SUBSTRATE USAGE AND ENERGY EXPENDITURE DURING AN ACUTE EXERCISE BOUT AFTER HABITUATION TO WHOLE BODY VIBRATION TRAINING

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ABSTRACT

HILARY MCNICHOLS: Substrate Usage and Energy Expenditure During an Acute Exercise Bout After Habituation to Whole Body Vibration Training
(Under the direction of Bonita Marks, PhD)

This study examined how whole body vibration training impacts energy expenditure and substrate utilization following eight weeks of core training. Healthy subjects (26 ± 6 yrs) were randomized into a vibration (n = 12) or non-vibration (n = 12) group. Each group participated in identical training but only the vibration group received the vibration stimulus. Metabolic data was collected during the last exercise session. There was no significant difference in energy expenditure (kcal/kg/min) between groups ($p = 0.396$). However, the vibration intervention group utilized 8.8% more carbohydrates and 8.9% less fat than the non-vibration control group ($p < 0.05$). While these findings suggest that WBV training may not be an effective exercise intervention for fat utilization, the enhanced carbohydrate utilization suggest it may be beneficial for strength training in healthy recreationally active normal-weight adults.

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VO_2 = Oxygen uptake

VCO_2 = Carbon dioxide production

RER = Respiratory exchange ratio

WBV = Whole Body Vibration

CHAPTER ONE

Introduction

Whole body vibration (WBV) exercise has been rapidly gaining popularity worldwide for over a decade as a new training method for improving strength and power output (Rittweger et al. 2002; Cardinale and Bosco 2003; Issurin 2005). WBV exercise sessions consist of having a person perform static and dynamic exercises while standing on a vibrating platform. Vibration delivered to the body is thought to stimulate the muscle spindles located within the muscle belly, triggering a reflexive muscular response that increases the intensity and rate of muscle fiber contractions. Vibrations are mechanical oscillations that are characterized by a combination of both the rapid changes in maximum and minimum height of the moving platform (amplitude) and the rate in which vibrations are delivered (frequency) (Romaiguere 1993). The impact of vibration on the body varies depending not only on the amplitude and frequency of the oscillation, but also body position on the plate and the duration of exposure (Rittweger et al. 2002; Cardinale and Bosco 2003; Jordan et al. 2005).

Exposure to vibratory oscillations elicits small rapid changes in muscle length which are detected by muscle spindles, or stretch receptors. The increase in muscular neural input causes increased activation of alpha motor neurons which leads to greater muscular contractions in response (Issurin et al. 1994; Bosco et al. 1998; Bosco et al. 1999; Cardinale and Wakeling 2005). This reflexive muscular contraction initiated by muscle stretch, termed the tonic vibration reflex (Martin and Park 1997; Mester et al. 1999; Wilcock et al. 2009), enhances neuromuscular potentiation by increasing motor unit recruitment, firing rate of motor units, and improving muscular synchronization (Issurin et al. 1994; Rittweger et al. 2000; Rittweger et al. 2003). In addition, the motor unit recruitment threshold is lowered during whole body vibration as compared to voluntary contraction. This induces a greater and more rapid recruitment of high-threshold Type II muscular fibers, which are heavily relied on during explosive and strength related muscular contractions (Romaiguere 1993).

Furthermore, vibratory loads have been shown to increase the earth's gravitational acceleration on the affected body from 3.5 to 17 g (1 g being the acceleration due to the Earth's gravitational field) depending on the size of the wave's amplitude, thereby placing the body in a hypergravitional situation (Bosco et al. 1998; Bosco et al. 1999; Bosco et al. 2000; Cardinale and Wakeling 2005). Hypergravity training, when applied during exercise routines, has been shown to be an effective method to elicit improvements in both force and velocity output even in already highly trained athletes (Bosco 1985). Therefore, activities that use explosive and powerful movements mediated by the tonic vibration reflex experience the most benefits from this type of training (Wilcock et al. 2009).

Many studies have shown that vibration training, defined as performing numerous bouts of WBV exercise over a period of time, is an effective exercise intervention for improving maximal strength and power in both trained and untrained individuals. Other potential benefits include increases in flexibility, bone density, metabolic rate, and fat loss (Issurin et al. 1994; Bosco et al. 1998; Bosco et al. 1999; Rittweger et al. 2001; Rittweger et al. 2002; Verschueren et al. 2004; Cochane et al. 2005; Nordlund and Thorstensson 2007; Paradisis and Zacharogiannis 2007, Vissers et al. 2010). These potential benefits make whole body vibration training appealing not only to elite athletes, but could have positive impacts on a wide variety of populations. It is now becoming more widely available to people throughout 92 countries, granting users access through health clubs, wellness centers, spas, hospitals, physical therapy and rehabilitation clinics, professional and collegiate athletic training facilities, and private fitness trainers (Power Plate 2010).

