

EFFECT OF WHOLE-BODY VIBRATION ON ACUTE
RECOVERY AFTER FATIGUING EXERCISE

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ABSTRACT

High-intensity intermittent or resistance activity for a short period of time causes an increased break down of energy stores and accumulation of metabolic by-products. Increased metabolic disturbances may lead to decreased muscle contractile function which eventually will lead to muscle fatigue. Sufficient recovery time is needed for optimal competitive performance and optimizing the ability to tolerate high-intensity, various lengths and duration training loads. There are a number of recovery modalities available that have been used between training sessions, pre- and post- training, and between competitions. In order to evaluate vibration as a recovery aid that contributes to improved performance, three studies were conducted. The first study evaluated the effects of whole-body vibration (WBV) and WBV plus cooling on lower-body peak and mean anaerobic performance, leg volume, perceived recovery, and muscle soreness. The second study evaluated the effects of WBV and upper-body vibration (UBV) on upper-body performance, perceived recovery and muscle soreness, and the third study evaluated the effect of WBV on sprint performance, leg volume and perceived recovery. Healthy and physically active male and female volunteers participated in the studies. In a repeated measures, counterbalanced design, participants completed fatiguing exercise, each recovery treatment and performance test. As indicated by the group mean data, results of the first study suggested possible psychological but not performance enhancing benefits after the use of WBV and WBVC as a recovery method. The findings of the second study suggest no psychological or physiological benefits using WBV and UBV as a recovery modality. The results of the third study suggest no benefits for WBV in enhancing recovery or sprint performance. However,

while actual recovery was not enhanced, perceived recovery was better after WBV compared to no vibration. Even though actual recovery or performance was not enhanced by the addition of WBV to the recovery, psychological perception of better recovery may be of some benefit for training or competition. It appears that acute exposure to WBV does not enhance performance under the conditions of this study.

DEDICATION

I dedicate this dissertation to my parents Tatjana Nepocatyh and Aleksandr Nepocatyh who have been a great example as parents to me and my brother Dmitrij Nepocatyh and his family who supported me. Also, I would like to dedicate this dissertation to coach Sigitas Skarelis and to coach Matt Liddy for believing in me, to Madeline Haft for being such an inspiration, to the Brown family for providing me with this great opportunity and to my friends for their tremendous support.

LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	analysis of variance
cm	centimeter
kg	kilogram
m	meters
y	year
n	sample size
s	seconds
p	probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
CON	control
CK	creatine kinase
HR	heart rate
PAR-Q	Physical Activity Readiness Questionnaire
RPE	rating of perceived exertion
<i>SD</i>	standard deviation
SPSS	Statistical Package for the Social Sciences
WBV	whole-body vibration
WBVC	whole-body vibration plus cooling

CMJ	upper-body vibration
=	equal to
<	less than
%	percent
*	significant difference ($p < 0.05$)
#	significant difference ($p < 0.001$)

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CHAPTER I

INTRODUCTION

Whole Body Vibration (WBV) is an emerging training technique proposed as an alternative to, or addition to, resistance training. It is hypothesized that mechanical stimuli to the muscles can be an effective way of improving muscle strength and power by increasing gravitational loading. With the feet on the vibrating platform, individuals receive mechanical stimulus to the feet and leg muscles due to the oscillatory motion (3) and receive mechanical stimulus to the upper-body muscles via the forearms during upper-body vibration (UBV).

Mechanical stimulation to the muscles causes muscles to subconsciously lengthen and contract, employing more muscle fibers than no vibration (3). Neural activity of the muscle being exposed to vibration increases significantly compared to the baseline values (2). WBV and UBV may be used before competitions as a warm-up routine or as an addition to traditional training techniques to improve strength, speed and power of an athlete (6, 4, 9).

In previous research on UBV and swimming performance, individual data indicated that more than half of the participants gained benefits and improved swimming performance after UBV intervention even though the group mean did not attain statistical significance compared to a standard warm-up (11). Therefore, UBV is a new research area that needs to be further investigated for possible roles in improved performance.

In recent years, the focus of WBV has been directed toward recreational and clinical settings. It has been shown that brief exposure to WBV increases peripheral circulation, as well

as muscle temperature, muscle blood flow, and skin blood flow (5, 7, 8, 10). It has been suggested that increased blood flow may help facilitate the delivery of oxygen and nutrients needed for muscle repair, buffer blood pH levels, aid in blood lactate removal, and increase creatine kinase (CK) clearance after fatiguing exercise. In theory, these effects may help overcome fatigue, decrease recovery time, and help improve athletic performance (12, 13).

High-intensity intermittent or resistance activity for a short period of time causes an increased break down of energy stores and accumulation of metabolic by-products such as lactic acid and inorganic phosphate due to increased anaerobic metabolism (14). Increased metabolic disturbances may lead to decreased muscle contractile function which eventually will lead to muscle fatigue (14).

Insufficient recovery time between training sessions and competitive events may lead to decreased performance or training ability needed to complete the required load. Therefore, sufficient recovery time is needed for optimal competition performance and the ability to tolerate high-intensity, various lengths and duration training loads (1). There are a number of recovery modalities available that have been used between training sessions, pre- and post- training and during competitions among competitive athletes. Massage, active recovery, cryotherapy, contrast temperature water immersion, hyperbaric oxygen therapy, nonsteroidal anti-inflammatory drugs (NSAIDs), compression garments, stretching, electromyostimulation and combinations of these modalities are most commonly used among competitive athletes (1). These recovery modalities are believed to decrease edema and relieve muscle pain, improve blood lactate removal and enhance CK clearance via increased blood flow (1). This helps to facilitate the healing process of the damaged muscles and ease delayed-onset muscle soreness (1). Finding an appropriate and effective recovery mode for team or individual sports that is

simple, cost-effective and functional, however, is difficult, because the aforementioned modalities could be expensive and time consuming. Thus, WBV could be an addition to existing recovery methods that would be practical and easy to use between exercise bouts or during breaks in competition for team or individual sports.

There is a relatively limited number of research studies available evaluating the effects of WBV and possible recovery benefits. Thus, the optimal duration and frequency of WBV and its effect on recovery between exercise bouts and performance is yet to be determined. With regards to the limited research available, the studies investigated different types of acute recovery methods using WBV, UBV, and WBV plus cooling after fatiguing exercise on perceived recovery, muscle soreness and performance.

In order to evaluate vibration as a recovery aid that contributes to improved performance, three studies were conducted. The first study evaluated the effects of WBV and WBV plus cooling on lower-body peak and mean anaerobic performance. The second study evaluated the effects of WBV and UBV on upper-body performance and the third study evaluated the effect of WBV on sprint performance. In addition, these studies evaluated the acute effect of vibration intervention and addition of cooling on actual and perceived recovery between exercise bouts in order to facilitate potential implementation of WBV use in training, competition and rehabilitation programs. It was hypothesized that vibration and vibration plus cooling interventions would provide better actual and perceived benefits compared to no vibration, thus improving athletic performance and perceived recovery and as well as decreasing muscle soreness after fatiguing exercise.

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CHAPTER II

EFFECT OF WHOLE-BODY VIBRATION AS A RECOVERY METHOD AFTER FATIGUING SQUAT EXERCISE

ABSTRACT

The purpose of this study was to compare three recovery methods: control (CON), whole-body vibration (WBV) and WBV+ local muscle cooling (WBVC) on lower-body performance, perceived recovery, and muscle soreness. Eight physically active male volunteers participated. In repeated measures, counterbalanced design, participants completed three sets of squats to fatigue, each recovery treatment, and two Wingate Anaerobic Tests to assess peak and mean anaerobic power. Lower leg volume, rating of perceived exertion (RPE), and heart rate (HR) were measured post fatiguing exercise, recovery treatment and maximal performance test. In Wingate 1, no significant differences ($p = 0.42$) were found among CON, WBV, or WBVC regarding peak power (1119 ± 239 , 1097 ± 225 , and 1146 ± 260 W, respectively), mean power ($p = 0.32$), or fatigue index ($p = 0.47$). In Wingate 2, no significant ($p = 0.17$) differences were found among CON, WBV, or WBVC regarding peak power (1042 ± 228 , 1078 ± 233 , and 1110 ± 268 W, respectively), mean power ($p = 0.38$), or fatigue index ($p = 0.15$). Analyses of individual data suggested that only one of eight participants positively responded to WBV and WBVC recovery treatments compared to no vibration as indicated by least significant difference analysis. A significantly better ($p = 0.01$) perceived recovery was observed after WBV (6 ± 1) and WBVC (6 ± 1) compared to CON (4 ± 1). Post-recovery treatment lower-leg volume was significantly higher than pre-treatment volume after WBV ($p < 0.001$) and WBVC ($p = 0.02$) but not after

CON ($p = 0.07$). The study findings support psychological but not performance enhancing benefits after the use of WBV and WBVC as a recovery method.

KEY WORDS: Peak power, cooling, perceived recovery, leg volume, Wingate Anaerobic Test

INTRODUCTION

Recently, whole-body vibration (WBV) has gained increased research interest. WBV has been used in athletics, recreational and clinical settings. There are a large number of studies investigating the effects of WBV and performance among healthy college students and athletes. Research results have been equivocal with most of the studies focusing on the effects of WBV on strength training (25), sprint performance (16), muscle electrical activity during a voluntary muscle contraction (6) vertical jump (13), flexibility (14), and agility (13). It is believed that brief exposure to WBV can provide performance improvements and training benefits in a short period of time due to increased neural activity and increased recruitment of muscle fibers (6, 7).

Research findings suggest that acute or chronic WBV significantly improved peak and mean power output (1, 5, 34, 36, 37, 38, 41, 42). Improved peak and mean jump height in continuous jumping were observed by Bosco et al. (1998) after 10 days of WBV training at a frequency of 26 Hz. Improved peak average power during squat jump was observed by Ronnestad et al. (2009) in trained and untrained individuals. In addition, acute exposure to WBV at a high frequency (50 Hz) provided the greatest improvements in the peak power during countermovement jumps (CMJs) (1).

In the past few years, effects of WBV on the peripheral vascular system have been investigated. Lohman et al. (2007) observed a significant increase in skin blood flow in the calf during a vibration intervention and 10 minutes following an intervention. In addition, increased blood cell velocity in the legs was observed by Lythgo et al. (2009) following a brief exposure to WBV at a frequency of 30 Hz. Increased peripheral circulation, muscle and skin blood flows (23, 24, 26), may augment delivery of oxygen and nutrients and help remove accumulated metabolic

by-products due to exercise (40, 43). Enhanced clearance of metabolic by-products may help overcome fatigue, decrease recovery time, and help improve athletic performance (40, 43).

Athletes frequently perform multiple events, or play in multiple innings or quarters during competition. Exhausting repeated exercise bouts will decrease muscle peak and mean power, deplete energy stores, and muscles will accumulate metabolic by-products, which will potentially lead to muscle fatigue (44). Adequate recovery is needed to perform well during an immediately successive competition or training session. However, sometimes there is not enough time available to recover adequately between the sessions; thus, athletic performance is impaired. Various recovery modalities individually, or in combination, are often used by competitive athletes to enhance recovery, reduce muscle soreness, and improve performance (3).

Recent research has shown that the application of high intensity WBV of 50 Hz before down-hill walking reduced muscle soreness and lowered creatine kinase (CK) levels 24 hours post exercise (2). In a study by Rhea et al. (2009) stretches performed on a WBV plate lowered perceived pain in untrained individuals after a strenuous exercise session. Therefore, as a result of the suggested benefits, WBV could be a useful recovery modality used to enhance athletic performance and alleviate muscle soreness following fatiguing exercise, but this has not been investigated.

In addition, it has previously been shown that pre-cooling leg muscles with ice packs improved peak power output during intermittent exercise performance (10) and mean power output during 70 s of high intensity cycling (27). It was hypothesized by Marsh and Sleivert (1999) that local muscle cooling decreases skin and increases muscle blood flow which increases the delivery of needed nutrients and clearance of metabolic by-products, thus

improving performance. Therefore, the addition of local muscle cooling to WBV intervention during recovery could help enhance recovery and improve performance.

The purpose of the present study was to evaluate the effects of WBV vibration and WBV plus local cooling as recovery modalities on lower-body peak and mean power, perceived recovery, muscle soreness and lower leg volume. We hypothesized that WBV and WBV plus cooling would provide better actual and perceived benefits compared to no vibration, thus, increasing peak and mean power, perceived recovery and blood flow as indicated by increase in lower leg volume and decreasing muscle soreness after fatiguing exercise.

METHODS

Experimental Approach to the Problem

A repeated measures study design was used in which participants completed three performance trials in counterbalanced order in order to evaluate the effects of WBV, WBV plus local muscle cooling or no treatment (control) during recovery on subsequent lower-body peak and mean power, perceived recovery, lower leg volume and muscle soreness after fatiguing exercise.

Participants

The study included eight physically active males between 19 and 40 years of age who participated in at least 300 minutes of moderate intensity physical activity per week. Power analysis suggested that with this sample size ($n=8$), we would be able to detect an effect for

lower-body peak power of 150 W with an alpha level at 0.05 and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72).

(Table 1 about here)

Participants were informed of any health risks and side effects such as itching and temporary edema before the study and provided written informed consent according to the guidelines of the local Institutional Review Board. In addition, participants completed the Physical Activity Readiness Questionnaire (PAR-Q) (28), and a current health status and training status questionnaire. Participants were asked not to participate in vigorous physical activity and to avoid alcohol at least 24 hours prior to each test session. In addition, participants were asked to refrain from vigorous physical activity for 72 hours after the session so as not to affect perceived muscle soreness response. Prior to the study, the purpose and performance trials were explained, and the different types of treatments were introduced. Participants were verbally introduced to the study procedures prior to agreeing to volunteer and signing an informed consent form. Only physically active participants participated in the study; therefore, the study requirements did not exceed their normal efforts. There were no previous studies that reported serious adverse effects of vibration; however, a temporary edema has been reported, which resolved rapidly after walking around (12, 31, 34).

Body composition was assessed using a skinfold caliper (LANGE, Beta Technology Incorporated, Cambridge, Maryland). Skin folds were measured at the thigh, chest and abdomen (20). Three measures were taken at each site and the average of the three was recorded. Body fat was estimated using the sum of skin folds and age (20). Participants' age, weight, height, percent body fat, and squatting weight are presented in Table 1

Procedures

Participants completed three performance trials in counterbalanced order, separated by at least 96 hours. Each participant completed trials consisting of: warm-up, three sets of back squats with 40% of body weight to volitional fatigue, four leg volume measures, one of three recovery treatments and two Wingate Anaerobic Tests. Study design is presented in Figure 1.

