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Research article

Comparing the effects of various whole-body vibration accelerations on counter-movement jump performance

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Abstract

While it seems that whole body vibration (WBV) might be an effective modality to enhance physical performance, the proper prescription of WBV for performance enhancement remains unknown. The purpose of this study was to compare the immediate effect of various WBV accelerations on counter movement jump (CMJ) height, the duration of any effect, and differences between men and women. Forty-four participants (33 men, 11 women) participated in no less than four CMJ familiarization sessions and completed all vibration sessions. Participants performed a pre-test (three maximal CMJs), followed randomly by one of five WBV accelerations; 1*g* (no-WBV control), 2.16*g*, 2.80*g*, 4.87*g*, and 5.83*g*. Participants performed three maximal CMJs immediately, five, and 10 minutes following each 45 sec WBV session. The mean of the three performances was used and calculated as a percentage of the pre-vibration mean value. A Repeated Measures Analysis of Variance (ANOVA; acceleration x time x gender) model was used to analyze the data. The two-way interactions of acceleration-gender ($p = 0.033$) and time-gender ($p = 0.050$) were significant. Women performed significantly better following the 2.80*g* ($p = 0.0064$) and 5.83*g* ($p = 0.0125$) WBV sessions compared to the 1*g* (control) session. Men, however, did not experience performance enhancing effects following any of the vibration sessions. While significant differences did not occur between time in either gender, the effects of the 45 sec WBV session in women were transient, lasting approximately five minutes. During the prescription of WBV, gender should be considered given that the results of this study seem to indicate that men and women respond differently to WBV. The results of this study suggest that WBV might be a useful modality as applied during the pre-competition warm-up.

Key words: Vertical jump, frequency, amplitude, gender.

Introduction

Whole-body vibration (WBV), at low frequencies and low amplitudes, has been reported to be a safe and effective method to improve athletic performance (Cardinale and Bosco, 2003; Cardinale and Wakeling, 2005). Specifically, exposure to WBV has been shown to increase performance in the vertical jump (Bosco et al., 2000; Cardinale and Lim, 2003a; Cochrane and Stannard, 2005; Cormie et al., 2006; Torvinen et al., 2002a). However, it appears that the effects of WBV exposure on performance might be dependent on characteristics (amplitude, frequency, acceleration magnitude) of the exposure (Luo et al., 2005). The combination of the amplitude and frequency determines the acceleration magnitude of vibration (Cardinale and Bosco, 2003; Issurin, 2005; Luo et al., 2005), measured in *g*s, where one *g* is the acceleration due to gravity ($1g = 9.81\ \text{m}\cdot\text{s}^{-2}$). Since most WBV platforms allow for multiple settings of amplitude and frequency, there are many possible combinations and resulting accelerations. In addition, vibration training protocols (duration, volume, and rest time) also differ in the literature, ranging from a single, 30 sec WBV exposure (Cormie et al., 2006) to 10 minutes of WBV spaced over 16 minutes (Bosco et al., 2000). Lastly, few studies (Torvinen et al., 2002a; 2002b) have compared the immediate effects of WBV on men versus women to examine gender differences, reporting no differences between gender. The variety of different training and experimental protocols found in the literature makes it difficult to determine the optimal WBV acceleration and the mechanisms leading to enhanced performance.

There seems to be some debate as to the mechanism by which WBV enhances performance. The most commonly cited mechanism is augmented neuromuscular activation via the tonic vibration reflex (TVR; Nordlund and Thorstensson, 2007), which was initially proposed by Eklund and Hagbarth (1966) as the result of a vibration exposure applied directly to the tendon. However, the connection between WBV and the TVR has not been fully discussed or demonstrated in the literature (Nordlund and Thorstensson, 2007). Others have proposed mechanisms of increased muscle temperature and blood flow (Issurin and Tenenbaum, 1999), change of perception by vibration (Liebermann and Issurin, 1997), and increase hormone secretion (Cardinale and Bosco, 2003). Though TVR is the most referenced mechanism, there is not a clear consensus in the literature (Luo et al., 2005).