However, little is known about the metabolic consequences of WBV beyond that of acute exposure. It has been suggested that acute vibration imposes a greater workload on the body, thus necessitating a larger amount of muscular activation and increasing metabolic work (Rittweger et al. 2001; Rittweger et al. 2003; Da Silva et al. 2007; Garatachea et al. 2007). Another reason muscle activation is elevated is in order to dampen the effects of vibratory waves on body tissues, thus further increasing the metabolic rate (Mester et al. 1999, Vissers et al. 2009). It has been widely accepted and demonstrated for the past two centuries that ventilatory measurements of oxygen uptake (VO_2) and carbon dioxide production (VCO_2) can be used to determine type and rate of energy expenditure and substrate utilization (Lusk 1923; Jequier et al. 1987). Three studies that recorded measures of VO_2 during single bouts of acute vibration concluded that acute exposure resulted in greater kcal expenditure in the vibration group as compared to a control group performing the same exercises without vibration (Rittweger et al. 2001; Rittweger et al. 2002; Da Silva et al. 2007). These studies demonstrated that caloric expenditure was greatest during vibration at larger frequencies, greater amplitudes, and using heavier external loads because of the increased exercise intensity, greater recruitment of muscle fibers, larger muscular contractions, and greater number of involuntary muscular contractions. Thus far, only acute studies have been conducted that consider the impact of vibration on energy expenditure (Da Silva et al. 2007; Garatachea et al. 2007).

However, the results of these historical studies are not meaningful in terms of metabolic benefits unless the vibration stimulus continues to have the same effects on oxygen uptake and metabolism after a period of training. Initial strength and power increases with a new training program are due to neuromuscular adaptations and contributes less to the overall training effects as the program continues to progress (Malara et al. 2007). Since acute WBV targets the neuromuscular system, it may be possible that neuromuscular adaption to chronic exposure to vibration will result in a neuromuscular ceiling effect in which additional training will no longer result in further neuromuscular benefits (Paradisis and Zacharogiannis 2007). It has been suggested that vibration training can augment this learning effect, but it is unknown to what degree this will continue to occur (Issurin et al. 1994). Since hypergravity conditions are similar to WBV and hypergravity exposure has been shown to augment neuromuscular learning, WBV may similarly increase neuromuscular learning, subsequent muscular activation, and metabolic rate after a person has become well trained using WBV.

According to Vissers et al. (2010), WBV aids weight loss by increasing the amount of fat that is used for energy during exercise. However that theory does not account for the fact that weight loss could have been a result of increased total energy expenditure (from both carbohydrates and fats) rather than an actual increase in fat utilization (Rittweger et al. 2001; Fjeldstad et al. 2009). A study conducted by Maddalozzo et al. (2008) observed that animals that were in the no vibration group accumulated less body fat over a maturation period than those in the vibration group. Further studies are needed to determine if Maddalozza et al's (2008) finding is applicable to humans. Research involving human subjects reported both positive and negatives changes in body fat and typically utilize unhealthy populations who were overweight, obese, post menopausal, or untrained females (Roelants et al. 2004;

Fjeldstad et al. 2009; Vissers et al. 2009, Vissers et al. 2010). The results of these studies are not generalizable since the populations considered in studies thus far have not included healthy populations. Although some studies have concluded that WBV training increases the reliance on carbohydrate as a fuel source, they were only applicable to specific populations (diabetic, elderly, or all males), again limiting their generalizability (Baum et al. 2007; Da Silva et al. 2007).

Statement of the Problem

Data is lacking concerning how WBV training impacts energy expenditure after habituation to regular training. Short term studies that considered energy expenditure have targeted males, obese/overweight women, and post-menopausal women. There is also insufficient information elucidating how habituation to WBV affects substrate utilization in healthy populations. The few studies that have considered substrate preference during a WBV training session only considered acute exposure using subjects who were elderly, diabetic, or male. Therefore, the *primary purpose* of this study was to determine if WBV exposure influenced substrate utilization during a single exercise session during their last week of WBV training. A *secondary purpose* of this study was to determine how WBV training impacts energy expenditure in a healthy adult population after a period of habituation to the WBV training stimulus.

Research Questions and Hypothesis

Research Question One: How does a WBV training session impact carbohydrate and fat metabolism after habituation to multiple WBV exercise sessions?

Hypothesis 1a: There will be a significant difference in fat utilization between the vibration intervention group and the non-vibration control group.

Hypothesis 1b: There will be a significant difference in carbohydrate utilization between the vibration intervention group and the non-vibration control group.

Research Question Two: How does energy expenditure respond to a WBV training session after habituation to multiple WBV exercise sessions?

***Hypothesis 2*:** Energy expenditure will be greater in the vibration intervention group as compared to the non-vibration control group.

