Displacement and Frequency for Maximizing Power Output Resulting From A Bout of Whole-Body Vibration

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Abstract

Bedient, AM, Adams, JB, Edwards, DA, Serravite, DH, Huntsman, E, Mow, SE, Roos, BA, and Signorile, JF. Displacement and frequency for maximizing power output resulting from a bout of whole-body vibration. *J Strength Cond Res* 23(6): 1683–1687, 2009—Whole-body vibration (WBV) has been shown to be effective for increasing lower-body power; however, the combination of frequency, displacement, and duration that elicits the best acute response has yet to be determined. The purpose of this study was to identify the protocol eliciting the greatest improvement in power after an acute bout of WBV. Forty men and women participated in this study, in which 8 different combinations of 30, 35, 40, and 50 Hz with 2-mm and 5-mm displacements were tested over 3 days. For all protocols, randomized to reduce potential order effects, subjects underwent 30 seconds of WBV while holding an isometric squat at a knee angle of 2.27 rad. Power was assessed by countermovement jumps. Subjects performed 3 jumps before WBV, immediately afterward, and 1, 5, and 10 minutes later. The highest normalized peak power (nPP) at each time point was determined using a 4 (frequency) $\times$ 2 (displacement) $\times$ 5 (time) repeated-measures analysis of variance. Significant effects were seen for frequency ($p \leq 0.026$) and time ($p \leq .0001$). Post hoc analyses revealed that the 30-Hz condition (1.010 $\pm$ 0.003) produced a higher nPP than 35 Hz (1.00 $\pm$ 0.003, $p \leq 0.026$) and 40 Hz (1.002 $\pm$ 0.002, $p \leq 0.028$) but not 50 Hz (1.004 $\pm$ .002). We also found a significantly higher nPP for the 1-minute post-treatment time point (1.011 $\pm$ .0003) vs. all other time points ($p \leq 0.006$). Our data show that an acute WBV bout can significantly increase power output at 1 minute post-treatment across all frequencies and displacements, although 30 Hz appears to have a greater effect on power output than either 35 Hz or 40 Hz, but not 50 Hz, at all post-treatment time points.

Key Words countermovement jump, acute peak power effects, triplanar plate

Introduction

The pressure to maximize fitness and performance in the shortest possible time has driven athletes and nonathletes alike to seek more efficient ways to achieve their goals. Whole-body vibration (WBV) training has been shown to be an effective method for increasing upper- and lower-body power output in both populations and continues to be studied by sports performance and health researchers as a potentially important fitness intervention (6,7,8,12,15,18).

WBV can provide a number of benefits that enhance or even supersede traditional power training methods. For athletes, WBV may provide a less time-consuming alternative to weight training or plyometrics, with lower levels of perceived exertion and tissue damage. WBV may also be an effective training tool during the low-intensity microcycle and taper periods commonly included in a periodization plan. Because WBV provides results comparable with more traditional training methods with a shorter time commitment and lower perceived exertion, it may also provide an environment that improves fitness and exercise compliance in the general population (8,9,12).

A number of studies have demonstrated the positive effects of WBV on power production (6,7,8,12,15,18), whereas others have reported either a decline (14) or no impact (6,7). The disparity in results among these studies may be partly caused by the different WBV devices used or variations in training protocols, including differences in duration, frequency, and amplitude. The 3 types of WBV devices currently being marketed are triplanar, vertical displacement, and centrally

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pivoting platforms. In triplanar devices, the vibration is applied in anterior/posterior, lateral, and vertical directions. Vertical displacement devices move in an up-and-down motion; centrally pivoting devices, as the name implies, tilt on a central axis. In addition, training protocols differ among WBV studies, in which treatment durations may range from 30 seconds to 4 minutes (4,6,7,18), with frequencies from 20 Hz to 50 Hz (4,6,7,10,16,18) and amplitudes from 2 mm to 10 mm (4,7,10,18).

The objective of this study was to expand on our earlier work, which examined WBV protocols for the purpose of eliciting improvement in power performance after a single exposure on a triplanar plate (1). To our knowledge, no work, other than our earlier study, has examined the frequency, displacement, and work-recovery duty cycle that would maximize power production using this type of WBV device.

Methods

Experimental Approach to the Problem

Because the use of WBV as a training intervention is becoming more common among competitive and recreational athletes, fitness enthusiasts, and clinical populations, the optimal application of frequency, displacement, and duration to WBV device exercise prescription is a key question. Therefore, a repeated-measures analysis of variance (ANOVA) was used to assess the impact differences in frequency, displacement, and length of time interactions on peak power after WBV exercise.

