLFV protocols (conditions 1–4) aimed at bringing about a state of PAP before the performance of CMVJs. Two different frequencies of WBLFV (30 and 50 Hz) were applied continuously (30 seconds) or intermittently (3 sets of 10 seconds vibration exposure with a minute's rest in between exposures) at high amplitude (4- to 6-mm peak–peak). Countermovement vertical jumps were performed before (3 jumps, greatest jump trial selected; T1p) and then at specific time points beginning at 2 minutes, and finishing at 17 minutes after

WBLFV exposure (9 jumps over 3 testing phases, 3 jumps per testing phase, and 1-minute rest between jumps). Subjects performed 2 WBLFV conditions per session separated by a 20-minute rest period. Two total sessions were completed (4 WBLFV conditions) separated by at least 48 hours. Measures of CMVJ height (cm), P_{max} (W), P_{max} kg^{-1} (W kg^{-1}), P_{av} (W), and V_{av} ($m \cdot s^{-1}$) were recorded directly using a linear velocity transducer (FitoDyne®), or indirectly via the Sayers Nomogram (42).

Subjects

A total of 21 male college students (aged 18–30 years) volunteered as subjects for the current study. They were informed of the experimental risks before completing a written informed consent form that had been approved by the University of Oklahoma's Institutional Review Board concerning experimentation with human subjects. All prospective subjects also completed a PAR-Q and preparticipation health-screening questionnaires, if they answered "yes" to any of the questions they were excluded from participating in the study. Twenty-one subjects met the inclusion criteria and participated, with all trials completed for all subjects.

Subjects had resistance trained for the last 6 months, worked out for no more than 3 times per week, and focused upon their lower extremities no more than twice per week. Because of their background resistance training status and none participation in National Collegiate Athletic Association (NCAA) or professional sports, they were classified as "recreationally" trained.

Subjects were asked to maintain their regular diet except exclusion of caffeinated beverages during the 8-hour period before testing sessions to negate potential ergogenic effects of caffeine. Subjects were instructed not to engage in heavy lower body exercise the day before testing. Such activity included moderate to heavy load or volume squatting and leg press exercises (loads greater 60% of 1RM, sets greater than 3), sprinting, runs over 3 miles in distance, or bicycle rides further than 10 miles.

Testing sessions were carried out over 2 days with at least 48 hours between testing sessions. Subjects randomly chose WBLFV exposures written on small pieces of paper withdrawn from a plastic cup. Two WBLFV exposures were used per testing session, with 20-minute rest between the end of 1 protocol and the start of another during which subjects sat with their legs elevated upon a chair 45 cm off the ground. The lower extremities were supported in such a manner to reduce mechanically loading and to facilitate recovery, and allow for any residual effects of the first WBLFV exposure to dissipate before the start of the second (Table 1).

Procedures

Subjects' weights (kg) were recorded while wearing the exact clothing they would later jump into. Standing height (cm) was measured with a stadiometer. After a 5- minute, low-intensity warm-up on an Ergomedic 828E Monark cycle ergometer (Sweden) pedaling at 60 rpm with a 0.5-kpond load, subjects rested in a chair for 3 minutes before performing the first series of baseline jumps (testing phase 1 or Tp1: 3 jumps (J1–J3), 1-minute rest between jumps). The peak height attained ($Tp1_{peak}$) was used for data analysis and was called Jump 1. Subjects then returned to a chair for a further 2 minutes of rest before the first WBLFV exposure was applied. The CMVJs were performed over a Just Jump diagnostic jump mat (Just jump technologies, Huntsville, AL, USA) which calculated jump height from flight time (equation height estimation). A broom handle was placed across the shoulders, so the arms could be held in a fixed position, and to allow a Fitrodyne linear line velocity transducer to be attached. The Fitrodyne (Fitodyne sports Powerlyzer, Tendo sports machines, Trencin, Slovak Republic) provided direct measures of mean power (P_{av}, W) and velocity (V_{av}, $m \cdot s^{-1}$).