Definition of Terms and Abbreviations

Whole Body Vibration (WBV): Vibration applied to a body which is standing on a vibrating platform.

Training: An exercise intervention that is continually repeated over a period of time.

Oscillation: A periodic alteration of displacement over time.

Vibration: An oscillatory displacement with an alternating change in velocity and direction.

Duration (sec): The total amount of time that a person spends on the platform.

Amplitude (mm): the extent of the oscillatory motion (meaning distance traveled), that the platform moves from resting position to the highest point during vibration.

Frequency (Hz): the number of vibratory cycles delivered per second.

Acceleration (m/s^2): the rate of change of velocity (V) as a function of time.

Body Position: the position of a user's body on the platform. This determines the amount of stimulus and area of the body in which the vibration is focused.

Carbohydrates (CHO): is a compound that consists of carbon, hydrogen and oxygen, commonly known as "sugar" (examples: rice, potatoes, spaghetti, bread).

Oxygen consumption (VO_2): volume of oxygen consumed in one minute.

Carbon dioxide consumption (VCO_2): volume of carbon dioxide produced per minute.

Respiratory Exchange Ratio (RER): the ratio of the amount of carbon dioxide produced to the amount of oxygen consumed (VCO_2/VO_2) when steady state cannot be assumed.

Delimitations

This study was delimited to healthy males and females between 18 - 45 years of age. Those with a history of vestibular or balance disorders, musculoskeletal injuries within the past six months that limited physical activity for more than two days, or metabolic conditions (i.e. diabetes) were excluded from the study. Pregnant women were excluded due to unknown negative effects of WBV on the mother or fetus (Seidel 1993).

Limitations

A limitation of this study was potential inaccurate reporting of the subject's abstinence from food, caffeine, and exercise prior to testing. Failure to adhere to these required conditions could produce erroneous RER values. To minimize potential non-compliance, subjects were asked to verify their four hour abstinence via a written recall. Another potential limitation was that subjects exercised in a semi-fasting state, which could have impaired their exercise performance. To minimize this potential limitation, subjects with metabolic conditions that required strict dietary control were excluded from the study to prevent potential hypoglycemic symptoms. Because this study took place over an eight week period, effects from other exercise/physical activity routines may have interacted with the WBV training results. To minimize outside exercise/physical activity as a confounding variable, subjects were instructed before they started WBV training to maintain their usual exercise routines in terms of intensity, frequency, duration, and mode. Because menstrual cycle may impact substrate reliance, females subjects were asked to report their menstrual cycle stage at the time of testing (Lavoie 1986).

Significance

The use of WBV as an exercise intervention is quickly gaining popularity because of its numerous purported benefits. Though many research studies have observed that measures of strength and power will improve under the right WBV training conditions, metabolic changes in response to WBV remain unclear. Results from this study will provide valuable information concerning possible effects of WBV training on energy expenditure and substrate utilization in response to a single exercise bout after habituation to an eight week training WBV training regimen. The outcomes from this study may be helpful for development of realistic expectations in regards to kcal expenditure, fat and carbohydrate utilization during WBV training.

CHAPTER TWO

Literature Review

Introduction

The primary purpose of this literature review is to explain the physiological impact of whole body vibration (WBV) training and to explore the responses from acute and chronic exposure as reported from previous research studies. This literature review will also critically evaluate studies which have focused on the impact of short term WBV exposure on energy expenditure and substrate utilization.

Physiological Impact of Whole Body Vibration

Whole body vibration is applied to the body or body segment that is placed on a vibrating platform which allows vibration to be distributed to the entire body or body segment. Vibration stimulates muscle spindles, which are activated in response to the vibration-provoked changes in muscle length. Greater sensitivity of muscle spindles increases activation of alpha motor neurons, resulting in reflex muscular contractions, also known as the tonic vibration reflex (Issurin et al. 1994; Bosco et al. 1998; Bosco et al. 1999; Cardinale and Wakeling 2005; Wilcock et al. 2009). Studies have shown that vibration exposure improves neuromuscular responses by increasing motor unit recruitment, firing rate of motor units, and improving synchronization of involved muscular units resulting in greater muscular activity (Issurin et al. 1994; Rittweger et al. 2000; Rittweger et al. 2003). Because reflexive muscle activity represents activation of the neuromuscular system in response to a muscular perturbation, WBV primarily impacts the neuromuscular system (Bosco et al. 2000; Cardinale and Bosco 2003). In addition, the motor unit recruitment threshold is lowered during whole body vibration as compared to voluntary contraction. This induces a greater and more rapid recruitment of high-threshold Type 2 muscular fibers, which are heavily relied on during explosive and strength related muscular contractions (Romaiguere 1993). Muscular activity is further increased in an attempt to dampen vibratory waves as they travel through soft tissue (Mester et al. 1999; Roelants et al. 2006; Vissers et al. 2009). This could be an attempt to maintain balance, to increase muscle and joint stiffness in order to stabilize body segments, and decrease force effects imposed on the muscle (Mester et al. 1999).