(Figure 1 about here)

Warm-up – A warm-up was performed on the cycle ergometer for five minutes at a self selected work rate.

Fatiguing exercise - One minute after the warm-up three sets of back squats using an Olympic bar with ~40% of body weight (depending on the availability of appropriate plate weights to match 40% of body weight) were performed to volitional fatigue or until they could not maintain proper technique or cadence, with two minutes of rest in between sets. The number of squats for each set was recorded. A three-s cycle was used to perform squats, 1.5 s for the eccentric and 1.5 s for the concentric phase, with a cadence of 40 to control the pace (20 squats per minute) with a metronome (SEIKO, Quartz Metronome, Seiko Instruments Inc., Hong Kong). The bar was positioned on the upper-back and shoulders. Proper technique was monitored: back straight, chest up and out, heels on the floor at all times, while squatting knees aligned over the feet, flexing knees and hips until parallel to the floor and back to the standing position.

Lower leg volume – Leg volume was used as an indicator of changes in blood flow to the leg. Leg volume was measured four times: at rest before the session, immediately after three sets of squats, immediately after the recovery treatment and 15 minutes after the last Wingate Anaerobic Test was performed. When participants arrived at the lab, they remained seated in the

chair for 15 minutes for the resting value to be obtained. Resting leg volume was measured in order to determine day-to-day reliability of lower leg volume among the recovery treatments. Leg volume after fatiguing exercise and after each recovery treatment was measured in order to determine if the blood flow to the leg increased due to WBV treatment. The last leg volume measure was made to ensure that leg volume increased due to WBV and not due to exercise induced edema.

The leg volume was measured by water displacement in a leg-sized plastic tank of water using a technique similar to that used by Pasley et al. (2008). Water temperature was held between 32-36° C and measured with a digital thermometer integrated with a copper-constantan thermocouple (OMEGA Engineering Inc., Stamford, CT). A mark was made near the knee with a marker to ensure that it was placed at the same depth every time. Participants were asked not to wash off the mark and if they did we reapplied the mark so it would be consistent for each leg volume measurement within the session. A spout was attached to the tank and a dry pitcher was placed under the spout. Participants slowly inserted their lower legs into the water to the mark and all displaced water was collected into the pitcher and volume measured to the nearest 10 ml.

Wingate Anaerobic Test – Five minutes after the recovery-from squatting treatment, a Wingate Anaerobic Test was performed on an electronically-braked cycle ergometer (Velotron, Racer Mate, Seattle, WA) in order to evaluate peak anaerobic power (highest mechanical power generated), fatigue (decline in power over 30-s period) and total anaerobic capacity (total work performed during 30-s). The test started with a 20-s warm-up wherein the participant was asked to pedal the stationary bike at his own pace. Participant then performed a 30-s “all out effort” involving pedaling as fast as possible with an applied predetermined resistance of 0.095 kg per

kilogram of body weight (39). Two Wingate Anaerobic Tests were performed with four minutes of rest in between.

Recovery Treatments

Each treatment was delivered after three sets of squats and immediately after the second leg volume measure. Immediately after the recovery treatment, a third leg volume measurement was taken.

Whole-Body Vibration Treatment – The WBV treatment was delivered using a WBV plate (VibePlate, Lincoln, NE). Participants were seated with feet placed on the vibrating plate with socks only. Vibration loading was 10 continuous minutes; vertical vibration form and the frequency of vibration was 35 Hz with amplitude of 2 mm.

Control Treatment – The protocol was the same 10-min duration as for WBV treatment with the participant seated and feet on the plate; however, during the control-treatment the vibration platform was not vibrating.

WBV and cooling Treatment - The protocol was the same as for the WBV treatment with the addition of cooling applied to the quadriceps and hamstrings muscle by a gel ice wrap. Multipurpose ice wraps (IceWraps.Net, Lumberton, NJ) were placed on both legs around the quadriceps and hamstrings for the first eight minutes (eight minutes with ice on and two minutes without ice).

Measures

RPE – Rating of perceived exertion was obtained four times: immediately after three sets of squats were completed, immediately after recovery treatment, and after each Wingate Anaerobic Test. Participants were asked to rate sessions using Borg’s 15-point scale (6-20) (4).

Heart Rate – Heart rate was recorded using Heart Rate Monitors (Polar Electro Inc., Lake Success, NY) immediately after each set of squats and after each Wingate.

Perceived Recovery Scale – The scale was used to determine each participant’s perceived recovery after control and each recovery treatment using a 0-10 scale (very poorly recovered to very well recovered) (22).

Overall Session Rating of Perceived Exertion – The OMNI 1-10 scale was used and collected 15 min post session (33).

Recovery Method Subjective Evaluation - Participants were given a questionnaire right after both Wingates were completed. The questionnaire consisted of eight questions evaluating the recovery method. Participants were asked about their recovery method experience and characteristics such as comfort, pain, intensity, time and improved performance ability. Participants were asked to draw a single, vertical, straight, mark along a line to indicate the response about how they felt using the recovery method on a 100-mm line for each of the above characteristics. The left end represented the least amount of that quality (not at all) and the right end represented the most amount of that quality (very much). For example: Do you feel using this recovery method improved your performance ability?

Not at all _____ Very much

Delayed Onset Muscle Soreness (DOMS) – DOMS was self-reported 24, 48 and 72 hours after the session. DOMS recorded muscle soreness using a Visual Analogue Scale (100-mm scale). For example: How much pain do you feel in your lower-body?

No pain _____ Very severe pain

Statistical Analyses

Differences among the recovery treatments were analyzed using separate repeated measures one-way analyses of variance (ANOVAs) (SPSS Version 16.0, SPSS Inc., Chicago, IL, USA) for the dependent variables: Wingate Tests peak power, mean power and fatigue index, perceived recovery post session, DOMS (24, 48 and 72 hours later) and leg volume. In addition, warm-up RPE and HR, number of squats, RPE and HR among the sessions, RPE post fatiguing exercise, RPE post recovery treatment, RPE post each Wingate Test, HR post fatiguing exercise, HR post treatment, HR post Wingate Test, session RPE and recovery method evaluation were analyzed using repeated measures one-way ANOVAs. LSD (Least Significant Difference) post-hoc multiple comparisons were used in order to determine individual differences among the three different types of treatments for each analysis. Alpha was set at 0.05.

Individual data, expressed as responders and non-responders to WBV and WBVC treatments were determined by a least-significant-difference analysis using the standard deviation from the study and power analysis. With a sample size of eight, we would be able to detect a 201-W and a 58-W difference in peak and mean power, respectively, for Wingate 1, and 203-W and 43-W higher peak and mean power, respectively, for Wingate 2 with alpha level at 0.05 and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72). Any participant improving his performance by these amounts would be classified as a positive responder.

RESULTS

Warm-up RPE ($p = 0.25$) and HR ($p = 0.31$) did not differ significantly among the sessions. There were no significant differences in the number of squats performed, RPE, and HR among the sessions (Table 2).

(Table 2 about here)

For Wingate 1, no significant mean differences ($p = 0.42$) were found for peak power between CON (1119 ± 239 W), WBV (1097 ± 225 W), or WBVC (1146 ± 260 W) treatments. Group mean and individual data for peak power are presented in Figure 2 and group means for mean power, fatigue index, HR, and RPE are presented in Table 3. Individual data for peak power indicated that one of eight participants responded to the WBVC recovery treatment compared to no vibration. However, there were no responders for mean power following WBV or WBVC recovery treatments compared to no vibration.

(Table 3 about here)

For Wingate 2, no significant ($p = 0.17$) mean differences were found for peak power between CON (1042 ± 228 W), WBV (1078 ± 233 W) or WBVC (1110 ± 268 W). Group mean and individual data for peak power are presented in Figure 3 and group means for mean power, fatigue index, and RPE and are presented in Table 3. Individual data for peak power indicated that the same participant responded to the WBV and the WBVC recovery treatment compared to no vibration. However, no responders were observed for mean power following WBV or WBVC recovery treatments compared to no vibration.

(Figure 2 and Figure 3 about here)

A significant mean difference ($p = 0.01$) was found in perceived recovery after WBV (6 ± 1) and WBVC (6 ± 1) compared to CON (4 ± 1) (Figure 4). However, no significant mean difference ($p = 0.75$) was found in HR response post CON, WBV, and WBVC recovery treatments (92 ± 15 , 93 ± 17 , and 94 ± 13 b/min respectively). In addition, HR response was available only for 7 out of 8 participants due to equipment malfunction.

(Figure 4 about here)

Mean lower leg volume pre- to post- recovery treatments were significantly higher after WBV ($p < 0.001$) and WBVC ($p = 0.02$) but not after CON ($p = 0.07$). There was no significant mean difference ($p = 0.77$) in resting leg volume prior to CON (3659 ± 553 ml), WBV (3670 ± 520 ml), and WBVC (3638 ± 453 ml). Results for group mean for lower leg volume at rest, fatiguing exercise, recovery treatment and 15 minutes after session are presented in Figure 5.

(Figure 5 and Figure 6 about here)

In addition, no significant difference between recovery modalities was observed in muscle soreness 24, 48 and 72 hours after recovery treatments $p = 0.66$, $p = 0.30$, and $p = 0.26$ respectively (Figure 6) and session RPE ($p = 0.33$) (Table 3). Subjective evaluations of the recovery treatments for CON, WBV, and WBVC are presented in Table 4.

(Table 4 about here)

DISCUSSION

Sufficient recovery is needed for an athlete to perform his/her best during competition or a training session. To our knowledge this is the first study evaluating the effects of WBV vibration and WBVC as a recovery modality on lower-body performance, perceived recovery,

leg volume (as indicator of blood flow change) and muscle soreness after fatiguing squat exercise. Contrary to our hypothesis, we found no significant mean difference in peak power, mean power and fatigue index for both Wingate Anaerobic tests after a single 10-minute bout of WBV or WBVC recovery treatments, compared to no vibration.

There is only limited literature evaluating the effects of WBV on anaerobic peak or mean power using cycle ergometry. Most of the previous studies evaluated acute warm-up and training effects of WBV, and not WBV as a recovery modality, on mechanical power measured by squat jump, countermovement jump (CMJ) height and CMJ peak power (9, 14, 15, 16, 17, 18, 19, 37). The current findings were inconsistent with the previous research reporting enhanced mechanical power of CMJ (14, 15, 37). This may be attributable, in part, to mechanical differences of the exercise when comparing CMJ and the Wingate Anaerobic Test, and to our use of WBV as a recovery aid. CMJ uses both concentric and eccentric muscle contractions whereas in cycling only concentric muscle contraction is required therefore power generated could differ. Also, CMJ is a very short test, whereas the Wingate is 30 s.

Previously, significant improvements were found in jump height and peak power after acute exposure to WBV as a warm-up routine (9, 14, 15, 37). Ronnestad and colleagues (2009) found significantly higher peak average power during squat jump after acute exposure to WBV at a frequency of 50 Hz compared to 20 Hz, 35 Hz and no vibration. Squat jump peak power was on average 7% higher in both trained and untrained individuals and on average CMJ peak average power was 4% higher in untrained individuals but not significantly higher in trained compared to no vibration (37). Also, a significant 4% increase in squat jump but not in CMJ was observed after 5-min low frequency (20 Hz) of WBV by Cardinale and Lim (2003). Additionally, Cochrane and colleagues (2005) observed an improved countermovement vertical

jump height with arm swings compared to controls after five minutes of exercises performed on WBV plate at a frequency of 26 Hz. Cormie and colleagues (2006) observed higher CMJ height, but, no difference in peak power immediately after a short bout of WBV treatment at a frequency of 30 Hz compared to sham. Whereas we use WBV as a recovery modality, we were unable to show any improvements in performance for WBV or WBVC compared to control.

Nonetheless, methodological differences must be considered when comparing studies. In the present study, we evaluated the effects of WBV as a recovery modality on peak performance after fatiguing exercise. The lack of group mean effects that we observed could be attributed to insufficient recovery time, vibration intensity, mode of WBV application, or perception of environment, individually, or in combination. Ten minutes of treatment may have been too short for participants to recover from fatiguing exercise. However, athletes frequently perform multiple events, or play in multiple innings or quarters during competition and have only 15 minutes to recover and get ready for the next event or second half of the game. Previously, various durations of WBV ranging from 30 s to 20 min as well as intermittent and continuous modes of administering WBV were studied (9, 14, 15, 16, 17, 18, 19, 37). However, no optimal time, mode or level of intensity has been determined.

Similar intensities of WBV were used when evaluating CMJ height, isokinetic leg press peak force and squat jump in performance studies (18, 37). However, a vibration frequency of 35 Hz may have been insufficient for the participant to recover properly and elicit any of the proposed benefits or possibly it may have been too intense adding to further fatigue. Most of the previous performance studies used frequencies ranging anywhere from 20 to 50 Hz when evaluating acute effects of WBV on power (9, 14, 15, 37). Although, WBV may not affect recovery regardless of intensity, additional intensities to enhance recovery need to be evaluated.

Furthermore, most of the previous studies evaluated the effects of WBV as a pre-activation warm-up routine before squat jump or CMJ where participants were standing or doing exercises on the WBV plate whereas we used passive recovery with participants sitting in the chair with their feet-only on the plate. In the present study, passive application was used so as not to elicit additional fatigue due to increased muscle metabolic demand caused by WBV treatment. An increase in oxygen consumption during WBV treatment was previously observed by Rittweger and colleagues (2001).

Due to individual variability, it is important to consider not only group means but also individual results. The least significant differences for Wingate 1 and Wingate 2 peak power were 201 and 203 W, and for mean power were 58 and 43 W, respectively. Individual results indicated that one of eight participants responded to the WBV and WBVC recovery treatments compared to no vibration. Therefore, these results suggest that WBV or WBVC recovery treatments may provide greater benefits for peak power but not for mean power for a small percentage of participants after fatiguing exercise. Also, we need to consider that 200 W improvements in some cases would suggest almost a 20% increase in total peak power for some participants. Thus, the practical application of these results should be considered. If some athletes, perform 200 W or 100 W better compared to no vibration, and the improvement was stable, this may be considered a significant enhancement in performance ability. Therefore, performance stability following WBV and WBVC recovery treatments may need to be determined individually.

We hypothesized that increased peripheral circulation (23, 24, 26) due to WBV would enhance delivery of oxygen and other nutrients and help remove accumulated metabolic by-

products (40, 43) which could help overcome fatigue, enhance recovery, and relieve muscle pain after strenuous exercise leading to an improved performance (40, 43).