Subjects were instructed to self-select the length of the jump amortization phase while attempting to jump as high as possible, keeping their legs underneath their torso until returning to the jump mat. These instructions were important because landing with the legs to the side or with excessive bend in the legs could result in false readings of maximal jump height (38,42–44). Three jumps were performed at 4 separate testing phases (Tp1–4:Tp1 (baseline); Tp2 (2 minutes post-WBLFV); Tp3 (7.5 minutes post-WBLFV); and Tp4: Seventeen minutes post-WBLFV) for a total of 12 CMVJs (J1–12) with 1-minute rest between jump trials. Jump height (cm) was calculated from flight time and peak power (P_{max}, W) estimated using the Sayers Nomogram (42). Measures of mean power (P_{av}, W) and velocity (V_{av}, $m \cdot s^{-1}$) were recorded directly using the FitroDyne.

Whole-Body Low-Frequency Vibration Exposure

Whole-body low-frequency vibration was applied using a Power Plate, Next Generation® vibrating platform (Power Plate USA, Northbrook, IL, USA). The plate's action is TriPlaner, but the majority of the vibration is directed up and down within the Z-plane. The acceleration imparted upon the body is a result of the combination of the frequency (30, 35, 40, and 50 Hz) and amplitude ("low" 2–4 mm, "high" 4–6 mm, peak–peak amplitude) selected. The range of accelerations used during the current study varied between

Table 1. Anthropometric data ($n = 21$).

	Age	Height	Weight
Mean ± *SD*	25.7 ± 3.40	179.1 ± 5.62	84.7 ± 11.38

Table 2. Pre-WBLFV measures for all conditions ($n = 21$).

Conditions	30 × 30 (C1)	30 × 3 × 10 (C2)	50 × 30 (C3)	50 × 3 × 10 (C4)
Height (cm)	45.68 ± 6.09	45.97 ± 6.74	45.43 ± 6.64	46.54 ± 6.61
P_{max} (W)	4,506.51 ± 575.76	4,521.58 ± 602.37	4,493.33 ± 558.31	4,551.08 ± 662.59
P_{max} kg^{-1} (W·kg^{-1})	53.37 ± 4.03	53.56 ± 4.51	53.26 ± 4.37	53.86 ± 4.27
P_{av} (W)	1,395.95 ± 204.93	1,430.67 ± 247.55	1,416.57 ± 221.53	1,431.76 ± 253.65
V_{av} (m·s^{-1})	1.69 ± 0.12	1.72 ± 0.14	1.71 ± 0.12	1.72 ± 0.13

3.8 G (30 Hz 2–4 mm peak–peak amplitude) and 5.83 G (50 Hz 4–6 mm peak–peak amplitude).

Subjects were instructed to stand on the WBLFV platform with foot position standardized for each subject to that used during CMVJ testing. Subjects were then instructed to descend into a goniometer standardized quarter squat position at 135 ± 5° (knee flexion angle) while placing their hands upon the WBLFV machines centralized handles. Four different WBLFV protocols were assessed: condition 1 (C1): 30 Hz for 30 seconds; C2: 30 Hz for 3 exposures of 10 seconds; C3: 50 Hz for 30 seconds; and C4: 50 Hz for 3 exposures of 10 seconds. The total time on the WBLFV platform was 30 seconds for all 4 experimental treatments; however, during the intermittent protocol, 3, 10-second bouts, with 1-minute rest periods were used (total time: 180 seconds).

Subjects then rested for 2 minutes before another series of CMVJs (Tp2), then rested for 3 minutes before the third series of CMVJs (Tp3), and then rested for a final 5 minutes before completing the final series of CMVJS (Tp4). After a 20-minute rest, the protocol was repeated with a different WBLFV treatment. The total length of testing sessions was approximately 90 minutes (Table 2).

Statistical Analyses

A 1-way repeated measures analysis of variance (ANOVA) indicated that there were no statistical differences between the baseline jumps recorded over the conditions so the highest jump (Tp1–peak) was used for other analyses. A general linear model repeated measures analysis of covariance (ANCOVA; baseline values as the covariate) was used to assess potential differences between WBLFV conditions (C1–4) across the 10 jumps (J1–J10). Bonferroni post hoc analysis was run on significant main effects for condition and jump to correct for inflated alpha levels resulting from multiple comparisons. A 2-way repeated measures ANOVA was calculated for percent change (percent potentiation %) normalizing Tp1–peak to equal 100% for all 4 WBLFV conditions. If significant Condition × Jump interactions were found, the data set was split by Condition and reanalyzed to asses within Condition differences. A series of 1-way ANOVAs were then used to compare specific Condition × Time point combinations with Bonferroni post hoc analysis. All statistical analyses were run using the Statistical Package for the Social Sciences (SPSS), version 15.0 for Windows (SPSS Inc., Chicago, IL). Statistical significance was set at a $p \leq 0.05$.