Whole body vibration also places the user in a hypergravity situation. The gravitational load imposed on the body undergoing vertical WBV is 3.5 to 17 times greater than the normal load imposed by gravity (g) (Bosco et al. 1998; Bosco et al. 1999; Bosco et al. 2000; Cardinale and Wakeling 2005). Wilcock et al. (2009) calculated that a body standing on a vertically vibrating platform vibrating at a frequency of 30 Hz and amplitude of 6 mm would experience an extra 7.7g of force on the legs. Thus the level of gravitational resistance is increased and the muscular work required to perform an exercise will be greater during exposure to vibration. Not surprisingly, hypergravitational training (accomplished when athletes perform exercises while wearing weighted vests) has been shown to be an effective exercise intervention for inducing muscular hypertrophy and force-generating capacity, even in highly trained athletes (Bosco 1985; Cardinale and Bosco 2003).

Whole Body Vibration Training Responses

Whole body vibration is hypothesized to target the neuromuscular system and increase fast twitch muscle fiber recruitment (Rittweger et al. 2003). This substantiates the findings of acute and chronic studies that conclude WBV is a successful exercise intervention for improving measures of strength and power, both of which rely heavily on neuromuscular potentiation for improved performance (Issurin et al. 1994; Bosco et al. 1998; Bosco et al. 1999; Rittweger et al. 2002; Nordlund and Thorstensson 2007; Paradisis and Zacharogiannis 2007). A review by Jim Luo et al. (2005) concluded that vibration training is capable of inducing muscular adaptations as long as the intensity and volume of the exercise alone is sufficient to require near max effort dynamic muscular contractions.

In two studies that failed to observe significant increases in strength and power in response to WBV, subjects were only exposed to vibration for five minutes while maintaining a static squat position. The duration of exposure was too short to have an effect on muscular strength and power, and exercise intensity was too low to elicit substantial muscular activation (de Ruiter et al. 2003a; Colson et al. 2009). Another study that failed to observe an increase in strength and power from WBV training utilized isometric static contractions as opposed to dynamic movements during a training period that ranged from 5-8 minutes (de Ruiter et al. 2003b). Delecluse et al. (2005) failed to find a significant increase in strength and sprint power in sprint-trained athletes utilizing a 5 week training program that involved 9-18 minutes of WBV and employing a similar protocol that had previously been used on untrained people. The authors concluded that the WBV exercise protocol was not adequate to enhance muscular performance considering the highly trained status of the population. Therefore, it is not only one factor (either frequency, amplitude, duration of exercise, length of training, or mode of exercise) that makes WBV training effective, but rather a combination of factors that are capable of eliciting muscular activation in the involved population.

The current study not only employed dynamic exercises but also required the subjects to perform these exercises during a session that was equal to or greater than the length of time of previous studies (10-30 minutes) who had positive findings (Bosco et al. 1998; Bosco et al. 1999; Roelants et al. 2004; Paradisis and Zacharogiannis, 2007). Luo et al's.(2005) review declared that a frequency range of 30-50 Hz has been shown to activate muscle most effectively; thus this range is utilized in the present study. Research is less clear concerning recommendations for the optimal amplitude but the range in the proposed study utilizes common amplitude ranges found in previous studies (2.5 - 5 mm) that have observed increased muscular activation and increases in strength and power (Delecluse et al. 2003; Roelants et al. 2004; Roelants et al. 2006; Paradisis and Zacharogiannis, 2007).

Metabolic Responses

Because muscular activity increases in response to WBV, oxygen consumption in the vibrating muscles is greater, resulting in an increase in metabolic demand (Yamada et al. 2005). The magnitude of increased oxygen consumption is dependent on the intensity of exercise, duration of exercise, and acceleration of vibration (determined by the combination of vibratory frequency (Hz) and amplitude (mm) of the wave) (Rittweger et al. 2001; Rittweger et al. 2002; Rittweger et al. 2003). Only two studies have researched the impact of WBV on energy expenditure using indirect calorimetry throughout a short WBV session (11.5 minutes in Da Silva et al. (2007) and 3 minute sessions in Garatachea et al. (2007)). Da

Silva et al. exposed subjects to vibration for 11.5 minutes for seven sessions at a frequency of 30 Hz and amplitude of 4 mm. He concluded that energy expenditure was 17% greater in the group performing weighted squats during vibration as opposed to the control group performing squats without vibration. The subjects in a study by Garatachea et al. (2007) were exposed to vibration three times for three minutes during one session (frequency: 30 Hz; amplitude: 4 mm) and concluded that metabolic work was 1 MET greater in the vibration group equal when compared against the control group performing identical exercises without vibration. Thus, there do not appear to be any studies that have considered the impact of WBV on energy expenditure after a period of WBV training beyond seven training sessions. The proposed study differs from these two previous studies in that Da Silva et al. (2007) did not consider specific substrate utilization and Garatachea et al. (2007) observed substrate utilization only during an introductory session (and found that the vibration group metabolized 58.6% more carbohydrates and 66.3% less fats than non-vibration groups while performing identical exercise) and not after multiple exposures to allow for habituation to WBV.