Many studies have shown performance increases; however, they all differ in the exposure by which these were elicited. Bosco et al. (2000) used a WBV session consisting of 10, 60 sec exposures, with 60 sec rest between, and an additional six minutes of rest after the fifth exposure, resulting in an enhancement of counter-movement jump (CMJ) height. In a study by Torvinen et al. (2002a), a 2.5% improvement in vertical jump height at two minutes following vibration was found using a four-minute WBV session (four, one minute intervals with one minute rest). No improvements in performance were found in a study of the same design (Torvinen et al., 2002b), with the only difference between the studies being the vibration amplitude (4 mm [Torvinen et al., 2002a] vs. 1 mm [Torvinen et al., 2002b]). While Torvinen et al. (2002a) demonstrated that an increase in WBV amplitude corresponded with improved performance, others hypothesized that the most important variable for determining the vibration effect might be frequency

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(Griffin, 1996; Jordan et al., 2005). Cardinale and Lim (2003a) compared the effects of 20 Hz and 40 Hz WBV frequency (4 mm amplitude, five minutes) on squat jump (SJ) and CMJ performance. A 4% increase in SJ at 20 Hz was observed, while decrements in SJ and CMJ were associated with the 40 Hz stimulus. Cochrane and Stannard (2005) used five minutes of 26 Hz, 6 mm WBV to enhance CMJ height by 8.1%. Most recently, Cormie et al. (2006) found a small (0.7%) but significant ($p<0.05$) increase in CMJ height after only a single WBV bout (30 Hz, 2.5mm) of 30 sec. While it seems that WBV might be an effective modality to enhance performance (0.7% to 8.1%), the inconsistency in experimental protocols within the current published studies makes comparison of study outcomes difficult and consequently, the proper prescription of WBV and its mechanisms remain unknown. Previous studies vary widely in frequency (15-65 Hz), amplitude (<1-10 mm), and acceleration magnitude (<1*g*-15*g*; Cardinale and Wakeling, 2005), possibly leading to the inconsistent results in performance and making it difficult to identify the most effective vibration prescription. Without correct recommendations (frequency, amplitude, magnitude, and duration), WBV over-exposure could lead to injury (Jordan et al., 2005) and insignificant exposure may not elicit sufficient warm-up effects. Therefore, the purpose of this study was to compare the effect of various WBV accelerations on CMJ height, the duration of any effect, and differences between men and women. It was hypothesized that as the overall WBV acceleration increases, CMJ performance would improve in men and women.

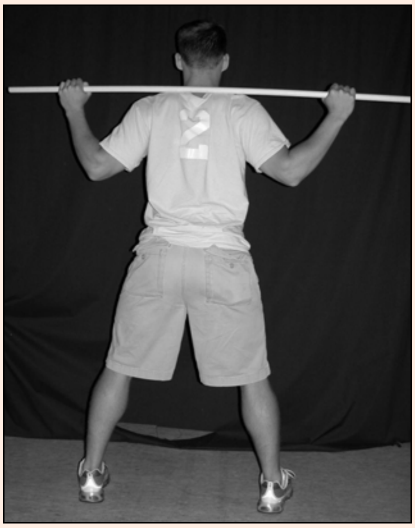

Figure 1. Countermovement jump test position with wooden stick held across shoulders and linear position transducer (not included) connected to the right end.

Methods

Participants

Fifty-eight untrained (mean [±SD] met-minutes/week: overall 4543.6 [5612.5], men 4942.5 [6207.6], women 3657.0 [4001.4] as measured by the International Physical Activity Questionnaire) participants (40 men, 18 women) were recruited for this study. The participants' characteristics were as follows: men (age 20.2 ± 2.1 years, height 1.79 ± 0.07 m, body mass 74.5 ± 11.8 kg); women (age 18.8 ± 1.0 years, height 1.64 ± 0.08 m, body mass 58.7 ± 7.3 kg). Men and women differed significantly in height ($p < 0.001$) and body mass ($p < 0.001$). The Institutional Review Board for the Protection of Human Subjects approved this study and participants were consented prior to their enrollment.