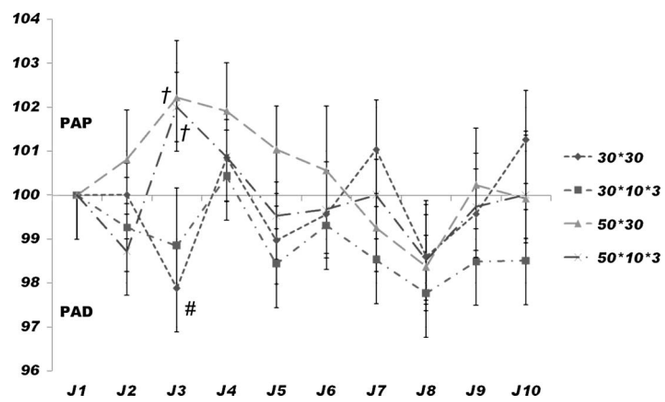

Figure 1. Whole-body low-frequency vibration + countermovement vertical jump (CMVJ) testing protocol: CMVJ height (%Δ), peak T1 (baseline) measures normalized to equal 100%. Above 100% indicates postactivation potentiation, below indicates postactivation depression. Significant Condition × Jump time point interaction ($p = 0.030$). †denotes C4, T3 > #C1, J3 ($p = 0.009$, mean diff 4.12%), C3, J3 > #C1, J3 ($p = 0.019$, mean diff 4.34%). (Data expressed as mean ± *SE*).

Results

The subjects had a mean height of 179.1 ± 5.6 cm, weight of

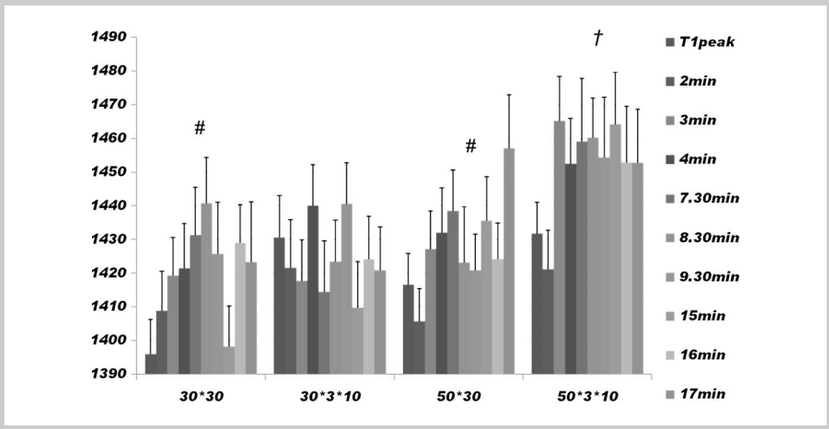

Figure 2. Countermovement vertical jump mean power (W) for 4 whole-body low-frequency vibration conditions over 10 time points. † denotes significant main effect for Condition ($p = 0.031$), †C4 > #C3 ($p = 0.043$, mean diff 23.78 W) and #C1 ($p = 0.038$, mean diff 32.03 W). (Data expressed as mean ± *SE*).