Effects of WBV on Fat Usage

Only one study has been conducted that concluded that WBV is an effective method for increasing fat loss (Vissers et al. 2010). Vissers et al conducted a year long study (frequency: 30-40 Hz; amplitude: low-high) that investigated the effects of diet and WBV on body composition and weight loss as compared to two other groups that employed diet only or diet and fitness only. Visceral and total body adipose tissue were measured with a CT scan at the beginning of the program and again at three and six months into the interventions in all three experimental groups. The study concluded chronic vibration training effectively decreased total adipose tissue and visceral adipose tissue more than both the diet or diet and fitness groups. Unlike Vissers et al. (2010), our current study investigated the use of indirect calorimetry to determine substrate utilization using a Respiratory Exchange Ratio (RER).

Determination of RER is a non-invasive technique used to estimate the percent of contribution from carbohydrate and fat to overall energy metabolism during non-steady state exercise. This ratio assumes that protein metabolism is negligible. Table one shows RER values and the approximate percentages of carbohydrate and fat contribution to overall energy production (Powers and Howley, 2009). In general, the lower the RER value, the greater contribution of fats; the higher the RER value, the greater the contribution of carbohydrates to overall energy production. However, RER is affected by a number of other factors including exercise intensity, fasting, and hyperventilation (Powers and Howley, 2009; Plowman and Smith, 2007). Higher intensity activities will recruit more type two muscle fibers which rely more on carbohydrates for energy; lower intensity activity will recruit mostly type 1 muscle fibers which rely more on fats for energy production. Fasting will reduce the RER value to near 0.70 due to a reliance on fats for energy in a semi-starvation state, resulting in greater O_2 use. On the other hand, hyperventilation will propel the RER values up to or beyond 1.00 due to over removal of CO_2 (Plowman and Smith, 2007). Thus in both situations the basic mathematical formula for calculating RER (VCO_2/VO_2) is impacted either by inflated O_2 use or inflated CO_2 production. Either way, RER can provide misleading information under certain conditions.

Table 1

Approximate % substrate contribution and corresponding RER values (Powers and Howley, 2009)

RER	% Fat	% CHO
0.70	100	0
0.75	83	17
0.80	67	33
0.85	50	50
0.90	33	67
0.95	17	83
1.0	0	100

RER=Respiratory Exchange Ratio
CHO=Carbohydrate

Effects of WBV on Carbohydrate Metabolism

Some studies have concluded that WBV may increase carbohydrate metabolism. Many studies have found that recruitment of type two muscle fibers increases during vibration exposure (Romaiguere 1993; Rittweger et al. 2000; Rittweger et al 2003; Paradisis and Zacharogiannis 2007; Pietrangelo et al. 2009). Since these fibers rely heavily on carbohydrates for energy production, there should be an overall increased rate of carbohydrate metabolism. A 12-week WBV training study using diabetic subjects (frequency: 30-35Hz; amplitude: 2 mm) found that vibration training significantly decreased peak glucose concentrations during oral glucose tolerance testing more so than in the strength training group. This occurred even though WBV sessions were about half as long as strength training sessions. Both groups performed eight exercises three times a week which targeted similar muscle groups and testing was administered both pre and post training. The vibration group experienced a decrease in HbA1c, a measure which indicates glycemia over the preceding two to three months (Baum et al. 2007). These findings indicate that repeated exposure to WBV may increase diabetics’ reliance on carbohydrates.

A 12-week training study on elderly (65 - 85 years old) individuals considered the effects of local vibration on cellular and molecular muscle changes. Enzymes associated with glucose and glycogen metabolism were upregulated, indicating an increase in reliance on glucose along with an increase in strength (Pietrangelo et al. 2009). However, this study had a small sample size of nine and used subjects who had been diagnosed with sarcopenia. Since subject's did not appear to participate in any form of exercise, it is possible that the benefits from vibration occurred because it was the only form of stimulation the sarcopenic muscle received. Thus the results may be different in a younger healthy population who are less likely to experience loss of muscle mass due to malnourishment and disuse. Furthermore, the study by Pietrangelo et al. (2009) used local vibration while the current proposal employs whole body vibration and it is possible these different stimulations may not impact muscles in the same way (Luo et al. 2005).