Familiarization sessions

All participants performed a five-minute warm-up on a cycle ergometer at a self-selected, moderate pace, followed by two practice CMJs. All CMJ tests were performed with a linear position transducer (LPT; PT5A, Celesco Transducer Products Inc., Chatsworth, CA USA) secured to the floor and connected to the right end of a wooden stick that the participants held across their shoulders (Figure 1). The position and set-up of the LPT was used to avoid contribution of the arms and did not seem to affect CMJ performance, as observed subjectively by the researchers. A sampling rate of 1000 Hz was utilized in conjunction with the Ballistic Measurement System (Innervations, Joondalup, WA 6027 Australia) for data collection. During the practice jumps, participants were familiarized with the position of the stick and LPT to become comfortable performing the tests. Participants were instructed to squat down to a comfortable depth and then to jump for maximal vertical height. The participants then performed nine maximal jumps with 10-15 sec between attempts. Each day following the initial familiarization session, for at least four days total, participants performed the same familiarization testing sequence. While familiarization sessions might not be necessary for CMJ measures in physically active men (Moir et al., 2004), a benchmark was used due to the inexperienced nature of the participants. If the participant's average height for the jumps on day four was within ±5% of the average of the previous two days (day one was excluded) they were allowed to begin the vibration protocol, otherwise participants continued with familiarization until this benchmark was met. Participants took an average of 4.91 (±1.27) days to complete familiarization. Intraclass correlation coefficients (ICC) suggested a consistent ability to replicate jump height between day two and three ($r = 0.94$ for men and $r = 0.96$ for women) and between days three and four ($r = 0.93$ for men and $r = 0.93$ for women). Descriptive statistics for familiarization days are presented in Table 1. Three participants (one man, two women), who did not reach this benchmark, were excused from the study. Participants who met this benchmark began the vibration sessions within three days following their final familiarization session.

Table 1. Jump height (cm) for familiarization sessions by gender. Data are means (±SD).

	Male	Female
Day 1	20.8 (5.20)	13.0 (2.58)
Day 2	21.3 (4.56)	13.2 (2.89)
Day 3	21.3 (4.74)	13.2 (2.35)
Day 4	21.5 (4.65)	13.5 (2.67)

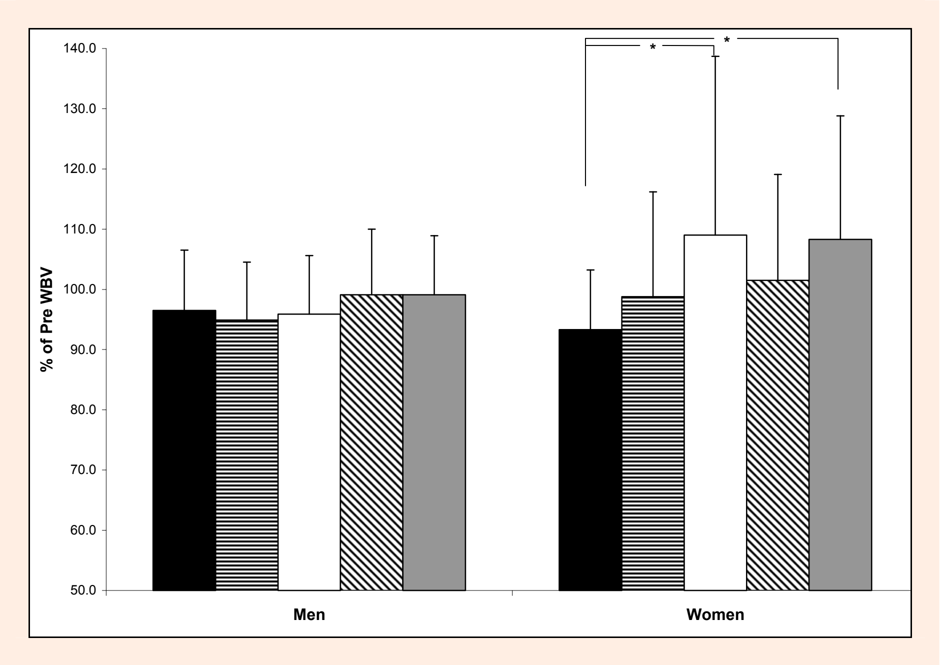

Figure 2. Percent changes of gender and intervention interaction. Black – 1g (Control); Horizontal Striped – 2.18g (30 Hz, 2-4 mm); White – 2.80g (40 Hz, 2-4 mm); Oblique Striped – 4.87g (35 Hz, 4-6 mm); Grey – 5.83g (50 Hz, 4-6 mm). * Significant pairwise differences between interventions.