Previously it has been suggested that whole-body vibration increases skin blood flow (23, 26) as well as peak and mean blood flow velocity (21, 24). Lythgo and colleagues (2008) observed a significantly 25% higher blood cell velocity during WBV at a frequency of 10 Hz and above compared to no vibration. In the same study common femoral artery diameter was measured; however, it was not significantly affected by frequency or displacement of WBV suggesting an increase in blood cell velocity occurring without vasodilation. Even though we observed a significantly higher leg volume following WBV and WBVC recovery treatments no improvement in recovery, performance, or perception of muscle soreness were seen.

However, the current findings of the study only partially supported the hypothesis. It has not been determined which physiological mechanisms were responsible for the increase in volume that we observed post-treatment. The most likely cause for the increase in total leg volume would be vasodilatation and consequent increase in blood flow to the lower extremities. One proposed mechanism of WBV suggests that increased gravitational load during vibration is sensed by muscle spindles which signal muscle to contract, increasing number of muscle fibers used. Previously it has been supported that during WBV while standing or doing exercises, muscle activity and metabolic muscle demand increases (6, 8, 32, 35). These effects might cancel any improvements in recovery.

Improvements in the power output after WBVC treatment were hypothesized to be due to increased blood flow and enhanced removal of metabolic by-products due to cold induced vasoconstriction to the skin thereby decreasing blood flow to the skin and diverting it deeper to the muscle (27). However, no direct benefits of adding cooling to WBV treatment in enhancing

recovery, improving performance or reducing muscle soreness were observed in the present study.

Delayed onset muscle soreness (DOMS) is often noted after unaccustomed eccentric exercise where pain and discomfort is experienced 24 to 72 hours post exercise (11). Even though the underlying mechanism of DOMS is not fully understood, a variety of preventative and therapeutic interventions are used to prevent and treat muscle soreness. The results of this study show that DOMS was not different after 24, 48 and 72 hours post exercise sessions among the recovery treatments. The muscle soreness peaked at 24 hours for all three recovery treatments and proportionally decreased thereafter. Although, there was a trend toward slightly lower perceived muscle soreness seen after WBV recovery treatment, it did not reach statistical significance.

The current findings are inconsistent with previous research of Rhea and colleagues (2009) who found significantly lower levels of reported perceived muscle soreness 12, 24, 48 and 72 hours after a workout session after WBV treatment compared to a stretching group. Resistance training and repeated sprints were used to induce muscle soreness following two sessions of 30 s of WBV massage at a frequency of 50 Hz and stretching 60 s at a frequency of 35 Hz for the same muscle groups. The difference in muscle soreness findings was most likely due to different methodologies as in our study we used physically active participants, passive vibration and cooling treatment whereas Rhea and colleagues (2009) compared vibration and stretching exercises in untrained participants.

Psychological responses may play a major role in athlete's performance. Perception of the competitive environment compared to the lab environment during the race and individual's motivation when racing against the clock and not other contestants may have influenced the

study results. We observed a small significant increase in perceived recovery after WBV and WBVC recovery treatments compared to no vibration. Participants felt moderately recovered after WBV and WBVC compared to somewhat recovered after no vibration. In addition, participants felt that using WBV and WBVC method helped them recover better and improved their performance ability as was observed on our Recovery Method Subjective Evaluation questionnaire. Also, in the questionnaire, participants indicated that they would choose WBVC as a choice of recovery treatment after a training session. There were no significant differences among which recovery treatments they would choose during a training session between sets or half-time. WBV and WBVC were perceived as higher intensity recovery treatments compared to no vibration; although, heart rate was not significantly different among the treatments suggesting similar physiological response. If an athlete feels better recovered, it may help override peripheral signals and perception of fatigue and possibly improve performance. However, no improvements in the group mean performance were observed.

In conclusion, WBV or WBVC recovery treatments did not provide greater benefits for peak or mean power after fatiguing exercise compared to no vibration as indicated by group means. With a limited amount of literature available the optimal time, mode and intensity of vibration needs to be determined in order to develop an effective recovery treatment routine.

PRACTICAL APPLICATIONS

The results of the present study indicate that acute exposure to WBV or WBVC did not provide greater benefits as a recovery modality after fatiguing squat exercise, however, one participant performed over 200 W better after WBV and WBVC compared to no vibration which

could have been due to random chance. Therefore, we recommend that coaches and athletes test the stability of the individual responses to any given recovery treatment and determine whether it helps to overcome fatigue, enhance recovery and improve performance. Due to individual variability recovery treatment duration, intensity and mode need to be determined for each individual athlete in order to provide the most effective recovery routine. In addition, based on the present study participants seemed to feel better recovered and believed that it improved their performance ability. If athletes need to recover in a short period of time WBV or WBVC may have potential psychological benefits but does not appear to aid performance under the conditions of the present study.

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Table 1. Physical Characteristics of Participants (n = 8). Values are Mean \pm SD.

Characteristics	Males n=8 Mean \pm SD
Age (y)	28 \pm 3
Weight (kg)	85 \pm 17
Height (cm)	180 \pm 7
% body fat	11 \pm 6
Squatting Weight (kg)	36 \pm 7

Table 2. Comparison of three sets of squats among WBV, WBVC and CON (n = 8). Values are Mean \pm SD.

	CON Mean \pm SD	WBV Mean \pm SD	WBVC Mean \pm SD	<i>p</i> - value
Set 1				
Squat (Nr)	70 \pm 34	83 \pm 71	77 \pm 53	0.47
RPE (6-20)	16 \pm 2	16 \pm 1	15 \pm 2	0.22
HR (b/min)	162 \pm 18	164 \pm 21	167 \pm 15	0.69
Set 2				
Squat (Nr)	51 \pm 41	42 \pm 22	50 \pm 31	0.41
RPE (6-20)	17 \pm 1	18 \pm 1	17 \pm 2	0.35
HR (b/min)	166 \pm 17	167 \pm 16	173 \pm 16	0.36
Set 3				
Squat (Nr)	46 \pm 42	43 \pm 32	45 \pm 33	0.81
RPE (6-20)	18 \pm 2	18 \pm 1	18 \pm 1	0.52
HR (b/min)	172 \pm 11	172 \pm 17	175 \pm 12	0.67

CON = control, WBV = whole-body vibration, WBVC = whole-body vibration + cooling, Nr = number, HR = heart rate, RPE = rating of perceived exertion, b/min = beats per minute.

Table 3. Comparison of Physiological Variables for WBV, WBVC and CON (n = 8). Values are Mean \pm SD.

	CON Mean \pm SD	WBV Mean \pm SD	WBVC Mean \pm SD	<i>p</i> - value
<i>Wingate 1</i>				
Mean Power (W)	610 \pm 86	589 \pm 57	604 \pm 68	0.48
Fatigue Index (%)	27 \pm 10	25 \pm 9	27 \pm 9	0.32
RPE (6-20)	19 \pm 1	19 \pm 1	19 \pm 1	0.29
HR (b/min)	181 \pm 6	178 \pm 12	180 \pm 9	0.48
<i>Wingate 2</i>				
Mean Power (W)	535 \pm 49	530 \pm 46	544 \pm 58	0.38
Fatigue Index (%)	25 \pm 9	26 \pm 9	28 \pm 10	0.28
RPE (6-20)	20 \pm 0	20 \pm 1	19 \pm 1	0.10
HR (b/min)	181 \pm 5	177 \pm 10	179 \pm 7	0.31
Session RPE (0-10)	8 \pm 1	8 \pm 1	8 \pm 1	0.33

CON = control, WBV = whole-body vibration, WBVC = whole-body vibration + cooling, HR = heart rate, RPE = rating of perceived exertion, b/min = beats per minute.

Table 4. Recovery Method Subjective Evaluation (RMSE) 100-mm scale for CON, WBV, and WBVC recovery treatments (n = 8). Values are Mean \pm SD. Mean shown with higher score indicates “more likely”.

	CON	WBV	WBVC	<i>p</i> - value
Do you feel using this recovery method helped you to recover better?	18 \pm 13*	68 \pm 14	70 \pm 9	< 0.001
Do you feel using this recovery method improved your performance ability?	17 \pm 14*	63 \pm 21	68 \pm 14	< 0.001
How did you feel about the intensity of the recovery?	6 \pm 11**	43 \pm 24	46 \pm 27	0.002
How did you feel about the amount/time of recovery?	28 \pm 14	39 \pm 22	42 \pm 17	0.16
Did you experience any leg discomfort during recovery period?	14 \pm 25	16 \pm 30	13 \pm 30	0.61
Did you experience any pain due to recovery treatment?	3 \pm 7	1 \pm 2	2 \pm 2	0.46
How likely would you be to choose this recovery method during training (between sets/intervals)?	47 \pm 22	64 \pm 16	67 \pm 19	0.16
How likely would you be to choose this recovery method after a training session?	51 \pm 21 [#]	68 \pm 18	82 \pm 16	0.04

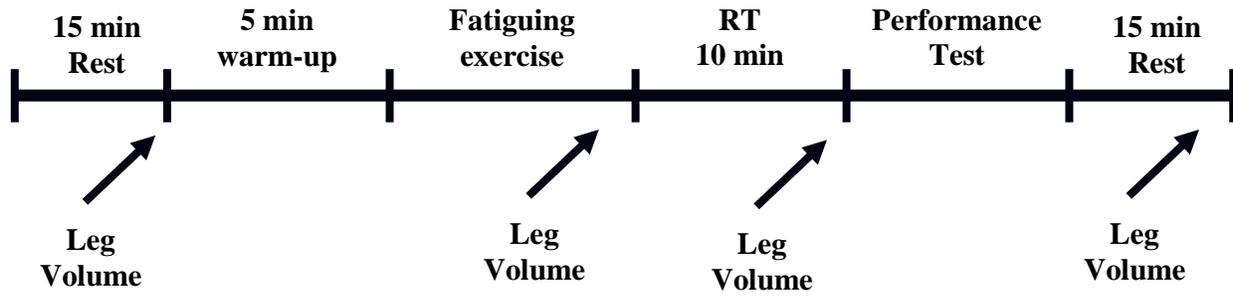
CON = control, WBV = whole-body vibration, and WBVC = whole-body vibration + cooling.

*RMSE response was higher after WBV and WBVC compared to CON ($p < 0.001$).

** RMSE response was higher after WBV and WBVC compared to CON ($p < 0.05$).

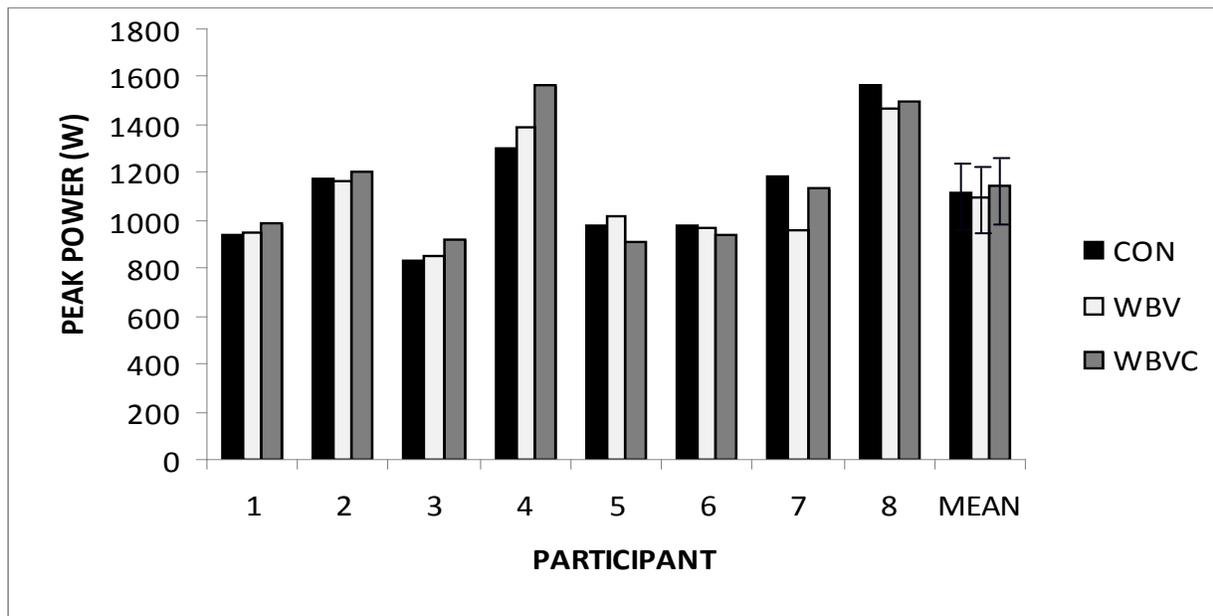
[#] RMSE response was higher after WBVC compared to CON ($p < 0.05$).

Figure 1.



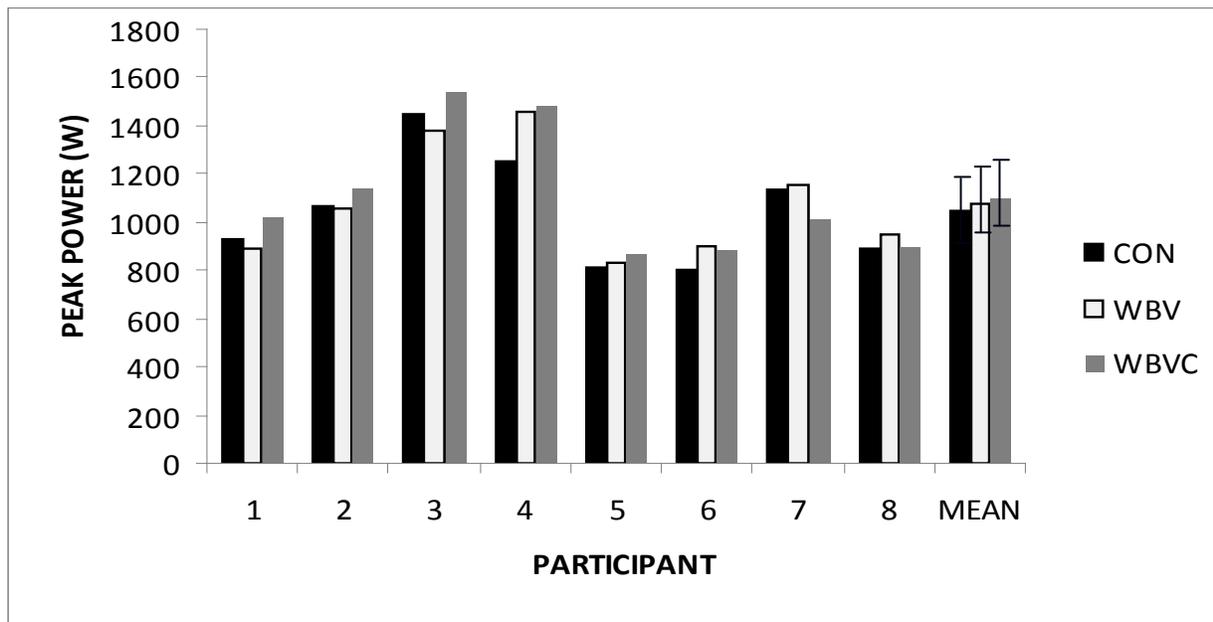
RT = recovery treatment

Figure 2.