Findings from the study by Garatachea et al. (2007) supported the conclusion that there is greater carbohydrate reliance as opposed to fat usage during vibration training in comparison to a control group performing identical exercises. However, the assumption that the subjects exercised in a steady state condition may have been erroneous since individuals only performed WBV exercise for three minutes. Three minutes may not have been enough time to achieve steady state. Furthermore, Garatachea et al's (2007) study only considered the impact of WBV on substrates after one exposure over the course of one day; it did not take into consideration how habitual use of WBV could impact substrate metabolism. Thus, it appears that no WBV study has been published that measured carbohydrate metabolism in a healthy younger population after the user has been exposed to WBV multiple times.

Conclusion

Whole body vibration training has the potential to enhance current training regimes by increasing muscle activation during vibration exposure, leading to greater strength and power gains. Past research has purported that vibration training may impact metabolism by prompting fat usage or by increasing carbohydrate metabolism. However, studies considering these variables have not targeted subjects who have been habituated to vibration exposure but rather have focused on using subjects who are unaccustomed to this type of training. Thus far, studies have not reported energy expenditure and substrate utilization in subjects who have performed whole body vibration exercise after having become habituated to the vibration stimulus. Studies which have looked at energy expenditure and substrate usage have largely used specific populations (unisex, obese, diabetic, elderly), thereby limiting the application of the studies' outcomes to healthy males and females. In contrast, the current study evaluated energy substrate utilization due to WBV usage in healthy subjects who have become habituated to WBV training. This current research will assist in the development of realistic training expectations from WBV training by using subjects who have been exposed to WBV training for an extended period of time.

CHAPTER THREE

Methodology

This was a prospective cross-sectional substudy from the main study entitled, "The effects of an 8-week strength training program with and without whole body vibration on measures of strength, flexibility and power". The study was approved by the Committee on the Protection of the Rights of Human Subjects at the University of North Carolina at Chapel Hill (P.I.:Darin Padua, PhD, BioMedical IRB#: 10-0786, funded by the National Academy of Sports Medicine (NASM)). Subjects from the main study were included in the present study during their eighth week of WBV training. Research supports a link between acute exposure to WBV and increased energy expenditure; however, to date no studies have reported how habituation to WBV impacts energy expenditure. Furthermore, though research has shown that WBV training impacts the rate of both carbohydrate and fat utilization, the historical research used specific populations which limits the generalizability of the results. The purpose of this study was to record energy expenditure and substrate utilization during one training session the last week of the WBV training using average healthy subjects, similar to those who might have access to WBV use.

Subjects

Twenty five healthy adults were recruited for this study and were randomly assigned into either the vibration intervention or non-vibration control group. In order to be eligible to participate, the subjects were between 18 - 45 years old with no known history of vestibular, balance, or musculoskeletal disorders/injuries within the past six months that limited physical activity for more than two days. Those with an acute illness or with known metabolic, cardio-pulmonary, or other disorders that precluded exercising in a fasting state were also excluded. Pregnant women were excluded due to unknown effects of whole body vibration on the mother or fetus (Seidel 1993).

Participants were recruited through informational emails, flyers, and from classes in the Department of Exercise and Sports Science at University of North Carolina at Chapel Hill (UNC-CH). Written informed consent was obtained from all subjects prior to testing. After the subjects signed the consent form, a copy was given to them and testing commenced. At the conclusion of the study, the subjects received $150 if they attended at least 80% of the required training sessions.

Instrumentation

The PowerPlate® Pro 5(Power Plate International B.V., Badhoevendorp, The Netherlands) was used for WBV training. The PowerPlate is capable of producing triplanar (mostly vertical) vibration frequencies ranging between 25 - 40 Hz and amplitudes ranging from low to high. These ranges correspond to those used in previous studies (Baum et al. 2007; Fjeldstad et al 2009; Vissers et al 2010). Additionally, a portable metabolic system, the Cosmed $K4b^2$ (Rome, Italy), was used during the exercise trials to collect metabolic and heart rate data. Several studies have concluded the Cosmed K4b2 to be an accurate, valid and reliable means of assessing energy expenditure (Hausswirth et al. 1997; McLaughlin et al. 2001; Duffield et al. 2004). A questionnaire was administered which queried the subjects' food and drink intake as well as exercise participation four hours prior to testing. The questionnaire also gathered optional information regarding female subjects' menstrual history *(Appendix 1).* Polar FS1 Fitness Heart Rate Monitor (Kempele, Finland) was used to track heart rate during exercise, which was recorded with the Cosmed. Height (cm) was measured with a Detecto balance beam scale with a height rod (Model 338, Webb City, MO) and weight (kg) was measured using a Detecto digital scale (Model 758c, Webb City, MO).