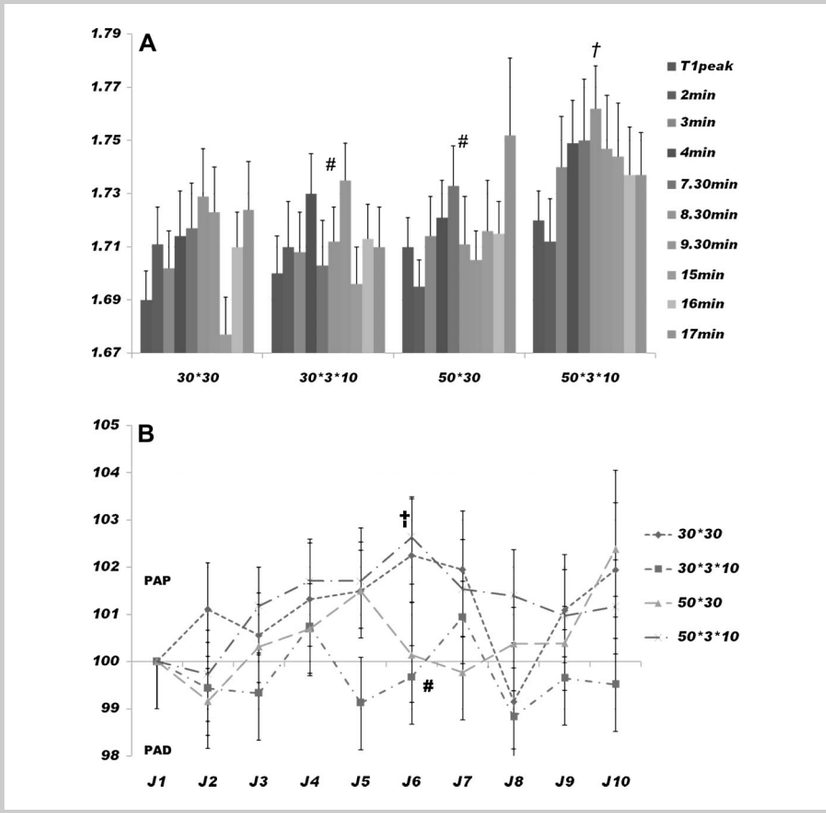

Figure 3. (A) Countermovement vertical jump mean velocity for 4 whole-body low-frequency vibration conditions over 10 time points. †denotes significant Condition × Jump time point interaction ($p = 0.007$), †C4, T6 > #C3, T6 ($p = 0.02$, mean diff 0.05 m·s^{-1}), †C4, J6 > #C2, J6 ($p = 020$, mean diff 0.05 m·s^{-1}). (Data expressed as mean ± *SE*). (B) Countermovement vertical jump mean velocity (%Δ), Peak T1 (baseline) measures normalized to equal 100%. Above 100% indicates postactivation potentiation, below indicates postactivation depression. † denotes significant Condition × Jump time point interaction ($p = 0.006$), †C4, J6 > #C2, J6 ($p = 0.012$, mean diff 2.97%). (Data expressed as mean ± *SE*).

84.7 ± 11.4 kg, and were aged 25.7 ± 1.5 years.

CMVJ Height, P_{max}, and P_{max} kg^{-1}

The analysis of CMVJ height (cm), Condition (4) × Jump (10) revealed no significant differences ($p > 0.05$). Figure 1 depicts the percent change (Δ%) for CMVJ height (cm) for the 4 WBLFV conditions over 10 jumps. There was a significant Condition × Jump interaction with ($p = 0.030$) C4, J3 > C1, J3 ($p = 0.009$, mean diff 4.12%) and C3, J3 > C1, J3 ($p = 0.019$, mean diff 4.34%).

The analysis of CMVJ P_{max} and P_{max} kg^{-1} of body mass and their respective %Δ revealed no significant differences between conditions ($p > 0.05$).

CMVJ P_{av} and V_{av}

Figure 2 depicts the CMVJ P_{av} data (W), which demonstrated a significant main effect for Condition ($p = 0.031$), with C4 > C3 ($p = 0.043$, mean diff 23.78 W) and C1 ($p = 0.038$, mean diff 32.03).

Figure 3A depicts the percent change (Δ%) data for CMVJ P_{av}. There were no significant differences between conditions ($p > 0.05$). Figure 3A depicts the CMVJ V_{av} (m·s^{-1}) for the 4 WBLFV conditions over the 10 jumps. There was a significant Condition × Jump interaction ($p = 0.007$) with C4, J6 > C3, J6 ($p = 0.014$, mean diff 0.05 m·s^{-1}), and C2, J6 ($p = 0.020$, mean diff 0.05 m·s^{-1}).

Figure 3B depicts the percent change (Δ%) for CMVJ V_{av} for the 4 WBLFV conditions over the 10 jumps. There was a significant Condition × Jump interaction ($p = 0.006$) with C4, J6 > C2, J6 ($p = 0.012$, mean diff 2.97%).