Subjects

Twenty men and women volunteered to participate in this study. All subjects were moderately trained recreational athletes. No athlete was in a competitive stage of training during the study. Exclusion criteria included any chronic medical condition or medications that could affect skeletal muscle performance and any contraindications to WBV use. Contraindications included unhealed fresh wounds, serious heart or vascular disease, recent hip or knee replacement, pregnancy, acute hernia, discopathy, spondylolysis, severe diabetes, epilepsy, tumors, acute inflammation, acute migraine, pacemaker, recently placed IUD, or fixation devices such as metal pins, bolts, or plates. This study was approved by the Subcommittee for the Use and Protection of Human Subjects at the University of Miami, and all subjects provided written consent before participating. Subject characteristics are presented in Table 1.

Procedures

The present study expands on data from an earlier pilot study that examined optimization of WBV protocols to increase power in individuals between 20 and 40 years old (1). In the pilot study, we examined all possible combinations of frequencies (30, 35, 40, and 50 Hz) and amplitudes (2–4 mm or 4–6 mm) and durations (30, 45, or 60 s) available on the Power Plate device (Power Plate North America, Inc., Northbrook, IL) (1). To examine all combinations, the subjects attended a total of 24 sessions, each separated by a 24-hour recovery period. Analysis of the data from this preliminary study showed no significant differences in power output as caused by the duration of WBV; however, we did note a significant frequency x displacement interaction. The power normalized to each person's pretest jump score (nPP) was highest for the low displacement condition at lower frequencies and the high displacement condition at high frequencies (1). Given these results, the current study was designed to increase the sample size by 20 subjects. Because there were no differences among training durations in our preliminary study and the greatest increases in power were attained with a 30-second duration, all testing was performed with the duration of 30 seconds. All other factors, including recruitment methods, testing patterns, and recovery intervals, were the same as used in the initial study. Because we needed to look at only 1 training duration, the number of testing conditions was reduced from 24 to 8.

Before testing, we randomized the protocols for each subject to minimize the potential for an order effect. Each subject visited the laboratory 4 times. During the first visit, subjects completed a health status questionnaire to confirm study eligibility. If inclusion criteria were met, procedures and risks were thoroughly explained, and a written informed consent was obtained. This visit was also a familiarization session for the subject with WBV platform use. He or she stood on the plate in a half-squat position with knees held at a 2.27 rad angle. Exposure time was 30 seconds at a frequency of 30 Hz and low displacement. Subjects were also introduced

Table 1. Subject characteristics.

	Age (yr)	Height (m)	Weight (kg)	BMI ($kg \cdot m^2$)
Sample	26.90 ± 5.32	1.73 ± 0.10	74.07 ± 17.58	24.61 ± 4.14
Women	25.95 ± 4.15	1.66 ± 0.07	62.38 ± 9.34	22.49 ± 2.51
Men	28.06 ± 6.41	1.80 ± 0.07	88.37 ± 14.42	27.21 ± 4.31

*BMI = body mass index.

to the hands-on-hips countermovement jump (CMJ) used to assess power.

On each subsequent testing day, subjects completed either 2 or 3 treatment protocols. This arrangement was necessary because of the odd number of testing days and even number of protocols. Subjects were instructed to refrain from training for 24 hours before a session, and all sessions were preceded by a 5-minute warm-up on a cycle ergometer at 50 watts. The protocols lasted 30 seconds and used either a high or low displacement and a frequency of 30, 35, 40, or 50 Hz. The decision about a subject performing 2 or 3 protocols on a given test day was made during the initial randomization process.

During all sessions, subjects were instructed to perform an isometric half-squat with feet shoulder-width apart. Knee angle was set at 2.27 rad using a handheld goniometer.

The impact of each WBV protocol on peak leg power was assessed using a CMJ (5,13). The CMJ test began with feet shoulder-width apart, hands on hips, and knees held at a 2.27 rad angle. Subjects were instructed to keep hand position constant and encouraged to give maximal effort for each jump. On hearing the word "go," the subject performed 3 jumps, with a slight delay between jumps to reduce the potential impact of stored elastic energy from the previous jump. All jumps were performed on a pressure-sensitive mat interfaced with a laboratory computer containing an assessment program (Axon Bioingeneria Deportiva, version 2.01, 2005). The program uses time off the mat to compute jump height. We selected the CMJ because it measures the combined effects of contractile, neural, and elastic elements, each of which could have adapted acutely to the WBV stimulus. Pearson correlation analysis yielded significant correlations between trials within any day ranging from $r = 0.913$ to 0.999 ($p < 0.01$). The Pearson correlation analysis across days within any trial yielded values ranging from $r = 0.946$ to 0.985 ($p < 0.01$). In addition, the *SEM* across trials within a day was 1.363 cm and across days was 1.564 cm.