Testing procedures

During each vibration session, participants again performed a five-minute warm-up on a cycle ergometer, followed by two practice jumps. Following the practice jumps and one minute of rest, they performed three measured maximal CMJs. Participants then rested for one minute before beginning the WBV exposure. After the vibration session, participants again performed three measured maximal CMJs immediately after vibration stimulus and again at five and 10 minutes post-vibration. Similar to the familiarization sessions, all test jumps were performed within 10-15 sec between jumps. Participants rested in a seated position between CMJ tests.

Vibration session procedures

Subsequent to the warm up period described above, participants were exposed to one of five WBV intensities while standing on the commercially available Power Plate® Next Generation WBV platform (Power Plate North America, Northbrook, Illinois). Mean acceleration magnitudes (*g*) of the WBV platform were measured using a Kistler Triaxial Accelerometer (8792A500, Kistler Instrument Corp., Amherst, NY, USA) at a sampling rate of 1000 Hz. The following frequency and amplitude combinations (as defined by the manufacturer's settings) were used to produce the different accelerations (in parentheses), as measured with the accelerometer: 0 Hz, 0 mm (1*g* [Control]); 30 Hz, 2-4 mm (2.16*g*); 40 Hz, 2-4 mm (2.80*g*); 35 Hz, 4-6 mm (4.87*g*); and 50 Hz, 4-6 mm (5.83*g*). The order of vibration application for these intensities was randomized, with at least two days of rest for each participant in between vibration sessions. Participants were blinded as to which frequency and amplitude combination the WBV platform was set at. They performed one squat every five s for 45 sec (nine squats total), to a depth of approximately 90° of knee flexion. Participants were instructed to move through the eccentric portion of the movement for three sec and the concentric portion for two sec. The duration of 45 sec was used in hopes of improving the performance enhancement found by Cormie et al (2006) who used a 30 sec WBV exposure. The dynamic movement during vibration exposure was used because this has not been studied as the sole vibration exercise; it has only been studied as part of more complex vibration sessions (Torvinen et al., 2002a; 2002b; Cochrane and Stannard, 2005). Eleven participants' data (six men, five women) were not used for analysis because all sessions were not completed. No complaints of pain or discomfort were reported by any of the participants during or after the WBV sessions.

Statistical analysis

Forty-four participants' data (33 men, 11 women) were use in the final analysis. Mean performances at zero, five, and 10 minutes post-vibration were calculated as a percentage of the pre-vibration mean values and served as the response variable of interest. A Repeated Measures Analysis of Variance (ANOVA) model was used to analyze the data (SPSS 14.0, Chicago, IL, USA). The ICC values of the pre-vibration results for men (r = 0.86) and women (r = 0.74) suggest that utilizing percentages was a reasonable design to normalize values between men and women, given that significant differences were found in initial CMJ height ($p < 0.001$) between gender. Because Mauchly's test of sphericity was significant at $\alpha = 0.05$ for time by acceleration (p = 0.028), suggesting a lack of sphericity, Wilks' Lambda was used for testing all mean comparisons. Contrasts looking at all Pairwise differences for significant effects were performed using Scheffe's correction to control for the type I error rate. The three