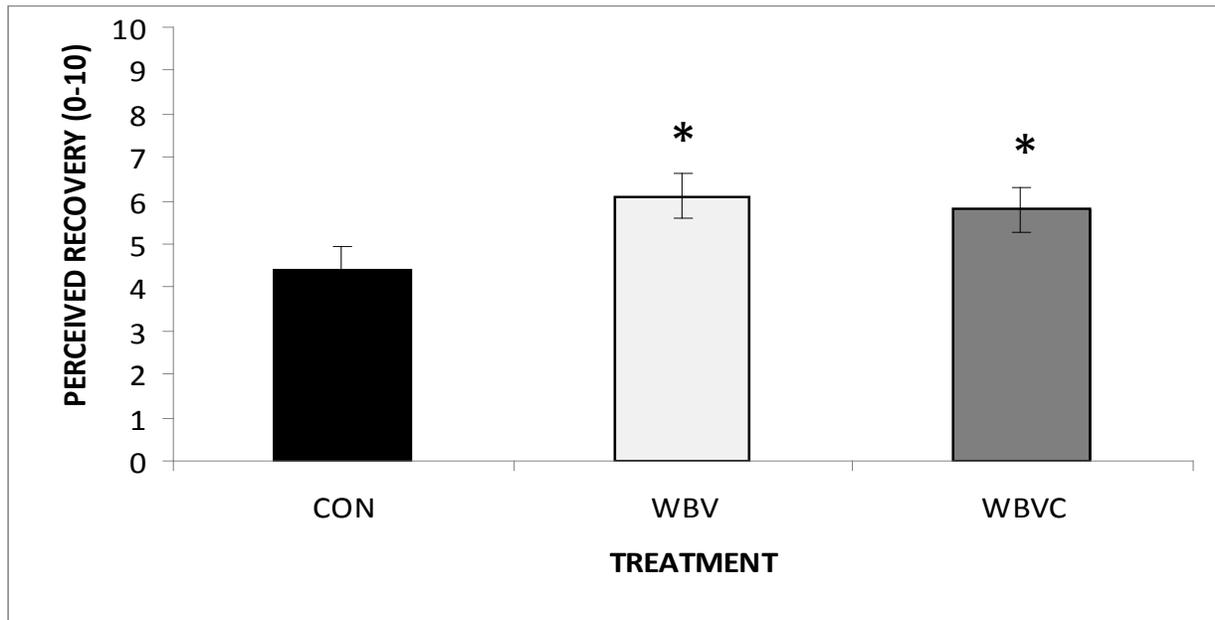
CON = control, WBV = whole-body vibration, WBVC = whole-body vibration + cooling, and W = watts. Values are Mean \pm SD. Participant # 4 positively responded to WBVC recovery treatment.

Figure 3.



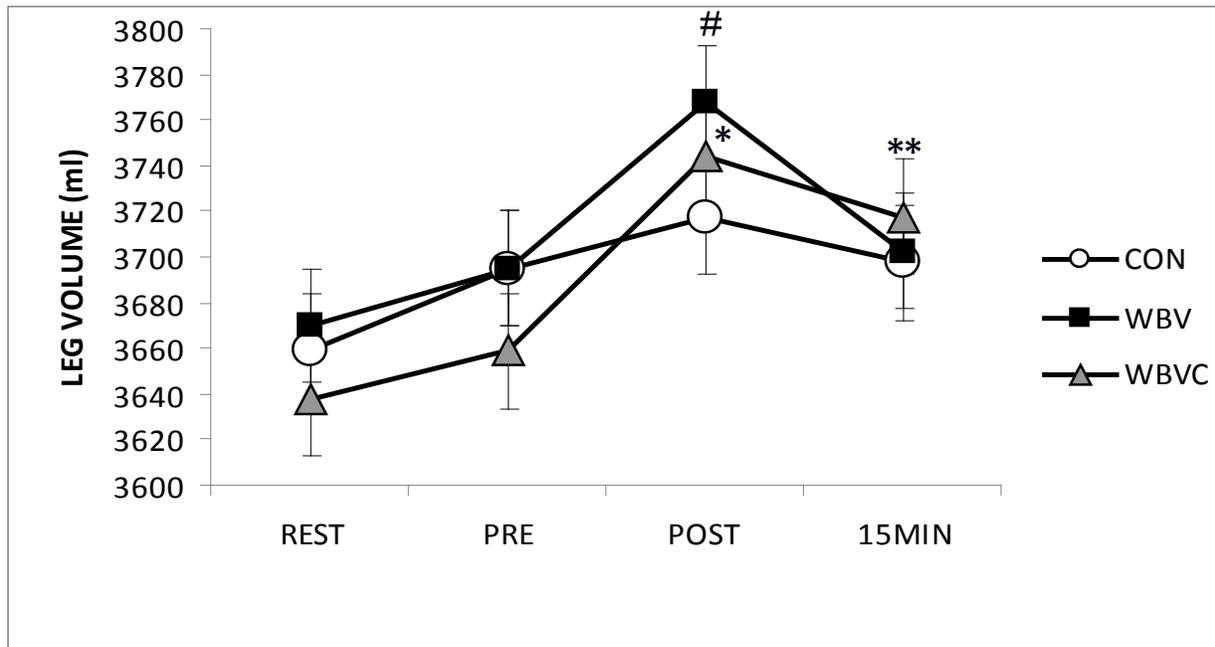
CON = control, WBV = whole-body vibration, WBVC = whole-body vibration + cooling, and W = watts. Values are Mean \pm SD. Participant # 4 positively responded to WBVC and WBV recovery treatments.

Figure 4.



CON = control, WBV = whole-body vibration, and WBVC = whole-body vibration + cooling.
* WBV and WBVC significantly higher compared to CON ($p < 0.05$). Values are Mean \pm SD.

Figure 5.



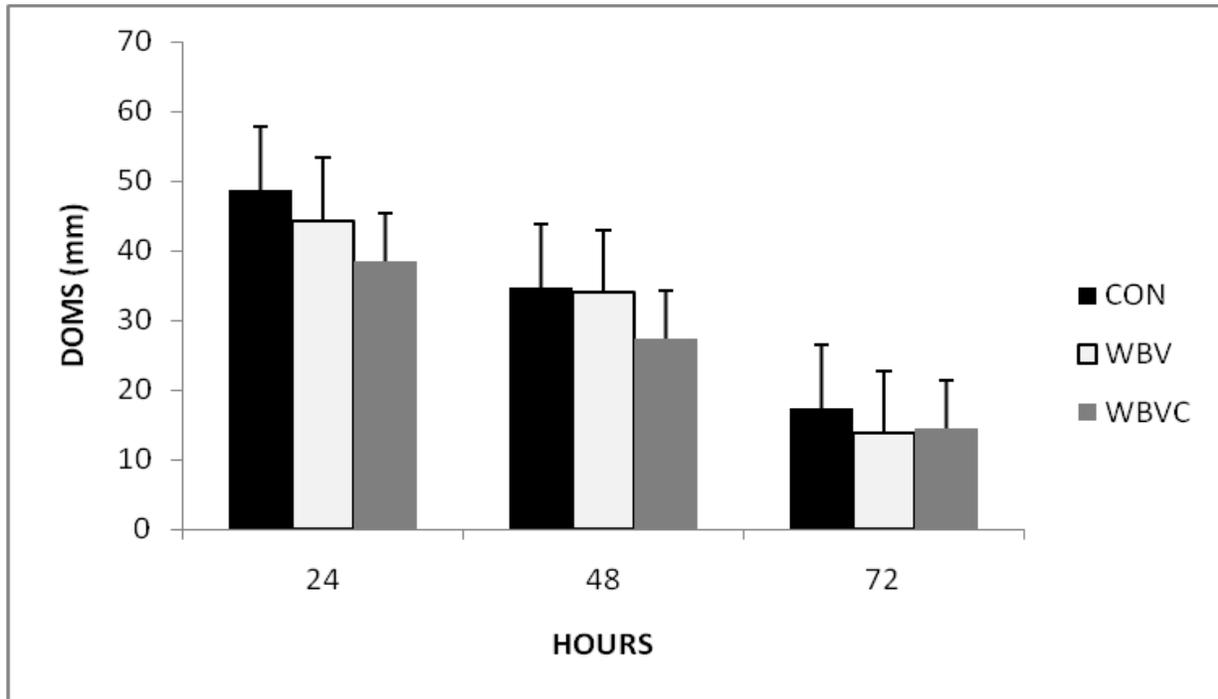
CON = control, WBV = whole-body vibration, WBVC = whole-body vibration + cooling, REST = 15 minutes after arrival to the lab, PRE = before recovery treatment, POST = after recovery treatment, 15MIN = 15 minutes after the second Wingate Test, and ml = milliliters.

* Mean Leg Volume pre compared to post recovery treatment was significantly higher after WBVC ($p < 0.05$).

** Mean Leg Volume post recovery treatment compared to 15 min post session was significantly lower after WBV ($p < 0.001$).

Mean Leg Volume pre compared to post recovery treatment was significantly higher after WBV ($p < 0.001$). Values are Mean \pm SD.

Figure 6.



CON = control, WBV = whole-body vibration, WBVC = whole-body vibration + cooling, and mm = millimeters. Values are Mean \pm SD.

CHAPTER III
EFFECT OF WHOLE-BODY VIBRATION ON UPPER BODY RECOVERY AND
PERFORMANCE AFTER FATIGUING EXERCISE

ABSTRACT

The purpose of this study was to compare three types of recovery methods: control (CON), whole-body vibration (WBV) and upper-body vibration (UBV) on upper-body performance, perceived recovery, and muscle soreness. Eight physically active male volunteers participated in the study. In a repeated measures, counterbalanced design, participants completed three sets of push-ups to fatigue, a given recovery treatment, and two upper-body Wingate Anaerobic Tests to assess peak and mean anaerobic power. Rating of perceived exertion (RPE), and heart rate (HR) were measured after fatiguing exercise, the recovery treatment and maximal performance test. In Wingate 1, no significant mean differences ($p = 0.19$) were found among CON, WBV, or UBV in peak power (560 ± 121 , 594 ± 116 , and 588 ± 109 W, respectively), mean power ($p = 0.49$), or fatigue index ($p = 0.14$). In Wingate 2, no significant mean differences ($p = 0.84$) were found among CON, WBV, or UBV in peak power (570 ± 151 , 557 ± 71 , and 564 ± 120 W, respectively), mean power ($p = 0.18$), or fatigue index ($p = 0.32$). Individual data suggest that two of eight participants positively responded to UBV and WBV recovery treatments compared to no vibration as indicated by least significant difference analysis. In addition, no significant mean difference ($p = 0.61$) was observed in perceived recovery and muscle soreness 24, 48 and 72 hours ($p = 0.66$, $p = 0.30$, and $p = 0.26$ respectively).

In conclusion, findings of the present study suggest no psychological or physiological benefits using WBV and UBV as a recovery modality.

KEY WORDS: Peak power, mean power, perceived, recovery, push-ups, arm cranking exercise

INTRODUCTION

Many sports rely on peak and mean power of the upper-body. Various traditional training techniques are used to improve power and enhance athletic performance. Insufficient recovery time between training sessions or competitive events may lead to decreased performance or inability to complete required loads during training. Sufficient recovery time is needed to replenish energy stores, and to remove metabolic by-products accumulated due to exercise. A wide range of recovery modalities are used by competitive athletes during a training session or in between sessions to speed recovery (1). Whole-body vibration (WBV) and upper-body vibration (UBV) could be an easy addition to existing recovery methods.

There is limited literature available on WBV or UBV and recovery and only few studies studied upper-body performance using UBV as opposed to whole body vibration. Improvements in mechanical power and neural activity in performance were previously observed by Bosco et al. (1999) and by Cochrane et al. (2008). Improvement in performance due to vibration application is believed to be due to increased neural activity and increased mechanical stimulation to the muscles, causing muscles to lengthen and subconsciously contract, which employs more muscle fibers; therefore, a more forceful contraction may be produced (3, 4).

Vibration intervention may enhance recovery by increasing peripheral circulation due to increased muscle metabolic demand, muscle and skin blood flow, and muscle temperature (7, 10, 12, 13). In a study by Lohman et al. (2007) an increase in the skin blood flow following WBV in the lower leg was observed. Similar results were found by Maloney-Hinds et al. (2008), where application of WBV to the dominant arm produced significant increases in the skin blood flow in the forearm during the brief exposure and remained elevated after the exposure to the vibration.

Also, increased blood cell velocity in the legs was observed by Lythgo et al. (2009) following a brief exposure to WBV.

Thus, improved circulation as a result of passive application of vibration may aid in recovery and tissue healing process by augmented delivery of oxygen and nutrients needed for repair and increased removal of accumulated metabolic by-products (12, 14, 24, 25). Blood flow redistribution to the lower limbs from the working muscles during WBV recovery intervention may help facilitate the removal of metabolic by-products, and thereby help overcome fatigue, decrease recovery time, and help improve athletic performance.

With no previous research available on acute effects of WBV or UBV on upper-body recovery, the purpose of the present study was to evaluate the effects of WBV and UBV as a recovery modality on upper-body peak and mean power, perceived recovery, and muscle soreness after fatiguing upper-body exercise. We hypothesized that WBV and UBV would provide better actual and perceived recovery benefits compared to no vibration, thus, improved peak and mean power, perceived recovery, and decreased muscle soreness after fatiguing exercise.

METHODS

Experimental Approach to the Problem

A repeated measures study design was used in which participants completed three performance trials in counterbalanced order to evaluate the effects of WBV and UBV as a recovery modality on upper-body peak and mean power, perceived recovery, and muscle soreness after fatiguing exercise.