Power for the 3 jumps was computed using the formula presented by Sayers et al. (17),

$$\text{PP (W)} = 51.9 \times \text{CMJ height (cm)} + 48.9 \times \text{BM (kg)} - 2007$$

where,

PP = peakpower

BM = bodymass

This formula is specific to the CMJ and has been used successfully to compute power for the hands-on-hips jump technique used in our study (5). The highest of the 3 recorded jump heights was selected to calculate the power values for statistical analysis.

Because the effects of WBV are extremely time sensitive (3,7,18), CMJ data were collected immediately after and at 1 minute, 5 minutes, and 10 minutes after each WBV bout. Subjects were instructed to remain seated after each CMJ. This procedure allowed comparison of changes in response level for each protocol over time.

Statistical Analyses

The response variable for this study was the peak leg power achieved by the subject. Peak power scores were normalized as a percentage of each subject's pretest jump score (nPP) according to the method of Cormie et al. (7) to account for intersubject variability. This step was necessary because our subjects comprised men and women of varying athletic abilities.

A repeated-measures ANOVA was used to assess the impact on nPP of frequency, displacement, and length of time after WBV. The criterion alpha level was set at $p \leq 0.05$. Bonferroni tests for multiple comparisons were used for all post hoc analyses.

From our initial study examining the impacts of frequency and displacement on power output (1), the power was estimated to be .996. This power exceeded the traditionally accepted criteria of .8, and thus there was no requirement to increase our sample size; however, we decided to add another 20 subjects to substantiate our previous results.

Results

Repeated-measures analyses of the jump height data revealed a significant main effect for frequency ($p \leq 0.026$) and time

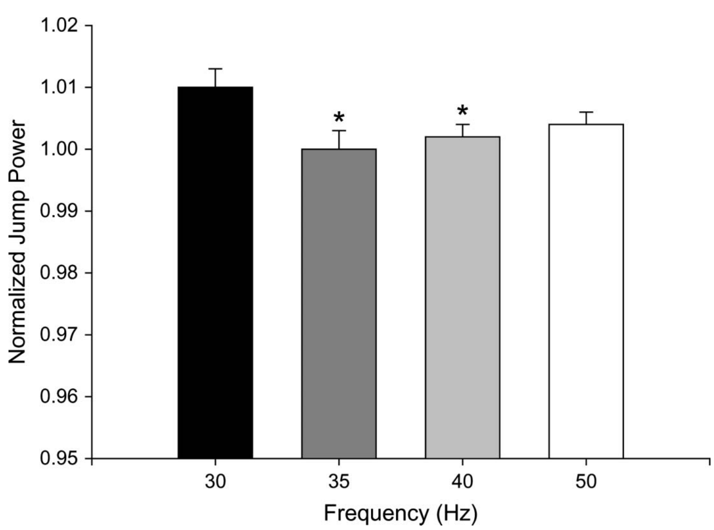

Figure 1. Changes in countermovement jump (CMJ) normalized peak power caused by frequency. *Significantly less than the 30 Hz condition.

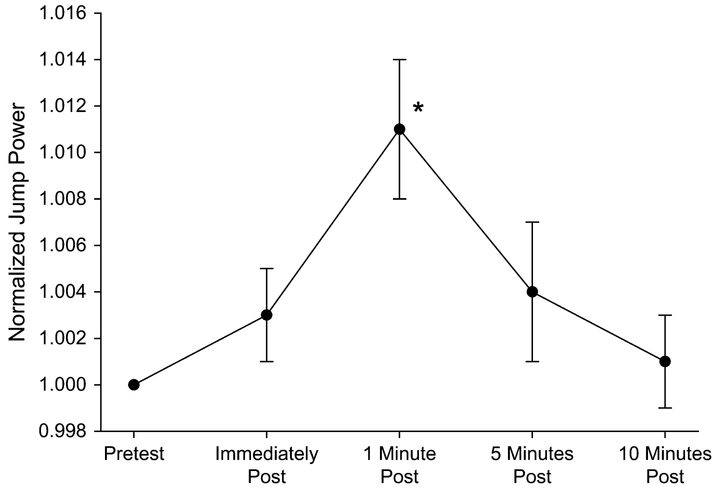

Figure 2. Changes in countermovement jump (CMJ) peak power over time, normalized to baseline values. *Significantly different from all other time points ($p < 0.006$).