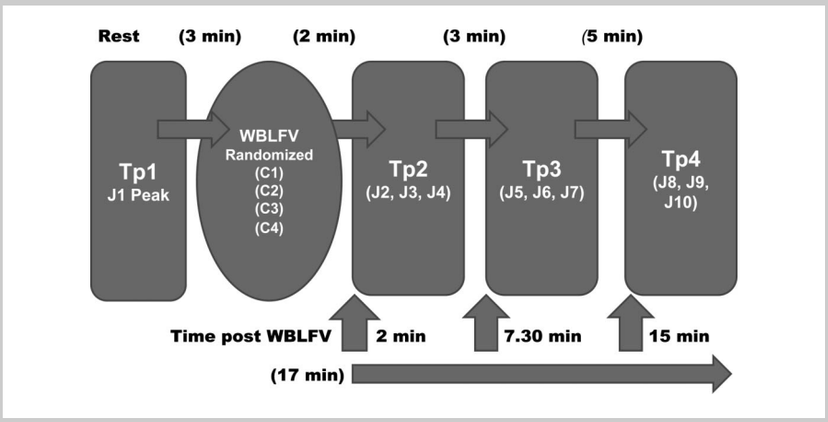

Figure 4. Tp1 , Tp2, Tp3, Tp4 correspond to time phases 1–4 respectively. C1, C2, C3, and C4 correspond to Conditions 1–4 respectively. J1 Peak denotes the counter movement vertical jump at baseline producing the greatest vertical height.

Discussion

The current study highlighted a number of differences concerning WBLFVs ability to induce PAP or PAD, resulting in either improvements or decrements in CMVJ parameters.

There were no significant differences in CMVJ height (cm) between conditions; however, when looking at %Δ, C4 and C3 were significantly greater than C1 at J3 (180 seconds post-WBLFV). This suggests the higher WBLFV frequency condition produced significantly more PAP than a lower frequency protocol for 30 continuous seconds. Both 50-Hz conditions also saw a 2% improvement in CMVJ height post-WBLFV, the key difference, a nonsignificant PAD (−1.27%) at J2 for C4 and PAP for C3 (+0.81%) at the same time point. The initial drop in jump height seen with C4 suggests fatigue initially predominated over PAP, but then dissipated by the 3-minute mark allowing PAP to dominate. Because maximal height jumped during CMVJs is heavily dependent upon peak velocity (V_{max}) at take-off, C3 and C4 would appear to have the strongest effect upon V_{max}. A direct measure of peak velocity (V_{max}) was not recorded; however, a direct recording of V_{av} did indicate a significant %Δ at Jump 6 (8.5 minutes post-WBLFV). V_{max} and V_{av}, although related, effect maximal maximum jump height differently, the former having the greatest impact (5–7,9,12,14,20,21,23,26,29,30,32,34,38,40, 42–44). Cormie et al. (14) reported an increase in CMVJ height immediately after 30 seconds of continuous WBLFV at 30 Hz (low amplitude) using PowerPlate. This would agree with Adams et al. (3) who suggested that lower frequencies work more effectively with lower amplitudes.

Potentially, during the current study, higher 1a afferent discharge rates were elicited using the higher WBLFV frequency, thus potentiating CMVJ height 3 minutes post-WBLFV. Supercompensation within the stretch and H-reflexes may have increased excitability of alpha motor neurons innervating predominantly type 2 muscle fibers. This would agree with the results of Armstrong et al. (4) who showed H-reflex depression during the first minute post-WBLFV exposure (40 Hz, 2- to 4-mm peak–peak amplitude, Powerplate) followed by recovery and facilitation of the H-reflex for some subjects. Such a depression at the 1-minute post-WBLFV mark during the current study for C4 may have been a result of initial H-reflex depression. Also, higher threshold motor units may have been "activated" at lower relative frequencies during WBLFV exposure facilitating the rate of force development and neuromuscular efficiency (1,2,11,12, 15,19–23,27,38,41,43). The lack of H-reflex PAP reported by Hopkins et al. (24) may be been because of the nature of the protocol used, which consisted of 5, 1-minute exposures at 26 Hz using a Galileo platform. Such a protocol may have been too long in terms of total WBLFV exposure leading to no significant performance enhancement. The depression then facilitation in CMVJ height seen during the current study may be correlated with H-reflex depression than recovery; however, because no H-reflex recordings were taken, this is only speculation.