Participants

The study included eight physically active males between 19 and 40 years of age who participated in at least 300 minutes of moderate intensity physical activity per week. Power analysis suggested that with this sample size ($n=8$), we would be able to detect an effect for upper-body peak power of 73 W with alpha level at 0.05 and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72).

(Table 1 about here)

Participants were informed of the health risks and side effects of being in the study such as itching and temporary edema before the study and provided written informed consent according to the guidelines of the local Institutional Review Board. In addition, participants completed the Physical Activity Readiness Questionnaire (PAR-Q) (16), and current health status and training status questionnaires. Participants were asked not to participate in vigorous intensity physical activity and to avoid alcohol at least 24 hours prior to each test session. In addition, participants were asked to refrain from vigorous physical activity for 72 hours after the session not to affect perceived muscle soreness response.

Prior to the study, the purpose and performance trials were explained, and the different types of treatments were introduced. Participants were verbally introduced to the study procedures prior to agreeing to volunteer and signing an informed consent form. Only physically active participants participated in the study; therefore, the study requirements did not exceed their normal efforts. There were no previous studies that reported serious adverse effects of vibration; however temporary edema has been reported, which resolved rapidly after walking

around (5, 18, 22). Physical activity routine, frequency and type, and prior lower- and upper-body injuries were assessed using an exercise and injury questionnaire.

Body composition was assessed using a skinfold caliper (LANGE, Beta Technology Incorporated, Cambridge, Maryland). Skin folds were measured at the thigh, chest and abdomen (9). Three measures were taken at each site and the average of the three was recorded. Body fat was estimated using the sum of skin folds and age (9). Participants' age, weight, height, and percent body fat are presented in Table 1.

Procedures

Participants completed three performance trials in counterbalanced order, separated by at least 96 hours. Each participant completed a trial consisting of: warm-up, three sets of push-ups to volitional fatigue, one of three recovery treatments and two Upper-Body Wingate Anaerobic Tests on an arm-crank ergometer. Study design is presented in Figure 1.

(Figure 1 about here)

Warm-up – A warm-up was performed on an arm-crank ergometer (Monark 824, ERGOMED, Sweden) for five minutes at a self selected work rate.

Fatiguing exercise – One minute after the warm-up, three sets of push-ups were performed to volitional fatigue or until they could no longer maintain proper technique or cadence with two minutes of rest in between sets. The number and total time performing push-ups was recorded. A three-s cycle was used to perform push-ups, 1.5 s for the eccentric and 1.5 s for the concentric phase. A cadence of 40 was used to control the pace (20 push-ups per minute) with a metronome (SEIKO, Quartz Metronome, Seiko Instruments Inc., Hong Kong). Proper

technique for the push-up was monitored: hands were shoulder width apart with elbows and body straight, low position with upper-arms parallel to the floor and back straight.

Wingate Anaerobic Test on Arm Ergometer - Two minutes after the recovery treatment from push-up exercise was completed, two Wingate Anaerobic Tests on an arm crank ergometer (Monark 824, ERGOMED, Sweden) were performed with four minutes of rest in between in order to evaluate peak anaerobic power (highest mechanical power generated), fatigue (decline in power over 30-s period) and total anaerobic capacity (total work performed during 30-s) for the upper-body. The test started with a 20-s warm-up wherein the participant was asked to pedal the stationary bike at his own pace. Participant then performed a 30-s “all out effort” involving pedaling as fast as possible with an applied predetermined resistance of 0.035 kg per kilogram of body weight (15).

Recovery Treatments

Each treatment was delivered immediately after three sets of push-ups were completed.

Whole-Body Vibration Treatment – The WBV treatment was delivered using a WBV plate (VibePlate, Lincoln, NE). Participants were seated with feet placed on the vibrating plate with socks only. Vibration loading was 10 continuous minutes; vertical vibration form and the frequency of vibration was 30 Hz with amplitude of 2 mm.

Upper-Body Vibration (UBV) treatment – The UBV treatment was delivered using WBV plate. Participants were seated in the chair with bare forearms placed on the vibrating plate (plate was placed on a table). Vibration loading was 10 continuous minutes; vertical vibration form and the frequency of vibration was 30 Hz with amplitude of 2 mm with similar intensity previously used by Bosco et al. (1999) in the upper-body performance study.

Control Treatment – The protocol was the same 10-min duration as for UBV treatment; however, during the control-treatment the vibration platform was not vibrating.

Measures

RPE – Rating of perceived exertion was obtained four times: immediately after the three sets of push-ups were completed, immediately after control and each recovery treatment, and after each Wingate Anaerobic Test. Participants were asked to rate sessions using Borg's 15-point scale (6-20) (2).

Heart Rate – Heart rate was recorded using heart rate monitors (Polar Electro Inc., Lake Success, NY) immediately after fatiguing exercise (push-ups), control and each recovery, and after each Wingate.

Perceived Recovery Scale – The scale was used to determine participant's perceived recovery immediately after UBV, WBV or CON recovery treatments using a 0-10 scale (very poorly recovered to very well recovered) (11).

Overall Session Rating of Perceived Exertion – The OMNI 1-10 scale was used and collected 15 minutes post session (21).

Recovery Method Subjective Evaluation - Participants were given a questionnaire right after each session was completed. The questionnaire consisted of eight questions evaluating the recovery method. Participants were asked about their recovery method experience and characteristics of comfort, pain, intensity, time and improved performance ability. Participants were asked to draw a single, vertical, straight, mark along a line to indicate the response about how they felt about each recovery method on a 100-mm line for each of the above characteristics. The left end represented the least amount of that quality (not at all) and the right

end represented the most amount of that quality (very much). For example: Do you feel using this recovery method improved your performance ability?

Not at all _____ Very much

Delayed Onset Muscle Soreness (DOMS) – DOMS was self-reported 24, 48 and 72 hours after the session. DOMS recorded muscle soreness using a Visual Analogue Scale (100-mm scale). For example: How much pain do you feel in your upper-body?

No pain _____ Very severe pain

Statistical Analyses

Differences among the recovery treatments were analyzed using separate repeated measures one-way analyses of variance (ANOVAs) (SPSS Version 16.0) for the dependent variables: Wingate Tests peak power, mean power and fatigue index, perceived recovery after fatiguing exercise and DOMS (24, 48 and 72 hours later). In addition, warm-up RPE and HR, number of push-ups performed, RPE and HR between sessions, RPE post fatiguing exercise, RPE post recovery treatment, RPE post each Wingate Test, HR post fatiguing exercise, HR post treatment, HR post Wingate Test, Session RPE and recovery method evaluation were analyzed using repeated measures one-way ANOVAs. LSD (Least Significant Difference) post-hoc multiple comparisons were used in order to determine individual differences among the three different types of treatments for each analysis. Alpha value was set at 0.05.

Individual data expressed as responders and non-responders to WBV and UBV treatments were determined by a least-significant-difference analysis using the standard deviation from the study and power analysis. With a sample size of eight, we would be able to detect a 96-W and a 53-W difference in peak and mean power, respectively, for Wingate 1, and a 95-W and a 43-W for peak and mean power, respectively, for Wingate 2 with alpha level at 0.05

and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72). Any participant improving his performance by these amounts would be classified as a positive responder.

RESULTS

No significant mean differences were found in warm-up RPE ($p = 0.72$), warm-up HR ($p = 0.41$), number of push-ups performed, RPE, and HR between the sessions (Table 2).

(Table 2 about here)

For Wingate 1, no significant mean differences ($p = 0.19$) were found among CON, WBV, or UBV regarding peak power (560 ± 121 , 594 ± 116 , and 588 ± 109 W, respectively). Group mean and individual data for peak power are presented in Figure 2 and group mean for mean power, fatigue index, RPE and HR are presented in Table 3. Individual data for peak power indicated that only one of eight participants responded to UBV recovery treatment for both peak and mean power and another participant responded to UBV and WBV recovery treatments for mean power.

For Wingate 2, no significant ($p = 0.84$) mean differences were found among CON, WBV, or UBV regarding peak power (570 ± 151 , 557 ± 71 , and 564 ± 120 W, respectively). Group mean and individual data for peak power are presented in Figure 3 and group mean for mean power, fatigue index, RPE and HR are presented in Table 3. Individual data for peak power indicated that none of the participants responded to UBV and WBV recovery treatment compared to no vibration. However, data for mean power indicated that the same person (as in Wingate #1) of eight participants responded to WBV recovery treatments compared to no vibration.

(Figure 2, Figure 3 and Table 3 about here)

No significant mean difference ($p = 0.61$) was found for perceived recovery after CON (5 ± 2), WBV (6 ± 2) and UBV (6 ± 2). In addition, no significant mean difference was found for recovery HR ($p = 0.48$) post CON, WBV, and UBV recovery treatments (95 ± 18 , 100 ± 15 , and 98 ± 17 b/min respectively), muscle soreness after 24, 48 and 72 hours ($p = 0.66$, $p = 30$, and $p = 0.26$ respectively) (Figure 4), and session RPE ($p = 0.66$). Recovery method subjective evaluation for CON, WBV, and UBV recovery treatments are presented in Table 4.

(Table 4 and Figure 4 about here)

DISCUSSION

This is the first study evaluating the effects of UBV and WBV as a recovery modality on upper-body peak and mean power, perceived recovery, and muscle soreness after fatiguing exercise. We hypothesized that UBV and WBV would provide better actual and perceived benefits compared to no vibration, thus, improving peak and mean power, perceived recovery and reduced perceived muscle soreness. However, we observed no significant mean differences in peak or mean power after a 10-minute bout of UBV or WBV recovery treatment compared to no vibration.

There is limited research available evaluating effects of vibration on recovery and upper-body performance. In a performance study rather than a recovery design, Cochrane and Hawke (2007) observed no significant mean difference in upper-body strength and power in climbers after a single 5-minute bout of UBV at a frequency of 26 Hz. There was no significant difference observed in the medicine ball throw, hand grip strength and campus distance after upper-body

vibration, arm-cranking or no vibration treatments (6) suggesting no neuromuscular enhancements in performance provided by upper-body vibration. Thus, our study supports these findings in that we did not observe any enhancement in group mean upper-body peak or mean power performed on a arm crank ergometer during Wingate Anaerobic tests following UBV or WBV recovery treatment. However, in a later performance based study Cochrane and colleagues (2008) observed a significant increase of 4.8% and 3% in peak power measured by prone-bench pull after upper-body vibration and arm cranking treatments, respectively, compared to no vibration treatment. Thus, with results being discordant it is difficult to determine whether it has a potential to benefit performance or not.

Peak power in the previous performance studies was determined by bench prone pull and medicine ball throw from a sitting position which may have been more sport specific and different from peak power generated during arm cranking exercise. Being the first study evaluating the effects of UBV and WBV on upper-body recovery it is challenging to compare the results of previous studies to the present investigation due to methodological differences and ways of measuring upper-body peak and mean power. Bench prone pull and medicine ball throw are very short tests compared to a 30 s upper-body Wingate test.

In addition, the differences among the performance studies could be attributed to different duration, intensity, mode and type of upper-body vibration used. In both of the previous performance studies, upper-body vibration treatment was delivered by electric-powered dumbbell with a frequency set at 26 Hz with the dumbbell held at five different shoulder positions for 60 s or alternating each hand every 30 s. In addition, in the previous study it has been speculated that perception of vibration stimulus while holding a dumbbell may have been slightly reduced at the end of the limb due to reduced oscillations by soft tissues, thus, vibration

stimulus may have been insufficient to provide any improvements (7, 8). Therefore, in the present study the recovery treatment was administered with the arms placed on the whole-body vibration plate for 10 continuous minutes to provide sufficient vibration stimulus and reduce the dampening effect of soft tissue. However, even with a greater stimulus we did not observe any beneficial effects on perceived or actual recovery.

In the present study, we investigated the effects of UBV as a recovery modality compared to a warm-up routine or pre-exercise activation mode as used in the previous studies; therefore, we used passive recovery so as not to cause further fatigue. Earlier, an increase in muscle activity and oxygen uptake has been observed during WBV while standing or performing squatting exercise (3, 19, 20, 23).

In addition, we used a slightly higher frequency of 30 Hz compared to the aforementioned studies. Previously, similar intensity was used by Bosco and colleagues (1999) who observed significantly higher average mechanical power recorded during arm flexion following upper-body vibration pre-activation treatment which occurred in conjunction with an increase in EMG activity with the values twice as high compared to the baseline (3). Therefore, the differences observed among the performance studies may have been due to the different intensities and perceived stimulus of vibration treatment by the participant.

We hypothesized that an increase in muscle activity during UBV and WBV recovery treatments would increase peripheral circulation and muscle blood flow facilitating the removal of metabolic by-products, and thereby, enhance recovery, reduce perceived muscle soreness and improve performance (10, 12, 14). An increase in skin blood flow in the arm during a 10-minute passive vibration at 30 and 50 Hz was observed by Maloney-Hinds and colleagues (2008). Skin blood flow peaked at minute 5 and remained elevated above baseline values during vibration and

15 minutes into recovery (14). Additionally, an increase in oxygenation, blood volume, peak and mean blood cell velocity was previously observed following WBV compared to no vibration (13, 26).

However, in the present study we did not observe actual or perceived benefits after UBV or WBV recovery treatments compared to no vibration, perhaps because vibration-induced fatigue might have occurred due to increased muscle metabolic demand. Previously, it has been reported that WBV treatment enhanced electromyography (EMG) response (3, 23), increased oxygen consumption (19, 20) as well as an increased oxygenation of the muscle (26) indicating increased muscle metabolic demand.

A non-significant trend in delayed-onset muscle soreness with higher responses following no vibration recovery treatment was observed. Previously, it has been shown that perceived muscle pain following strenuous exercise session was attenuated by WBV massage and stretching treatment (17). However, we did not observe any group mean difference in reduced perceived muscle soreness. Even though perceived recovery did not differ among recovery treatments, participants felt using UBV helped them recover better and improved their performance ability compared to no vibration as indicated by the Recovery Method Subjective Evaluation questionnaire. Although, UBV and WBV were perceived as higher intensity recovery treatments, no significant differences in the HR response after recovery treatments were observed suggesting similar physiological responses.

Due to individual variability, we assessed individual results expressed as responders and non-responders to recovery treatments. Individual data suggested that only one of eight participants responded to UBV recovery treatment where peak and mean power was higher compared to no vibration and another participant responded to UBV and WBV where mean

power was higher compared to no vibration. Coaches work with individual athletes and not group means; therefore, an improvement in one athlete's performance, if proved stable and not occurred due to random chance, could be a useful achievement. Thus, finding the best recovery treatment for an athlete that works the best in a short period of time could be a key to successful performance.