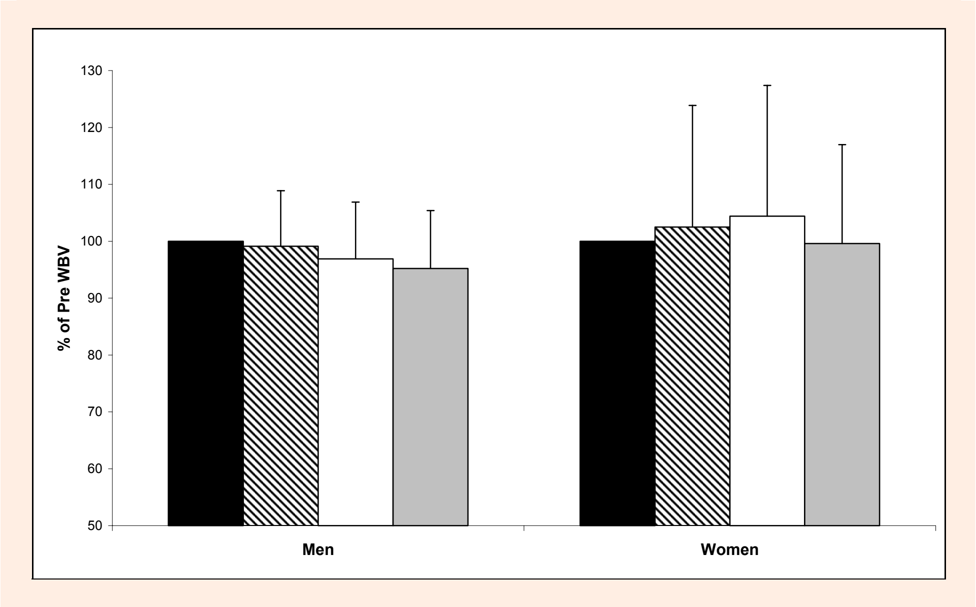

Figure 3. Percent changes of gender and time interaction. Black – Pre WBV; Oblique Striped – Immediately Post WBV; White – Five Minutes Post WBV; Grey – 10 Minutes Post WBV. No significant pairwise differences between times were found.

independent variables were included time (zero min post, five min post, 10 min post), acceleration (1*g*, 2.16*g*, 2.80*g*, 4.87*g*, 5.83*g*), and gender (men, women). Significance was set at $\alpha \leq 0.05$.

Results

The three-way interaction was not significant (p = 0.522, $\omega^2 = 0.17$). A significant two-way interaction was found for time X gender (p = 0.05, $\omega^2 = 0.14$) and acceleration X gender (p = 0.033, $\omega^2 = 0.23$) but not for acceleration X time (p = 0.204, $\omega^2 = 0.25$). Percentage data is presented for these two-way interactions in Figures 2 and 3, respectively, and means and standard deviations are presented for these interactions in Tables 2 and 3. Pairwise analyses using Scheffe's correction demonstrated significant increases in the 2.80*g* (p = 0.0064) and 5.83*g* (p = 0.0125) accelerations compared to the 1*g* (control) acceleration for women. Significant differences were not found between any of the accelerations for men. Similarly, the Pairwise comparisons for time within each gender did not demonstrate any significant differences.

Discussion

The results of this study demonstrate that a short WBV exposure can increase CMJ performance. This enhancement was not seen in men, however, in women the 2.80g and 5.83g WBV accelerations showed significant increases of 9.0% and 8.3 %, respectively, over the control session. Our original hypothesis that increases in WBV accelerations would lead to subsequent (i.e. linear) performance improvements was not supported. It seems that, in the current study, accelerations mattered less than the vibration frequency since the 40 Hz (2.80g, 2-4 mm) and 50 Hz (5.83g; 4-6 mm) vibration sessions demonstrated the greatest performance enhancements. The 30 Hz (1.81g, 2-4mm) and 35 Hz (4.87g, 4-6 mm) vibration sessions did not elicit changes in performance, regardless of acceleration or amplitude. This study does not confirm or deny that the frequency of vibration is the most important vibration characteristic.

The improvement in CMJ performance for the women participants of this study was greater than the improvements reported previously in a study using a similar duration (Cormie et al., 2006), but in a population of resistance trained men. Cormie et al. (2006) used a 30-sec duration with smaller, but significant, increases (0.7%) in vertical jump performance compared to the current study and a frequency-amplitude combination of 30 Hz and 2.5 mm. The current study used a very similar frequency-amplitude combination (2.18g; 30 Hz, 2-4 mm) to Cormie et al. (2006) as one of its WBV accelerations;

Table 2. Jump height for gender and acceleration interaction. Data are means (±SD).