Cardinale et al. (10) showed EMG root mean square (RMS) from the Vastus Lateralis to be greatest during WBLFV at 30 Hz. Although 50 Hz was shown in the same study to reduce average RMS, after removal, and recovery to allow for "supercompensation," the 50-Hz condition could potentiate the simple stretch reflex (and muscle activation) and increase synchronization of higher threshold motor units leading to increased rates of force development (1,2,11,12,15,19–22,27,38,41,43). Hazell et al. (23) recorded EMG RMS activity during dynamic unloaded squats while receiving WBLFV ranging from 20 to 45 Hz. Electromyographic activity increased with increasing frequency, with the 45-Hz condition producing the greatest average RMS.

Electrical stimulation studies attempting to increase twitch force and rates of force development typically show reduced high-frequency force after maximal tetanic contractions up to 10 seconds. (9,19,21,24). However, upregulation in dynamic rates of force development at higher frequencies are seen, which suggests the higher WBLFV 50-Hz frequency and intermittent application may lead to preferential activation and synchronization of high-threshold motor units (1,2,11,17,19,22,41,45). Such synchronization coupled with increased MLC phosphorylation rates could "add" to reflex

potentiation, leading to PAP of rates of force development (17,22,24,33,34,45).

Resistance training studies report peak PAP effects within the first 3–8 minutes poststimulus, agreeing with the current study. Because PAP and fatigue initially coexist, fatigue may at first predominate, and then dissipate allowing PAP to provide a small, significant (1–3%) performance effect (12,19–22,31, 38,41,43,45). Bove at al. (8) reported that the H-reflex might take at least 100 seconds to recover after vibration exposure. This, coupled with potential neural, metabolic, and low-frequency fatigue could explain why previous 'doses' of WBLFV have failed to produce PAP. Also, exposure times used during acute WBLFV studies vary but are typically between 30 seconds and 1 minute (5,6,9,13,17,18,33,35,37, 38,41). This coupled with multiple exposures, with short rest periods between, and then before ballistic SSC tasks could result in fatigue predominating over PAP. No more than 30 continuous seconds of WBLFV exposure was used during the current study in an attempt to minimize such fatigue states and to prevent potential disruption to proprioceptive function. Jump height remained elevated above baseline for C3 for 8.5 minutes post-WBLFV during the current study, a time frame that could be practically manipulated by coaches to impact performance.

No significant differences were seen between conditions for P_{max} (Sayers nomogram for peak power). The greatest actual %Δ was seen for C4 at J3 (+1.0%), which was similar to C3 (+0.94%), with both 30-Hz protocols producing trends toward PAD at this time point (C1: −1.12% and C2: −0.70%). No significant between condition differences were seen for P_{max} kg^{-1}, although, C4 and C3 potentiated jump height more than C1, but not C2 at J3. Trends were seen for all conditions to recover from the end of one series to the beginning of the next with the largest relative drop in performance for all conditions between J7 and J8. The 5-minute rest period between these 2 jumps appeared to diminish the WBLFV effect. Condition 2 was the least responsive over the 17-minute period, resulting in a trend toward PAD across 8 of the 9 jumps. A lack of; reflexive upregulation and fatigue resistance that occurred with this WBLFV condition may have led to PAD seen from J5 onward.

A Tri-planar vibration platform was used in the current study, but the majority of the WBLFV was within the Z-plane. Using a similar plate, Adams et al. (3) reported a 2% Δ for P_{max} 1 minute post-WBLFV at 50 Hz and high amplitude. This is a slightly larger increase in magnitude for P_{max} than that seen during the current study (1%; C4). Of interest, the time point post-WBLFV exposure at which P_{max} occurred differed between studies (1 minute post-WBLFV vs. 3 minutes post-WBLFV). Because the first post WBLFV CMVJ was not performed until 2 minutes post during the current study, direct comparison cannot be made at the 1 minute post-WBLFV time point. However, significant PAD was seen for C4 at the 2-minute post-WBLFV followed by a "supercompensation" resulting in nonsignificant PAP at the 3-minute post-WBLFV mark. Condition 3 did not see PAD at the 2-minute post-WBLFV but saw nonsignificant PAP of 0.25%. Such a condition is similar to that used by Adams et al. (3) but produced less of an acute facilitation of P_{max}. Larger relative increases in P_{av} during CMVJs (4.4%) were reported by Ronnestad et al. (40) while applying WBLFV during CMVJs for untrained subjects but not in trained subjects, prompting the authors to suggest reflex activity during SSC had already been "fine tuned" by chronic resistance exercise.