In conclusion, UBV and WBV recovery treatments did not provide greater group mean benefits as a recovery modality after fatiguing upper-body exercise compared to no vibration. However, for a few athletes it might hold promise for enhanced recovery and improved performance if proved stable.

PRACTICAL APPLICATIONS

The results of the present study indicate that we cannot expect, on average, acute exposure to UBV or WBV to enhance recovery compared to no vibration based on the protocol used in this study. Although a few athletes may improve performance following UBV or WBV, stability of that result should be determined.

Coaches and athletes should keep in mind that this is the first study evaluating the effects of UBV and WBV as a recovery modality. In order to elicit any improvement in recovery, greater vibration exposure might be required. Acute exposure to UBV or WBV may not be sufficient enough, thus, multiple exposures may be needed. Therefore, UBV and WBV cannot be considered a useful recovery modality under the conditions of this study.

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Table 1. Physical Characteristics of Participants (n = 8). Values are Mean \pm SD.

Characteristics	Males n=8 Means \pm SD
Age (y)	27 \pm 3
Weight (kg)	81 \pm 18
Height (cm)	176 \pm 2
% body fat	12 \pm 7

Table 2. Comparison of three sets of push-ups between the sessions (n = 8). Values are Mean \pm SD.

	CON Mean \pm SD	WBV Mean \pm SD	UBV Mean \pm SD	<i>p</i> - value
Set 1				
Push-up (Nr)	29 \pm 9	29 \pm 8	29 \pm 7	0.70
RPE (6-20)	15 \pm 2	15 \pm 3	16 \pm a	0.32
HR (b/min)	146 \pm 21	151 \pm 18	148 \pm 20	0.50
Set 2				
Push-up (Nr)	18 \pm 7	18 \pm 7	18 \pm 7	0.70
RPE (6-20)	16 \pm 2	17 \pm 2	17 \pm 2	0.06
HR (b/min)	152 \pm 19	151 \pm 17	155 \pm 22	0.45
Set 3				
Push-up (Nr)	14 \pm 8	14 \pm 7	14 \pm 7	0.98
RPE (6-20)	17 \pm 2	17 \pm 3	17 \pm 2	0.85
HR (b/min)	149 \pm 17	149 \pm 19	149 \pm 21	0.98

Nr = number, HR = heart rate, RPE = rating of perceived exertion, b/min = beats per minute, CON = control, WBV = whole-body vibration, and UBV = upper-body vibration.

Table 3. Comparison of physiological variables of performance after CON, WBV, and UBV recovery treatments (n = 8). Values are Mean \pm SD.

	CON Mean \pm SD	WBV Mean \pm SD	UBV Mean \pm SD	<i>p</i> - value
<i>Wingate 1</i>				
Mean Power (w)	350 \pm 59	354 \pm 68	362 \pm 64	0.49
Fatigue Index (%)	55 \pm 9	58 \pm 8	61 \pm 11	0.14
RPE (6-20)	18 \pm 1	18 \pm 2	18 \pm 1	0.92
HR (b/min)	178 \pm 11	178 \pm 15	172 \pm 6	0.35
<i>Wingate 2</i>				
Mean Power (w)	316 \pm 49	295 \pm 56	312 \pm 49	0.18
Fatigue Index (%)	61 \pm 11	65 \pm 10	63 \pm 12	0.32
RPE (6-20)	20 \pm 1	20 \pm 1	19 \pm 1	0.64
HR (b/min)	181 \pm 10	177 \pm 12	179 \pm 5	0.23
Session RPE (0-10)	8 \pm 1	8 \pm 2	8 \pm 0	0.66

HR = heart rate, RPE = rating of perceived exertion, b/min = beats per minute, CON = control, WBV = whole-body vibration, and UBV = upper-body vibration.

Table 4. Recovery Method Subjective Evaluation (RSME) 100-mm scale for CON, WBV, and UBV treatments (n = 8). Values are Mean \pm SD. Mean shown with higher score indicates “more likely”.

	CON Mean \pm SD	WBV Mean \pm SD	UBV Mean \pm SD	<i>p</i> - value
Do you feel using this recovery method helped you to recover better?	30 \pm 19*	40 \pm 24	65 \pm 19	0.009
Do you feel using this recovery method improved your performance ability?	28 \pm 19*	37 \pm 21	67 \pm 16	0.001
How did you feel about the intensity of the recovery?	6 \pm 11**	28 \pm 23	52 \pm 28	0.002
How did you feel about the amount/time of recovery?	34 \pm 14	42 \pm 23	47 \pm 20	0.11
Did you experience any leg discomfort during recovery period?	4 \pm 7	12 \pm 31	6 \pm 16	0.57
Did you experience any pain due to recovery treatment?	10 \pm 22	3 \pm 4	1 \pm 2	0.36
How likely would you be to choose this recovery method during training (between sets/intervals)?	56 \pm 20	30 \pm 30	50 \pm 25	0.12
How likely would you be to choose this recovery method after a training session?	60 \pm 22	41 \pm 36	67 \pm 17	0.13

CON = control, WBV = whole-body vibration, and UBV = upper-body vibration.

* RMSE response was lower after CON compared to UBV ($p < 0.05$).

** RMSE response was higher after WBV and UBV compared to CON ($p < 0.05$).

Figure 1.

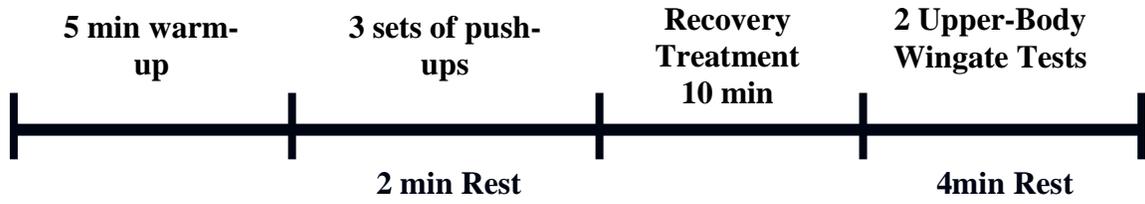
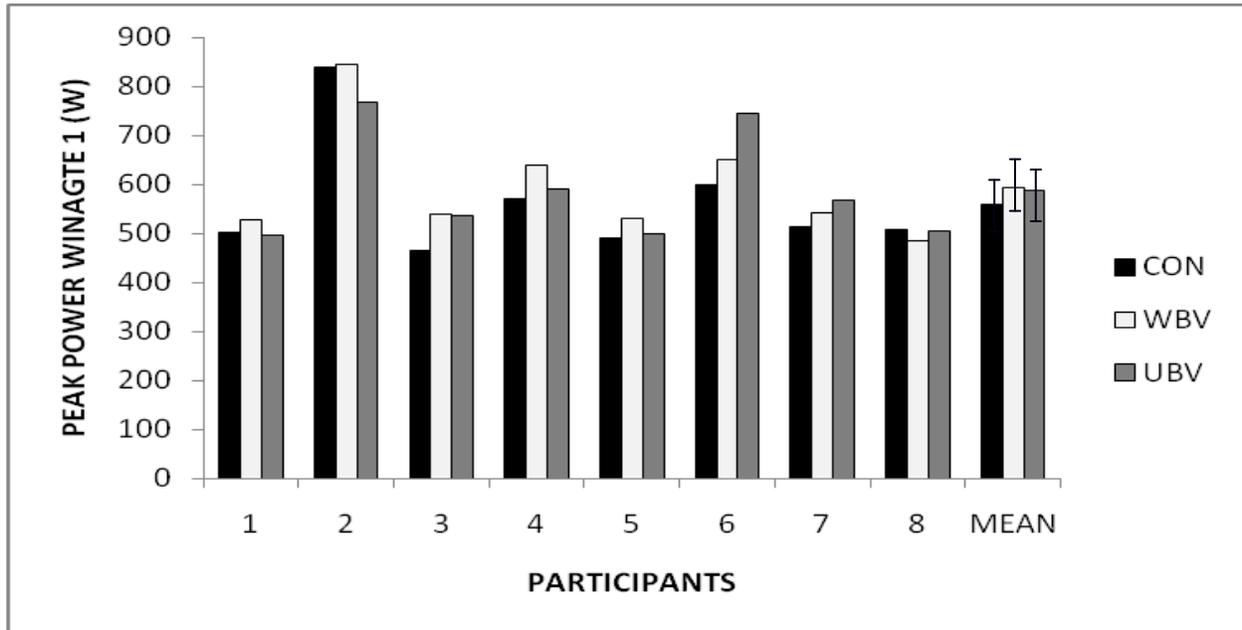
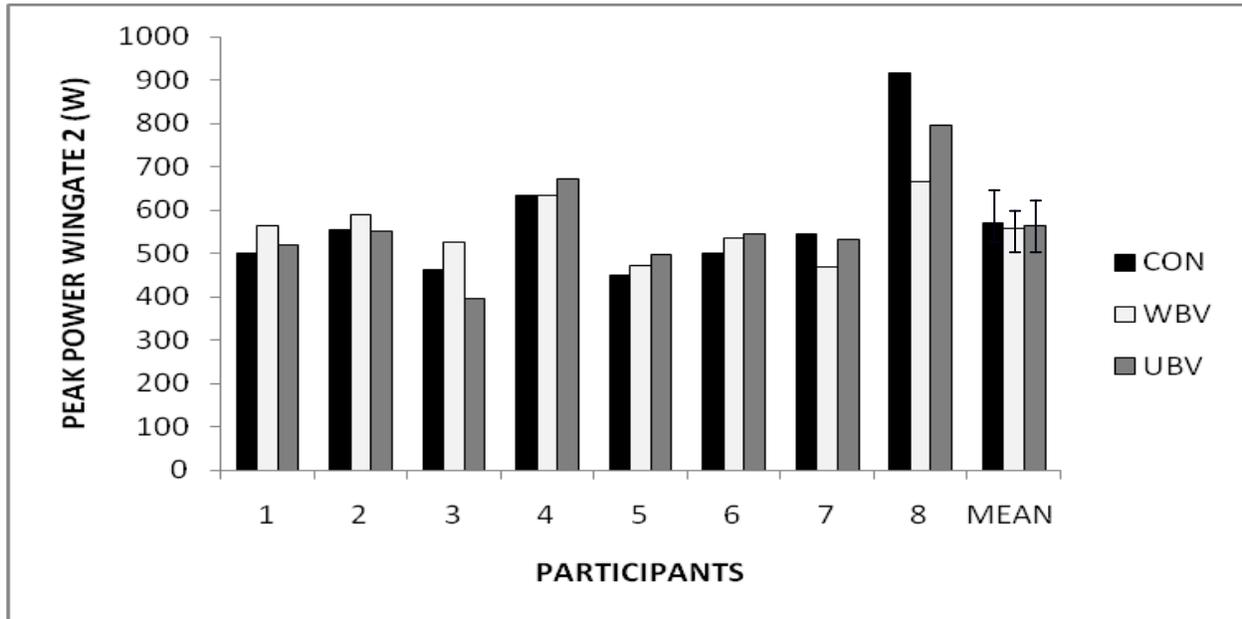


Figure 2.



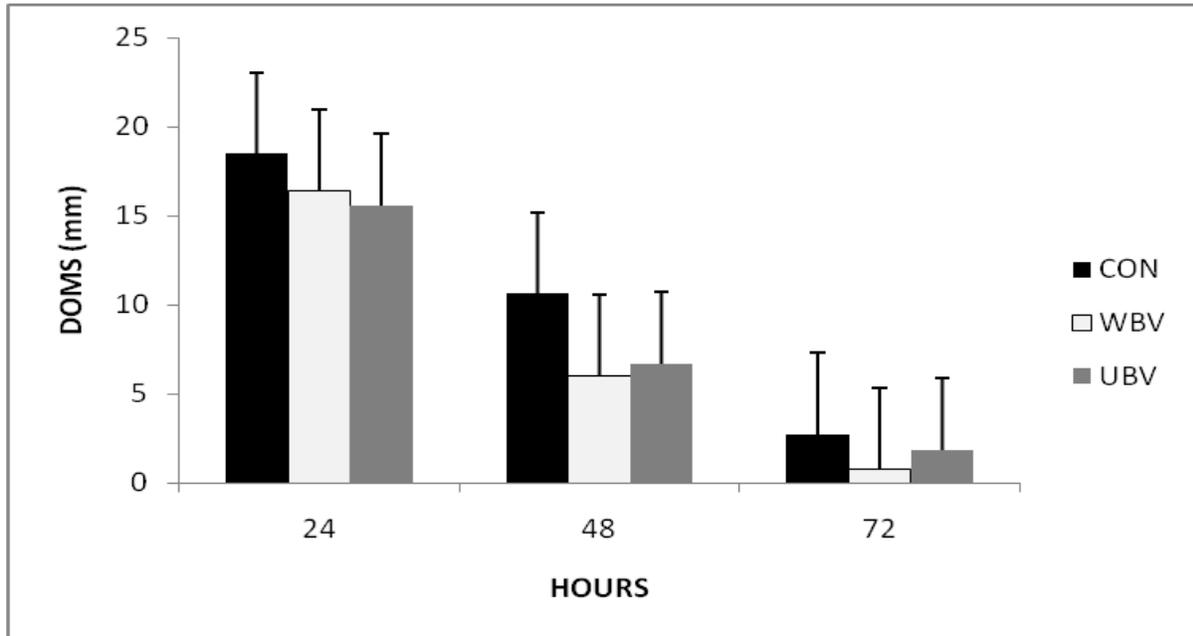
CON = control, WBV = whole-body vibration, UBV = upper-body vibration, and W = watts. Values are Mean \pm SD. Participant # 6 positively responded to UBV recovery treatment.

Figure 3.



CON = control, WBV = whole-body vibration, UBV = upper-body vibration, and W = watts. Values are Mean \pm SD.

Figure 4.



CON = control, WBV = whole-body vibration, UBV = upper-body vibration, and mm-millimeters. Values are Mean \pm SD.