	Male		Female	
	Jump Height (cm)	**% of Pre WBV**	**Jump Height (cm)**	**% of Pre WBV**
1g (0 Hz, 0 mm)	20.6 (5.11)	96.5 (9.9)	12.6 (3.72)	93.3 (9.9)
2.16g (30 Hz, 2-4 mm)	20.7 (4.64)	94.9 (9.6)	12.9 (4.15)	98.8 (17.4)
2.80g (40 Hz, 2-4 mm)	21.0 (4.82)	95.9 (9.7)	13.1 (3.35)	108.9 (29.7)
4.87g (35 Hz, 4-6 mm)	21.2 (5.06)	99.1 (10.9)	12.9 (3.32)	101.5 (17.6)
5.83g (50 Hz, 4-6 mm)	20.9 (4.71)	99.1 (9.8)	12.5 (3.70)	108.3 (20.5)

Table 3. Jump height for gender and time interaction. Data are means (±SD).

	Male		Female	
	Jump Height (cm)	% of Pre WBV	Jump Height (cm)	% of Pre WBV
Pre WBV	21.4 (4.74)	100.0 (0.0)	12.8 (3.62)	100.0 (0.0)
0 Min Post	21.2 (4.96)	99.1 (9.8)	12.8 (3.56)	102.5 (21.4)
5 Min Post	20.7 (4.92)	96.9 (9.9)	13.1 (3.83)	104.4 (23.0)
10 Min Post	20.3 (4.80)	95.3 (10.2)	12.5 (3.60)	99.6 (17.4)

however, a reduction in performance (-5.1% in men and -1.2% in women) was shown following this vibration session. In the men, the sessions of 40 Hz also decreased performance by 4.1%. Since WBV decreased jumping performance in men, it is also possible that the vibration sessions of 30 Hz and 40 Hz used in this study caused fatigue. Cardinale and Lim (2003b) reported that a WBV frequency of 30 Hz (10 mm) elicited the greatest EMGrms values compared to 40 Hz and 50 Hz in professional women volleyball players. However, a significant-difference was not found between the 30 Hz and 40 Hz vibration exposures (Cardinale and Lim, 2003b). While it is possible that fatigue in men is responsible for reduction in performance, this seems unlikely given that previous studies have utilized four to 10 minutes of WBV and reported positive results.

While the current study differs greatly in duration (45 sec vs. 4-10 minutes) compared to previous studies (Bosco et al., 2000; Cardinale and Lim, 2003a; Cochrane and Stannard, 2005; Torvinen et al., 2002a), the performance improvements for the women in the current study were similar in magnitude (i.e. percent change). Torvinen et al (2002a) elicited a 2.5% enhancement of jump height in active participants using four minutes of WBV while others used five minutes and reported 4.0% (Cardinale and Lim, 2003a) and 8.1% (Cochrane and Stannard, 2005) increased jump height performance in untrained participants and elite female field hockey players, respectively. Bosco et al (2000) utilized 10 minutes of WBV, a duration of over 10 times that of the current study, and describe a similar increase in jump performance of 3.9% in physically active men. Though performance improvements occurred, it might be that the longer duration in these previous studies caused some fatigue, leading to a less than optimally enhanced performance. This is a similar effect seen with postactivation potentiation (PAP) protocols using electrical stimulation or short-duration, high-intensity resistance exercises to enhance performance. PAP is defined as an increase in the contractile ability of muscle after a bout of previous contractions (McBride et al., 2005). PAP and fatigue co-exist and optimal performance occurs when fatigue subsides (Hodgson et al., 2005). However, if fatigue is too great, the potentiated effect is not realized. Cardinale and Bosco (2003) also suggest that while an exposure of short duration might elicit increased neural potentiation (i.e. PAP); a long-duration vibration stimulus causes fatigue and produces a reduction in muscle-force capabilities. Previous studies (Cardinale and Lim, 2003a; Rittweger et al., 2000; 2003) have reported fatiguing effects with WBV. The opposite might also be proposed: if the stimulus is not sufficient to produce PAP, significant neuromuscular activation would not occur and improvements in performance would not be seen (Bazett-Jones et al., 2005; Koch et al., 2003). PAP might not have occurred in men because the stimulus used in the current study was insufficient.