Procedures

All subjects were habituated to exercise for eight weeks. Subjects reported to the Sports Medicine Research Laboratory in Fetzer Gym for exercise three times per week for eight weeks, totaling 24 sessions. Subjects were required to attend a minimum of 19 sessions, approximately 80% of the total exercise sessions. To improve adherence, subjects received payment if they completed at least 19 sessions. For descriptive purposes, height and weight was measured and fitness status was estimated from a validated non-exercise formula (Jackson et al. 1990):

$$VO_2\ peak = 56.363 + (1.921*PAR) - (0.381*age) - (0.754*BMI) - (10.987*gender).$$

Where:
Gender : 0 = F, 1 = M;
PAR (physical activity rating) = 1 – 7;
BMI (body mass index) = weight (kg) ÷ height (m^2).

Because menstrual cycle phases and oral contraceptive use are factors which may impact energy expenditure, questionnaires were given to subjects immediately prior to the last session to collect data concerning these possible confounding variables (Webb 1986).

Groups. Subjects were divided into a vibration intervention group who performed exercises while standing on a vibrating plate, and a non-vibration control group who performed exercises on the plate without vibration exposure.

Vibration intervention group. There were 12 subjects in the vibration group. The vibration group's exercise sessions initially lasted 20 minutes and progressed to 35 minutes by the end of the eight week training period. Each session consisted of a warm-up (2 exercises, 2 minutes), exercise session (5-6 exercises, 14 minutes during the 1st week - 26 minutes during the 8th week), and cool-down (2 exercises, 3-4 minutes) performed on the PowerPlate® Pro 5 whole body vibration platform.

Non-vibration control group. There were 12 participants in the non-vibration group who performed identical exercises on the platform for the same duration as the vibration group, but without turning on the PowerPlate. The difficulty of exercise sessions was progressed weekly throughout the course of training in the same fashion as the vibration group.

Exercise protocol. The two minute warm-up consisted of both hamstring and quadriceps/hip flexor stretches performed on the PowerPlate. The 26 minute treatment period aimed at strengthening the quadriceps, hamstrings, gluteals, calves, and core musculature and exercises included: single leg squats/Romanian dead lifts, deep squats, lunges, calf raises, and planks. The three minute cool-down portion consisted of both quadriceps and hamstring massages applied at the end of each exercise session. This was achieved by instructing the subject to lay both supine and prone with legs on the vibration platform. A dense foam platform placed next to the PowerPlate was used for body support while legs were on the PowerPlate for massage. Progressions included increased time (30 -

60 seconds), increased frequency of vibration (30 - 40 Hz), modified execution (static to dynamic to explosive), added exercises (from five to six), and increased balance and strength demands by removal of hand support. Please see *Appendix 2* for the complete exercise protocol.

Energy Expenditure Monitoring**.** Respiratory values were measured by the Cosmed $K4b^2$, a portable metabolic measurement system that analyzes expiratory gases breath-by-breath (VO_2, VCO_2). It weighs less than two pounds and was worn over the back. It was secured to the body via a lightweight harness system placed over the shoulders and across the chest. A Polar chest strap heart rate monitor was used to track heart rate and a sensor on the Cosmed recorded HR data each time a breath-by-breath VO_2 measurement was recorded. Expired air was measured via a flexible rubber facemask that was placed snuggly over the participants' mouth and nose using a head strap secured with four clips.

Inspired and expired air travels through a bi-directional digital turbine located in facemask of the Cosmed system. Air flow causes a low mass rotor blade housed in the turbine to begin to rotate. These rotations are measured by an opto-electric system which counts the revolutions per second. The flowmeter can determine the airflow rate and calculate the volume of expired air per minute. Concentrations of expired oxygen (F_EO_2) and carbon dioxide (F_ECO_2) are sampled breath-by-breath through a removable sampling plug, housed within the turbine unit. These concentration measurements are used to determine carbon dioxide expiration (VCO_2) and oxygen consumption (VO_2) when incorporated into calculations along with data collected from the Cosmed including: ventilation (V_E), concentration of expired carbon dioxide (F_ECO_2), concentration of expired oxygen (F_EO_2), and taking into account oxygen and carbon dioxide concentrations in the environment (Pinnington et al. 2001).

The subjects wore the Cosmed for two sessions during their last week of exercise (week 8). The first session, lasting approximately 10 minutes, was used to habituate the subject to the measurement device. This practice session was necessary to reduce any potential anxiety associated with wearing the unit on the actual test day. If a person is too anxious, he/she may hyperventilate and artificially inflate the expired carbon dioxide values. The subjects then wore this same device during their final exercise session for the entire exercise time period, approximately 35 minutes. All subjects performed exercises in a fasted state of at least four hours the morning of their last training session. A fasted state was necessary in order to avoid the possible elevation in metabolism due to foods immediately ingested (LeBlanc et al. 1985; Poehlman et al. 1985). Fasted conditions were confirmed by observing the subject's resting RER values immediately prior to beginning the whole body vibration exercise session. If subjects were not in a fasted state (e.g. RER ~0.70 - 0.88) (Plowman and Smith, 2007; Jensen et al. 2009) immediately prior to initiation of the last exercise session, the session was immediately rescheduled for next possible day and the subject was reminded to refrain from ingesting any food of drink other than water at least four hours prior to the rescheduled testing session.