CHAPTER IV
ACUTE EFFECT OF WHOLE-BODY VIBRATION ON
SPRINT PERFORMANCE AND RECOVERY

ABSTRACT

The purpose of this study was to compare two recovery methods, control (CON) and whole-body vibration (WBV), on actual and perceived recovery, lower leg volume and sprint performance. Physically active female volunteers ($n=12$) participated in the study. In a counterbalanced design, participants completed a Yo-Yo intermittent test to volitional fatigue, 5 x 20-m sprints, each of three recovery treatments on separate occasions, and post-recovery 5 x 20-m sprints to assess sprint performance. Rating of perceived exertion (RPE), heart rate (HR), and lower-leg volume were measured after fatiguing exercise, recovery treatment, and sprints. No significant mean differences ($p = 0.97$) were found between CON and WBV regarding average of best three 20-m sprint times (3.85 ± 0.2 and 3.84 ± 0.25 s, respectively), or ($p = 0.94$) 10-m split times (2.22 ± 0.12 and 2.21 ± 0.15 s, respectively). Individual data suggested that one of eight participants responded positively to WBV recovery treatment compared to no vibration, as indicated by least significant difference analysis. In addition, a significantly better ($p = 0.02$) perceived recovery rating was observed after WBV (7 ± 2) compared to CON (5 ± 2). Post-recovery lower-leg volume was significantly higher than pre-treatment volume after WBV ($p = 0.03$) but not after CON ($p = 0.07$). In conclusion, no benefits were observed for WBV in enhancing recovery or sprint performance.

KEY WORDS: Passive vibration, cooling, perceived recovery, leg volume, Yo-Yo test

INTRODUCTION

Many sports are high-intensity, intermittent activities requiring extreme conditioning. High rates of energy expenditure and accumulation of metabolic by-products occur during high intensity activities due to increased anaerobic metabolism. Energy depletion and accumulation of by-products such as lactic acid and inorganic phosphate eventually contribute to fatigue and reduced performance. Adequate recovery is needed to replenish energy stores and clear metabolic by-products. However, sometimes there is a limited amount of time available for the recovery between exercise sessions which can lead to impaired performance. Various recovery modes are used individually or in combination by competitive athletes (1). These recovery modalities are believed to decrease edema and relieve muscle pain and soreness, improve blood lactate removal and enhance creatine kinase (CK) clearance via increased blood flow which assist the healing process of the damaged muscles and ease delayed-onset muscle soreness (1).

Whole-body vibration (WBV) is a training intervention gaining popularity among competitive and recreational athletes. Many recent studies evaluated the effects of WBV as a warm-up routine or training technique on strength (17), sprint performance (10), electrical activity during a voluntary muscle contraction (3), vertical jump (7), flexibility (8), and agility of the lower-body (7). Improvements in performance following WBV intervention are believed to be due to increased neural activity and mechanical stimulation to the muscle which causes increased recruitment of the muscle fibers (3, 5).

There is limited amount of research available on effects of WBV on recovery after fatiguing exercise and sprint performance. Most of the previous research focused on the effects of WBV as a warm-up or pre-activation routine before sprint performance. In the performance

study, by Bullock et al. (2008) faster 5- to 10- meter split times, however, no significant improvement in overall sprint performance, squat jump and countermovement jump (CMJ) were observed following WBV compared to control treatment. Although, WBV may not have any potential benefits to aid sprint performance as warm-up routine it could be useful as a recovery modality.

WBV could be a practical and easy addition to existing recovery methods used in a variety of athletic settings. Increased neural activity and mechanical stimulation to the muscle due to WBV increases muscle metabolic demand (3, 6, 21, 22, 24) which may cause an increase in blood flow to supply the need of increased demand. Recently, it has been shown that WBV increases peripheral circulation, muscle and skin blood flow and increases muscle temperature (9, 12, 15, 18). Thus, it was hypothesized that increased circulation may help facilitate delivery of needed nutrients, enhance clearance and removal of metabolic by-products accumulated due to high intensity exercise, which, could help to overcome fatigue and aid recovery, thus improving performance (25, 26).

Therefore, the purpose of the present study was to evaluate the effects and benefits of WBV as a recovery modality on sprint performance, lower leg volume (as indicator of blood flow change), and perceived recovery after fatiguing exercise. We hypothesized that WBV would provide better actual and perceived benefits compared to no vibration, thus, improved sprint performance and perceived recovery after fatiguing exercise.

METHODS

Experimental Approach to the Problem

Participants completed two performance trials in counterbalanced order to evaluate the effects of WBV as a recovery modality on sprint performance, perceived recovery, and lower leg volume after fatiguing exercise.

Participants

The study included 12 physically active females between 19 and 40 years of age who participated in at least 300 minutes of moderate intensity physical activity per week. Power analysis suggested that with this sample size ($n=12$), we would be able to detect an effect of 0.15 seconds with alpha level at 0.05 and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72).

Participants were informed of health risks and side effects such as itching and temporary edema before the study and provided written informed consent according to the guidelines of the local Institutional Review Board. In addition, participants completed the Physical Activity Readiness Questionnaire (PAR-Q) (20), and current health status and training status questionnaires. In addition, participants were asked not to participate in vigorous intensity physical activity and to avoid alcohol at least 24 hours prior to each test session. Prior to the study, the purpose and performance trials were explained and different types of treatments were introduced. Participants were verbally introduced to the study procedures prior to agreeing to volunteer and signing an informed consent form. Only physically active participants participated in the study; therefore, the study requirements did not exceed their normal efforts. Physical

activity routine, frequency and type, and prior lower-body injuries were assessed using an exercise and injury questionnaire.

Body composition was estimated using a skinfold caliper (LANGE, Beta Technology Incorporated, Cambridge, Maryland). Skin folds were measured at the suprailiac, triceps and thigh (11). Three measures were taken at each site and the average of the three was recorded. Body fat was estimated using the sum of skin folds and age (11). Participants' age, weight, height, and percent body fat are presented in Table 1.

(Table 1 about here)

Procedures

Participants completed two performance trials in counterbalanced order, separated by at least 72 hours. Each participant completed a trial consisting of: warm-up, Yo-Yo intermittent test to volitional fatigue, 5 x 20-m sprints, four leg volume measurements, recovery treatment and 5 x 20-m sprints. Study design is presented in Figure 1.

(Figure 1 about here)

Warm-up – A warm-up was performed on a cycle ergometer for five minutes at a self selected work rate.

Fatiguing exercise - One minute after the warm-up, the Yo-Yo intermittent test level one (13) was performed to volitional fatigue. In addition, five 20-m sprints were performed with 30 s rest in between sprints. Total distance covered during the Yo-Yo intermittent test was recorded. In this test, participants repeatedly performed intervals of 20-m runs over a prolonged period of time to volitional fatigue. The participant had to run 20-m, turn around and run 20-m back between the markers in a steadily decreasing duration of time. Participants started with speed

level five and had to run back and forth between the markers in 14.5 s, then progressed to speed levels 9, 11, 12, 13, 14 and 15. After each run back and forth, participants had ten seconds of rest. As the test progressed, the recovery period and time for running were reduced. A warning was given if the participant did not complete the run in allocated time. The participant was stopped the next time they did not complete the run in allocated time or whenever the participant chose to stop.

Lower leg volume – Leg volume was used as an indicator of changes in blood flow to the leg. Leg volume was measured four times: at rest before the session, immediately after the Yo-Yo test and 5 x 20-m sprints were completed, immediately after the recovery treatment, and 15 minutes after the last sprint was performed. When participants arrived at the lab, they remained seated in the chair for 15 minutes for the resting value to be obtained. Resting leg volume was measured in order to evaluate the consistency of the starting point of lower leg volume among the recovery treatments. Leg volume after fatiguing exercise and after recovery treatment was measured in order to determine if the blood flow to the leg increased due to WBV treatment. The last leg volume measure was made to evaluate whether the leg volume increased due to WBV and not due to exercise induced edema.

The leg volume was measured by water displacement in a leg-sized plastic tank of water using a technique similar to that used by Pasley et al. (2008). Water temperature was held between 32-36°C and measured with the thermometer (OMEGA Engineering Inc., Stamford, CT). A mark was made near the knee with a marker to ensure that the leg was placed at the same depth every time. Participants were asked not to wash off the mark. If they did we reapplied the mark so it would be consistent for each leg volume measurement for each session. A spout was attached to the tank and a dry pitcher was placed under the spout. Participant slowly inserted

their lower leg into the water to the mark and all displaced water was collected into the pitcher and volume measured to the nearest 10 ml.

Sprints - Two minutes after the recovery treatment, five maximal performance 20-m time trials were performed (5 x 20-m sprints with 30 seconds rest in between). Splits were measured at 0-10 m and 0-20 m and recorded to the nearest 0.01 second using a timing system (Brower Timing System, Draper, Utah). Each sprint was done using a standing start and words “Get ready” and “Go.”

Recovery Treatments

Each treatment was delivered after fatiguing exercise and immediately after the second leg volume measure. Immediately after the recovery treatment, a third leg volume measurement was taken.

Whole-Body Vibration Treatment – The WBV treatment was delivered using a WBV plate (VibePlate, Lincoln, NE). Participants were seated with feet placed on the vibrating plate with socks only. Vibration loading was 10 continuous minutes; vertical vibration form and the frequency of vibration was 30-35 Hz with amplitude of 2 mm (Figure 2).

(Figure 2 about here)

Previously, it has been reported that WBV treatment enhanced electromyography (EMG) response of the leg muscles (6, 24). Additionally, an increase in oxygen consumption (21, 22) as well as an increase in oxygenation of the vastus lateralis (27) following WBV has been observed indicating increased muscle metabolic demand during WBV. Therefore, we used passive application of WBV not to cause further fatigue.

Control Treatment – The protocol was the same 10-min duration as for WBV treatment; with the participant seated and feet on the plate; however, during the control-treatment the vibration platform was not vibrating.

Measures

RPE – Rating of perceived exertion was obtained four times: immediately after the Yo-Yo test, sprints, recovery treatment, and after second session of sprints. Participants rated sessions using Borg's 15-point scale (6-20) (2).

Heart Rate – Heart rate was recorded using Heart Rate Monitors (Polar Electro Inc., Lake Success, NY) immediately after fatiguing exercise and after recovery treatment, and after each sprint performance.

Perceived Recovery Scale – The scale was used to determine participant's perceived recovery after control and each recovery treatment using a 0-10 scale (very poorly recovered to very well recovered) (14).

Overall Session Rating of Perceived Exertion – The OMNI 1-10 scale was used and collected 15 minutes post the entire session (23).

Recovery Method Subjective Evaluation - Participants were given a questionnaire right after each session was completed. The questionnaire consisted of eight questions evaluating the recovery methods. Participants were asked about their recovery method experience and characteristics such as comfort, pain, intensity, time and improved performance ability. Participants were asked to draw a single, vertical, straight, mark along a line to indicate the response about how they felt using the recovery method on a 100-mm line for each of the above characteristics. The left end represented the least amount of that quality (not at all) and the right

end represented the most amount of that quality (very much). For example: Do you feel using this recovery method improved your performance ability?

Not at all _____ Very much

Statistical Analyses

Differences between CON and WBV were analyzed using Student's paired, two-tailed *t*-test on excel spreadsheet (Microsoft Excel, Microsoft Corporation) for the dependent variables: average of three best 10-m and 20-m sprint times, leg volume and perceived recovery. In addition, RPE and HR: warm-up, post fatiguing exercise, post recovery treatment, and post each sprint; Yo-Yo intermittent test distance, overall RPE, leg RPE, breathing RPE, session RPE and subjective recovery method evaluation were analyzed using Student's paired *t*-test, two-tailed on excel spreadsheet (Microsoft Excel, Microsoft Corporation). Alpha value was set at 0.05.

Individual data, expressed as responders and non-responders to WBV treatment were determined by a least-significant-difference analysis using SD from the study and power analysis. With a sample size of 12, we would be able to detect a 0.11 and a 0.2 s difference in sprint times with WBV recovery treatment for 10- and 20- meter sprint times, respectively, compared to no vibration with alpha level 0.05 and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72).

RESULTS

Warm-up, Yo-Yo intermittent test and 5 x 20-m sprint results before recovery treatment are presented in Table 2.

(Table 2 about here)

10-m and 20-m Sprint Times

No significant mean differences ($p = 0.94$) were found between CON and WBV for average of best three 10-m times (2.22 ± 0.12 and 2.21 ± 0.15 s, respectively) and 20-m times (3.85 ± 0.2 and 3.84 ± 0.25 s, respectively) ($p = 0.97$). Also, no significant mean differences ($p = 0.60$) were found for average HR between CON and WBV (143 ± 12 and 144 ± 13 b/min, respectively). Individual data indicated that 1 of 12 participants responded to WBV recovery treatment and performed faster average 10- and average 20- meter sprint times compared to no vibration as determined by least significant difference analysis.

Perceived Recovery

A significant mean difference ($p = 0.02$) was found in perceived recovery after WBV (7 ± 2) compared to CON (5 ± 2) (Figure 3), but no significant mean differences ($p = 0.61$) were found in recovery HR after CON and WBV recovery treatments (100 ± 14 and 99 ± 7 b/min). In addition, no significant mean differences between CON and WBV were found for overall RPE ($p = 0.80$), breathing RPE ($p = 0.84$), leg RPE ($p = 0.25$) or session RPE ($p = 0.72$).

(Figure 3 about here)

Leg Volume

A significant mean difference was found for mean lower leg volume pre- and post-recovery treatment. Lower leg volume was significantly higher after WBV ($p = 0.03$) but not after CON ($p = 0.07$) (Figure 4). There was no difference ($p = 0.65$) in resting leg volume

between sessions CON (2826 ± 220 ml) and WBV (2809 ± 275 ml); however, a significant mean difference ($p = 0.04$) was found post recovery treatment between WBV and CON.

(Figure 4 about here)

Subjective Evaluation

Recovery method subjective evaluation for CON and WBV recovery treatments are presented in Table 3.

(Table 3 about here)

DISCUSSION

The purpose of this study was to evaluate WBV as a recovery modality, perceived recovery and lower leg volume after fatiguing running exercise. This is the first study evaluating the effects of WBV as a recovery modality on sprint performance. The results of this study show little evidence that WBV has potential to enhance recovery or improve sprint performance compared to no vibration, under the conditions of this study. In this study we observed no significant mean difference in 10- or 20- meter sprint times or HR response after a single bout of WBV recovery treatment compared to no vibration.