The vibration plate used by Bosco et al. (6,7) pivoted about a central axis, providing a medial–lateral "wobble" WBLFV stimulus. A greater relative increase was seen (12% increase P_{max} $p < 0.05$) during a continuous 5-jump test suggesting a high level of musculotendinous stiffness was produced by WBLFV. This may have had a greater impact on continuous SSCs using faster amortization phases than standard CMVJs. The amortization phase of a standard CMVJ is considerably longer than (268–300 ms vs. 50–100 ms [40]) than "reactive" touch and go depth jumps relying more heavily upon "short latency" (60 ms ≤) reflex potentiation. However, previous work from this author's laboratory (29,30) has shown PAD after WBLFV at 50 × 3 × 10 for depth jumps (DJs) suggesting reflex inhibition. Potentially, the WBLFV "dose" used during these studies by Lamont et al. (29,30) led to presynaptic inhibition at type 1a afferents, and GTO, type 1b–mediated force reduction, resulting in disrupted SSC dynamics. The CMVJ and DJ are on a continuum in terms of SSC use, and have differing requirements regards short (M1) and medium reflex loop (M2, M3) use (8,35,45). Potentially, longer rest periods should be used between WBLFV exposures and plyometric type movements using "fast" SSCs, to allow for sufficient short latency reflex loop recovery and subsequent super compensation. Alternatively, reducing the WBLFV frequency by 5–10 Hz may prove beneficial.

Measures of P_{av} revealed C4 was more effective than C3 and C1 but similar to C2. Practically, these data suggest if increased P_{av} is of interest, an intermittent protocol at 50 Hz and high amplitude may be more effective than a continuous protocol at 50 Hz. The very strong trend toward statistical significance ($p = 0.059$) with C4, 3 minutes post-WBLFV P_{av} (3. 77%) compared with C2 suggests practical merit for C4. As with other CMVJ measures, C2 did not provide a sufficient enough neuromuscular stimulus to see any PAP.

Rhea et al. (36) reported a 5.2% increase in P_{av} during a back squat exercise after WBLFV at 30 Hz using the itonic WBLFV platform. Ronnestad et al. (40) reported a 4.4% increase in CMVJ P_{av} within previously untrained subjects applying WBLFV during CMVJs at varying loads using Powerplate. The %Δ seen during the current study for P_{av} of 3.77% at 3 minutes post-WBLFV is of a slightly lower magnitude than that reported by Ronnestad et al. (40) using a similar high frequency. The mode of application was different however (WBLFV applied during CMVJ vs. WBLFV applied before CMVJs) with concurrently applied WBLFV

facilitating CMVJ performance during their performance, and WBLFV applied before leading to an improvement in performance 3 minutes after WBLFV exposure. The former could be classified as concurrent potentiation (CP) with the latter PAP. Both would seem to have merit but CP may eventually lead to a greater degree of fatigue if multiple CMVJs are performed. Comparative studies looking at the residual effects of CP during CMVJs vs. PAP based acute WBLFV before CMVJ'S may prove valuable.

Analysis of V_{av} data revealed C4, J6 was greater than C2 and C3 at the same time point, with similar trends for %Δ. Condition 4 produced the greatest average %Δ at Jump 6 (8:30 minutes; 2.64%). Because V_{av} reached a peak potentiated state later than CMVJ height, but remained elevated for a greater time period, it would appear that V_{av} and V_{max} are affected differently by WBLFV.

From a neuromuscular perspective, P_{av}, V_{av}, and P_{max}, V_{max} may be affected by differing mechanisms; the former dependent upon high motor unit recruitment and discharge throughout an entire movement, the latter, by high motor unit recruitment, synchronization before ballistic tasks, and peak discharge rates during the point of the task were muscle length and muscle stiffness are optimized.