While it did not appear that men experienced PAP during the WBV sessions, the results from the women participants are consistent with enhanced performance via PAP. Women experienced performance improvements of 9.0% and 8.3% following the 2.80g and 5.83g acclerations, respectively. Since no measures of muscle activation (e.g. EMG, H-reflex) were obtained, a PAP mechanism in this study can only be postulated. Vibration might elicit the muscle contractions necessary to induce PAP (i.e neural potentiation; Cardinale and Bosco, 2003) via the TVR as described by Eklund and Hagbarth (1966). Increases in vibration frequency have been shown to produce linear increases in muscle tension (Issurin, 2005; Nigg and Wakeling, 2001; Wakeling and Nigg, 2001). This increase in tension, via neuromuscular activation, might be explained by the “muscle tuning” hypothesis (Nigg and Wakeling, 2001; Wakeling and Nigg, 2001); that muscles contract to reduce or dampen the impact of vibration on the body’s structures (Cardinale and Wakeling, 2005; Cardinale and Lim, 2003a; Nigg and Wakeling, 2001; Wakeling and Nigg, 2001). Dampening of the vibrations is dependent on the individual’s viscoelastic properties (i.e. stiffness), among others (i.e. muscle spindles, receptors of the skin and joints, and the proportion of type II muscle fibers; Cardinale and Wakeling, 2005; Cardinale and Lim, 2003a). Since women are proposed to be less stiff (Granata et al., 2002a; Granata et al., 2002b), they might require greater neuromuscular activation to dampen the WBV stimulus and therefore, a greater PAP effect. This would also explain why the men in the current study saw no immediate effects, in comparison to the significant increase experienced by women. However, this is speculative since this current study did not measure muscle activity or stiffness.

As stated previously, this study is limited by the lack of other measures (i.e. EMG) that would have allowed further explanation of these results. These current results would seem to indicate that women exhibited much greater variability than men. There seems to be three possible explanations for this variability; 1) the task of jumping with a stick across the shoulders may be novel enough that a greater learning period is necessary; 2) the women were untrained, possibly causing greater variability through inexperience; and 3) the small sample (n = 11) size of women in this study, possibly contributing to increased variability. The most reasonable explanation seems to be a combination of 2 and 3. While the authors attempted to control for this via four-days of familiarization and a benchmark, this may have affected our results. Additionally, the literature lacks information regarding familiarization of jumping in women, as only men have been utilized for this purpose (Moir et al., 2004; 2005).

The purpose of this study was to provide insight into how various WBV accelerations affected CMJ performance, the duration of these effects, and differences between men and women. While a sizeable and significant performance increase was found in women exposed to 2.80g and 5.83g WBV, it did not elicit an effect in men as a result of the same exposure. Performance enhancement via WBV might be dependent on many factors including WBV characteristics (frequency, amplitude, duration) and/or participant characteristics (gender, strength, stiffness, training level). Future research should systematically investigate these factors and their effect on WBV performance changes as to better understand the WBV mechanisms and to further determine the proper prescription of this modality.

Conclusion

One 45 sec bout of WBV at 2.80g (40 Hz, 2-4 mm) and 5.83*g* (50 Hz, 4-6 mm) seems to be effective stimuli to elicit an improvement in CMJ performance in untrained women. In addition, the performance enhancing effects are transient in nature, lasting at least five minutes but less than ten minutes following exposure. These effects were not seen in men as all accelerations produced a reduction in performance. During the prescription of WBV, gender should be considered given that the results of this study seem to indicate that men and women respond differently to WBV. The results of this study suggest that WBV might be a useful modality as applied during the pre-competition warm-up.

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Key points

- WBV accelerations of 2.80g (40 Hz, 2-4 mm) and 5.83g (50 Hz, 4-6 mm) seem to elicit a performance enhancement effect following short-duration (45 sec) exposure in untrained women.
- The performance enhancement effect of a short-duration is transient, lasting less than 10 minutes following exposure.
- Men and women might differ in their response to the WBV stimulus, as measured by countermovement jump.

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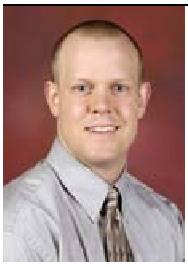

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