($p \leq 0.0001$). Post hoc analysis of frequency demonstrated significantly higher nPP after the 30 Hz condition compared with the 35 Hz ($p \leq 0.026$) and 40 Hz ($p \leq 0.028$) conditions (Figure 1). Post hoc analysis for time revealed a significantly higher value at 1 minute post-treatment compared with all other time points including the pretest ($p \leq 0.0001$), immediately post-test ($p \leq 0.001$), and the 5-minute post- ($p \leq 0.006$) and 10-minute post- ($p \leq 0.0001$) time points (Figure 2).

Discussion

The first major finding of our study was that the 30 Hz condition produced significantly higher nPP improvements than either the 35 Hz or 40 Hz condition, but not the 50 Hz condition, regardless of displacement. The results indicating that 30 Hz produced a significantly greater nPP than 35 or 40 Hz, but not 50 Hz, regardless of displacement, differs slightly from the results of our original study, which found a significant frequency x displacement interaction (1). In that study, the 50 Hz condition produced a significantly higher nPP than all others at a 5-mm to 6-mm displacement, and the 30 Hz condition produced a significantly higher nPP at a 2-mm to 3-mm displacement. The fact that no significant difference was found between the 30 Hz and 50 Hz conditions supports our initial finding of their efficacy compared with the 35 Hz and 40 Hz conditions when using WBV to enhance power performance.

Our findings are partially supported by the results of Cormie et al. (7), who found that applying 2.5-mm displacement at 30 Hz significantly increased normalized CMJ height after 30 seconds on the Power Plate WBV unit. Our results conflict with those of Bazett-Jones et al. (2), who reported a significant increase in jump height for their female subjects using 40 Hz at a 2-mm to 4-mm displacement and 50 Hz at a 4-mm to 6-mm displacement. They also reported no significant increase in jump heights in males after bouts at 30 Hz and 40 Hz and 2 mm to 4 mm or 35 Hz and 50 Hz at 4 mm to 6 mm. The differences seen between our results and those of Bazett-Jones and colleagues may be attributable to several factors. First, Bazett-Jones et al. divided their sample by sex and showed a significant sex-by-intervention interaction. Our data reflect the combined results of the men and women who participated in our study. Second, the conditions used by Bazett-Jones et al. did not include a high amplitude for the 30 Hz condition, which if it had been included in their analysis, may have affected their final results. A third factor is the 45-second exposure used in their study, rather than the 30-second exposure used for our study. This last possibility, however, is questionable, because our initial study showed no significant difference in CMJ caused by the duration of WBV.

The second major finding of our study was that power performance peaked at 1 minute post-WBV and declined at 5 minutes and 10 minutes post-treatment. These results support our initial finding that an acute bout of WBV led to a transient increase in power that peaked significantly at 1 minute post-treatment and declined by 5 minutes post-treatment. This finding is in partial agreement with the 2 other studies that examined the acute effect of WBV on the Power Plate. Cormie et al. (7) reported a significant increase in CMJ height immediately after a single 30-second bout of WBV performed at 30 Hz and 2 mm to 4 mm. This increase returned to a level below baseline by 5 minutes after WBV. Our results are also similar to those of Bazett-Jones et al. (2), who reported a significant increase in CMJ height that occurred immediately after WBV and lasted 5 minutes. It should be noted that neither of these studies examined the 1-minute post-WBV time point shown to be the most effective in our studies.

It is possible that our results, indicating that the 1-minute time point produced the greatest improvement in CMJ, could have been affected by our testing procedure. At each time point, 3 CMJs were performed. It is possible that the performance of each jump affected subsequent CMJ performance, even though the protocol included a delay. A kinetic analysis of complex training interval effect on vertical jump performance by Jensen and Ebben (11), however, found no significant differences among 5 trials of CMJ performed at 10 seconds, 1 minute, 2 minutes, 3 minutes, and 4 minutes after a set of squats at a 5 repetition maximum load among performances.

Practical Applications

The results of this study contribute to our understanding of effective training prescription during WBV. Our acute results demonstrate the effectiveness of the 30-Hz frequency in improving power performance regardless of displacement. Our data also indicate that maximal athletic performance should occur approximately a minute after the application of WBV. These results may help future researchers and clinicians use WBV to increase lower-body power output acutely. We suggest that future studies continue to examine the potential for a frequency-amplitude match, as shown in our earlier study, and that durations of 0 and 1 minute and 1 and 5 minutes be examined to determine more exactly the point of maximal response after WBV.

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