The results from the current study agree with others with regards to facilitation of CMVJ height, but differ slightly in terms of the protocol used, and the magnitude of the WBLFV effect (3,6,7,9,10,14,26,30,33,40). There does appear to be merit to using 50 Hz and high amplitude in conjunction with intermittent application because this protocol was more effective than 30-Hz protocols for potentiating CMVJ height (%Δ cm), and V_{av}. The differing patterns seen between conditions suggest amplitude (high peak–peak 4–6 mm) and exposure (30 seconds continuous or intermittent) affected the resultant outcomes. Further, the intermittent protocol from the current investigation (50 Hz with 3 exposures of 10 seconds) may have helped reduce the ratio of Fatigue:PAP leading to an increased likelihood of CMVJ facilitation, and may have lessened; metabolic fatigue, depletion of localized adenosine triphosphate-creatine phosphate (ATP-CP) stores, and reduced Lactate and Hydrogen ion production and accumulation. Because the current study was cross sectional and not a training study,-only acute responses can be talked about with any real authority; however, there does seem to be some merit to acutely applying a similar dose of WBLFV (50 Hz × 3 exposures × 10 seconds, 1 minute between exposures) between sets of resistance exercise (29,30).

More acute studies are needed to delineate the most appropriate, and "least effective dose" of WBLFV based upon gender, training status, muscle fiber composition, and fatigue state for performance improvements, while minimizing injury potential. Also comparative studies looking at MVC and heavy dynamic constant external resistance vs. WBLFV-based PAP protocols and combinations of the 2 (MVC + concurrent WBLFV application) are needed.

Practical Applications

Much debate still surrounds the use of WBLFV for acute performance enhancement with potential performance decrements and increased injury potential seen when such technology is used inappropriately. Being able to apply the most appropriate "dose" of WBLFV before high-powered ballistic performance and then being able to modify such a dose would be valuable to the strength and Conditioning coach. Using the "least effective dose" for performance enhancement while reducing injury potential would seem appropriate. Having WBLFV platforms at hand within the "warm up area" before sporting events would allow athletes to perform a specific warm-up that is easy, convenient and less time consuming than traditional PAP warm-up routines. However, the resultant PAP produced may not be as great as that seen using more traditional routines. Acute improvements in P_{av} and V_{av} may be more specific to heavy load, nonballistic resistance exercises such as squats, deadlifts, and bench presses, with P_{max} more specific to Olympic lifts, jump height, striking power (punches and kicks), baseball, golf swings, and maximal throwing distance.

When attempting to elicit acute improvements, using a higher frequency (50 Hz), after appropriate warm up when the athlete is "fresh" may produce the greatest PAP. This may be especially helpful during high-powered ballistic and semiballistic movements were P_{max}, high dynamic rate of force development (RFD), and high V_{max} are required. Potentiation of P_{av} and V_{av} may be beneficial before, and between sets of heavy load, nonballistic movements using frequencies between 30 and 50 Hz.An intermittent WBLFV protocol may decrease the ratio of Fatigue:PAP while allowing for stretch reflex "supercompensation" between exposures. If a sport requires maintenance of high-powered SSC actions over a longer duration (football and basketball), a second or third application (or more) of WBLFV may still produce PAP. However, caution should be exercised in an attempt to minimize accumulated fatigue from multiple exposures, and to account for increased; fatigue and subsequent injury potential the longer a game continues by modifying the WBLFV dose. If using multiple exposures, dropping down to as little as 5 seconds may still facilitate SSC performance while decreasing fatigue and injury potential. Further modification of the frequency (going from higher to lower), amplitude (moving from high to low) and timing between exposures (increasing time between exposures) may be manipulated by Strength and Conditioning Coaches based upon known performance characteristics and perceived fatigue state of individual athletes. Athletes anaerobically trained, possessing a higher ratio of type 2: Type 1 muscle fibers and low fatigue resistance may respond more favorably to higher WBLFV frequencies initially, but then have to reduce frequency at greater rates than athletes possessing a higher ratio of type 1: type 2 muscle fibers and greater fatigue resistance.

The less well trained, or those previously not exposed to WBLFV may benefit from periodizing the WBLFV "dose," starting at lower frequencies and amplitudes, then increasing frequency and amplitude while decreasing exposure time. Such a gradual increase in WBLFV intensity may facilitate acute adaptations to WBLFV.

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