In their performance study, Bullock et al. (2008) compared squat jump, CMJ and a maximal 30-m sprint before and after acute exposure of WBV compared to the control treatment. They observed faster 5- to 10- meter split times after 3 x 60 s of WBV at a frequency of 30 Hz and a non-significant trend for the 30-m sprint time performed after WBV to be faster compared to the control. However, no other significant differences were found between any other split

times. The differences between the present recovery study and Bullock and colleagues (2008) may be attributable, in part to the type of exercise that was performed before sprint performance and WBV treatment application. In the present study we used the Yo-Yo intermittent test and five 20-m sprints to induce fatigue; therefore, WBV was used as a passive recovery routine, whereas, Bullock and colleagues used WBV as pre-activation of fast twitch muscle fibers after a full sprint competition warm-up. Although, the intensity was similar in both studies, the duration of WBV was longer in the present study, which, still may have been insufficient to elicit any improvements, or conversely, could have contributed to further fatigue. Additionally, neuromuscular rehearsal over time of the recovery treatment routine may be needed to elicit any performance improvements.

Most of the time coaches work with individuals and not groups. Therefore, it is important to evaluate not only group means but also individual results. According to the individual data, only one of the participants responded to WBV recovery treatment compared to no vibration as indicated by least significant difference analysis. Therefore, if results of improved recovery and sprint performance proved stable for one of the athletes it may be used to optimize one's recovery and enhance performance.

In the present study, we observed a significant increase in total leg volume following WBV recovery treatment. This supports the work of Kerschman-Shindl et al. (2001) and Lythgo et al. (2009) who reported an increase in leg blood flow following WBV treatment. An increase in mean blood flow velocity of quadriceps and gastrocnemius muscles was observed after 9-minutes of standing with three sets of different positions on a WBV platform at a vibration frequency of 26 Hz (12). Similar results were found by Lythgo et al. (2009) who reported an increase in peak and mean blood cell flow velocity at various frequencies ranging from 10-30

Hz, however, no significant increase in systolic and diastolic diameter of the artery was observed suggesting that an increase in blood flow velocity occurred without vasodilation. Even though, the exact physiological mechanism responsible by which leg volume was increased in our study is not certain. It may be suggested that an increase in total leg volume in the present study was most likely due to increased vasodilation and blood flow in the lower extremities augmented by WBV.

In the past, an increase in EMG (6, 24) and oxygen consumption during WBV treatment were observed (21, 22). Thus, we hypothesized that increased muscle activity and metabolic demand due to WBV would drive an increase in blood flow and thereby it could enhance delivery of oxygen and needed nutrients, enhance clearance and removal of metabolic by-products, which would aid recovery and improve performance (25, 26). However, we did not observe any potential benefits or improvements in recovery and sprint performance following WBV compared to no vibration.

While actual recovery was not enhanced, perceived recovery was better after WBV compared to no vibration. Participants reported being well recovered after WBV compared to being adequately recovered after no vibration. Higher responses were observed after WBV recovery treatment on the Recovery Method Subjective Evaluation questionnaire regarding which recovery method helped participants to recover better and improve performance ability. WBV was perceived as a higher intensity treatment; however, HR was not significantly different among recovery treatments suggesting no additional strain on cardiovascular system added by WBV compared to no vibration. Also, no difference was observed in perceived pain or leg discomfort by the participants after WBV treatment. A non-significant trend was observed for

the choice of recovery treatment during and after training sessions of higher response after WBV compared to no vibration.

In conclusion, acute WBV when used as a recovery modality after fatiguing running exercise did not enhance recovery sprint performance compared to no vibration as indicated by the group mean data. However, psychological perception of better recovery may be of some benefit for training or competition.

PRACTICAL APPLICATIONS

Our study showed that 10 min of WBV at 30-35 Hz, on average, did not appear to affect recovery after fatiguing running exercise; and only one of twelve participants responded to WBV recovery treatment. When a limited amount of time for proper recovery is available, finding the best possible technique is a key to successful performance. Although, no actual benefit of recovery was observed, participants felt better recovered after WBV and believed that WBV improved their performance ability compared to no vibration. Thus, psychological perception of fatigue may be overridden by modifying it and helping athletes to improve their performance. Many coaches work with individual athletes and not a group, therefore, if WBV recovery treatment proved stable for an athlete it may be used as a recovery modality after fatiguing running exercise to optimize performance. However, time, mode and intensity may vary for each individual and thus needs to be determined.

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Table 1. Physical Characteristics of Participants (n = 12). Values are Mean \pm SD.

Characteristics	Females n=12 Means \pm SD
Age (y)	24 \pm 3
Weight (kg)	59 \pm 4
Height (cm)	164 \pm 5
% body fat	20 \pm 3

Table 2. Comparison of physiological variables for warm-up and fatiguing exercise between CON and WBV recovery treatment sessions (n = 12). Values are Mean \pm SD.

	CON	WBV	<i>p</i> - value
	Mean \pm SD	Mean \pm SD	
W-up RPE (6-20)	9 \pm 2	8 \pm 1	0.20
W-up HR (b/min)	109 \pm 14	109 \pm 25	0.81
Yo-Yo Distance (m)	620 \pm 265	653 \pm 285	0.41
Yo-Yo RPE (6-20)	17 \pm 1	17 \pm 2	0.34
Yo-Yo HR (b/min)	177 \pm 13	179 \pm 11	0.59
Average 20-m Times (s)	3.80 \pm 0.24	3.80 \pm 0.18	0.99
Average 20-m HR (b/min)	144 \pm 12	145 \pm 17	0.83

CON = control, WBV = whole-body vibration, HR = heart rate, RPE = rating of perceived exertion, b/min = beats per minute, s = seconds, m = meters, and W-up = warm-up.

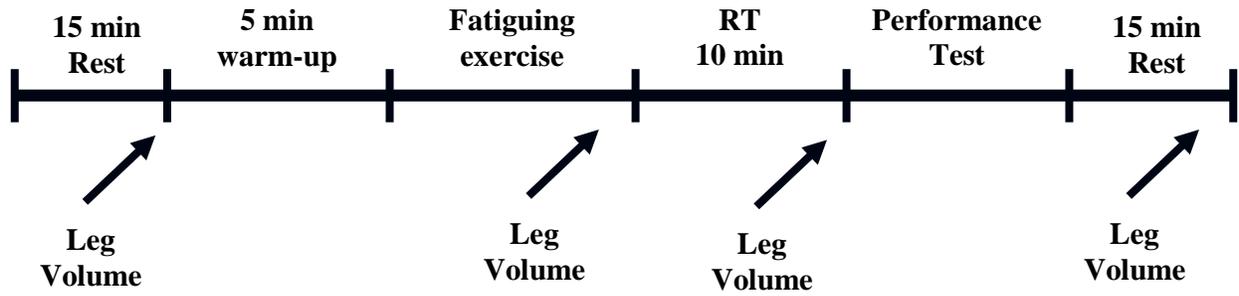
Table 3. Recovery Method Subjective Evaluation 100-mm scale for CON and WBV recovery treatments (n = 12). Values are Mean \pm SD. Mean shown with higher score indicates “more likely”.

	CON Mean \pm SD	WBV Mean \pm SD	<i>p</i> - value
Do you feel using this recovery method helped you to recover better?	25 \pm 21*	64 \pm 24	0.004
Do you feel using this recovery method improved your performance (sprint) ability?	21 \pm 19*	59 \pm 20	0.003
How did you feel about the intensity of the recovery?	18 \pm 26*	40 \pm 30	0.002
How did you feel about the amount/time of recovery?	50 \pm 9	54 \pm 19	0.48
Did you experience any leg discomfort during recovery period?	16 \pm 22	11 \pm 12	0.53
Did you experience any pain due to recovery treatment?	7 \pm 14	5 \pm 9	0.7
How likely would you be to choose this recovery method during training (between sets/intervals)?	39 \pm 32	59 \pm 22	0.16
How likely would you be to choose this recovery method after a training session?	46 \pm 34	67 \pm 28	0.16

CON = control and WBV = whole-body vibration.

* RMSE response was higher after WBV compared to CON ($p < 0.05$).

Figure 1.

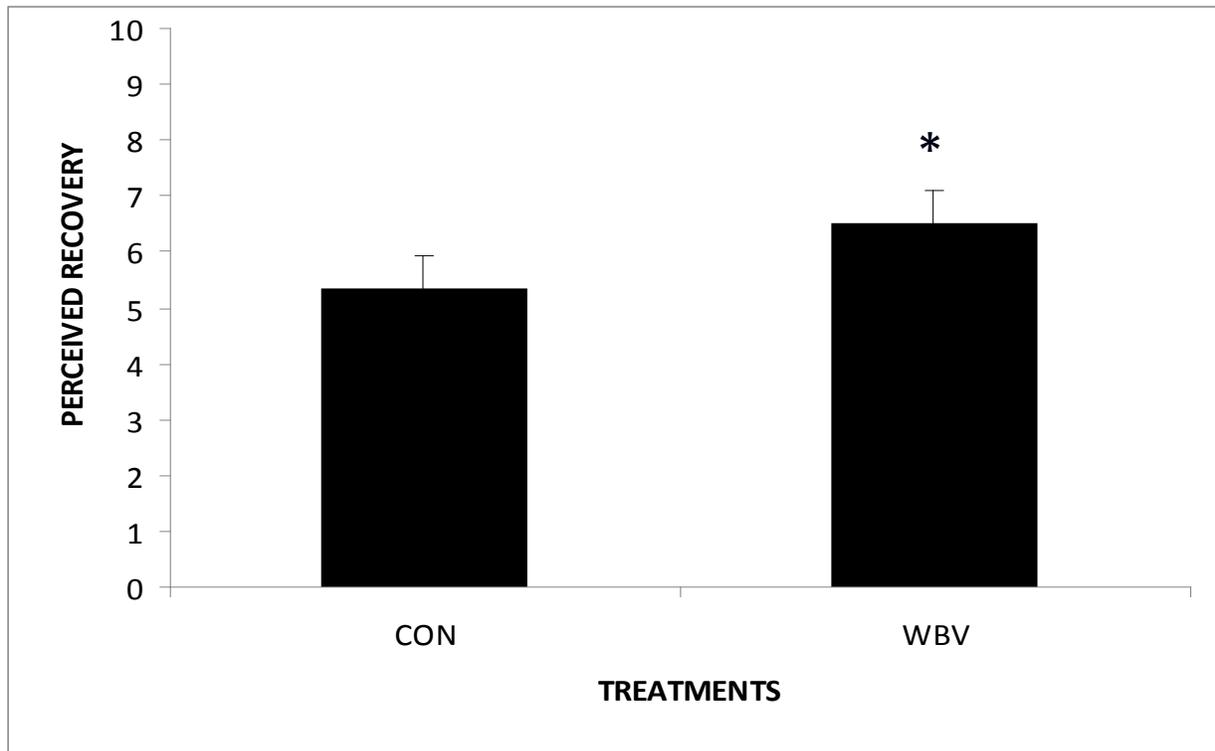


RT = recovery treatment.

Figure 2.

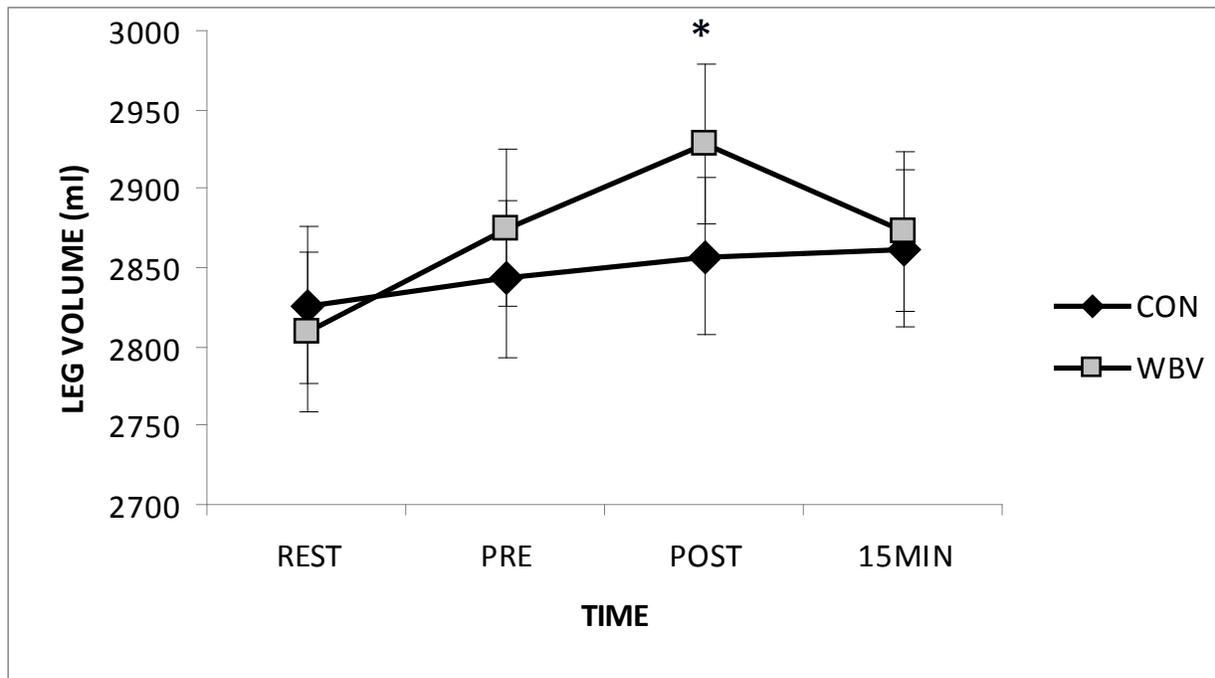


Figure 3.



CON = control and WBV = whole-body vibration. * PR was higher after WBV recovery treatment compared to CON ($p < 0.05$).

Figure 4.



CON = control, WBV = whole-body vibration, ml = milliliters, REST = 15 minutes after arrival to the lab, PRE = before recovery treatment, POST = after recovery treatment, 15MIN = 15 minutes after the last sprint.

* Mean leg volume pre and post recovery treatment was significantly higher after WBV ($p < 0.05$).

CHAPTER V

CONCLUSIONS

In conclusion, addition of WBV did not provide greater benefits for performance after fatiguing exercise compared to no vibration as indicated by group means under the conditions of the present studies; although, for a few athletes it might hold promise for enhanced recovery and improved performance if the effects are shown to be stable. Coaches and athletes should test the stability of the individual responses to any given recovery treatment and determine whether it helps to overcome fatigue, enhance recovery, and improve athlete's performance. When a limited amount of time for proper recovery is available, finding the best possible technique is a key to successful performance. If athletes need to recover in a short period of time WBV may have potential psychological benefits but does not appear to aid performance. Psychological perception of better recovery may be of some benefit for training or competition. Because there is variability among athletes, and many potential combinations of training and performance, duration, frequency, intensity, and mode, additional combinations of these variations should be evaluated before dismissing WBV or UBV as an effective recovery technique.