Each subject's ventilatory measurements were collected breath-by-breath throughout the entire exercise session via the Cosmed which then computed metabolic parameters (i.e. carbohydrate and fat utilization, RER, and energy expenditure). Energy expenditure was calculated from the volume of oxygen consumed (1 liter $O_2 \cong 5$ kilocalories). The Respiratory Exchange Ratio ($RER = VCO_2/VO_2$, where V = volume) was used to estimate fat and carbohydrate utilization (assuming protein metabolism was negligible). The RER values, collected during both the strength exercises and the rest period between the exercises, were averaged for each subject. Substrate utilization was determined by averaging the percent of each energy source that contributed to overall energy production over the course of the exercise session.

Research Design and Statistical Analysis

This study was a prospective experimental design with vibration exposure as the independent variable and energy expenditure (kcal/min), fat and carbohydrate metabolism (% of total energy expenditure) as the dependent variables. The mean value of each dependent variable for each subject was recorded. The dependent variable values were averaged during the exercise and rest section of the testing session. Descriptive statistics (means, standard deviations) were used to summarize the personal characteristics of the subjects (height, weight, age, gender, and estimated aerobic fitness status). Statistical significance was set a priori at $p < 0.05$ for all analyses. The data was analyzed using SPSS statistical software package (SPSS Inc, SPSS 17.0, Chicago, IL). The following analyses were used to test the specific research questions and corresponding hypotheses:

Research Question One. How does a WBV training session impact carbohydrate and fat utilization after habituation to multiple WBV exercise sessions?

Hypothesis 1a. There will be a significant difference in fat utilization between the vibration intervention and non-vibration control groups.

Hypothesis 1b. There will be a significant difference in carbohydrate utilization between the vibration intervention and non-vibration control groups.

Statistical Analyses. Seperate One-Way ANOVAs were used to determine if differences existed in substrate utilization (carbohydrate, fat) between the vibration intervention group and non-vibration control group. Scatterplots and bivariate correlations were used to describe specific relationships between energy expenditure (kcal/kg/min) and substrate utilization (% fats and % carbohydrates) for the vibration intervention and non-vibration control groups.

Research Question Two. How does energy expenditure (kcal/min) respond to a WBV training session after habituation to multiple WBV exercise sessions?

Hypothesis 2. Energy expenditure will be greater in the vibration intervention group as compared to the non-vibration control group.

Statistical Analysis. A t-test was used to determine energy expenditure differences during exercise between the vibration intervention group and the non-vibration control group.

CHAPTER FOUR

Results

Subjects

Metabolic data was collected from twenty five adults (13 males, 12 females) during the last session of an eight week whole body vibration training program. However, one female's data was excluded due to a Cosmed malfunction rendering the data unusable. The average time subjects spent in the treatment period was 27.9 min (± 1.0 min). Pre-exercise RER values (averaged during first 30 seconds of warm-up) confirmed that subjects were in a fasting state (RER 0.80 ± 0.08). These values are similar to overnight fasting RER values (0.82 ± 0.05) reported by Goedecke et al. (2000). Pre-exercise heart rate data was within ranges expected per pre-exercise conditions (92.3 ± 21.8 bpm). Physical characteristics of the subjects are summarized in the table below. No significant differences were found between groups for any variable ($p \geq 0.05$).

Table 2

Descriptive characteristics of subjects per group (mean ± SD).

	Vibration	Non-vibration
N	12	12
Age (yrs)	25.83 ± 6.49	25.83 ± 4.84
Height (cm)	173.21 ± 9.44	174.18 ± 16.67
Body Mass (kg)	75.61 ± 13.63	72.27 ± 14.13
Estimated Peak VO_2 (mL/kg/min)	42.50 ± 6.49	43.86 ± 8.92
BMI (kg/m^2)	25.09 ± 3.31	23.76 ± 3.02
RER during exercise	1.01* ± 0.05	0.95 ± 0.06
HR (bpm) during exercise	151.20* ± 12.23	132.96 ± 17.55
EE (kcal/min) during exercise	7.62 ± 1.62	6.87 ± 2.25

Body Mass Index (BMI) = body weight (kg) / height(m^2); RER = respiratory exchange ratio; HR = heart rate; EE = energy expenditure
***** $p < 0.05$

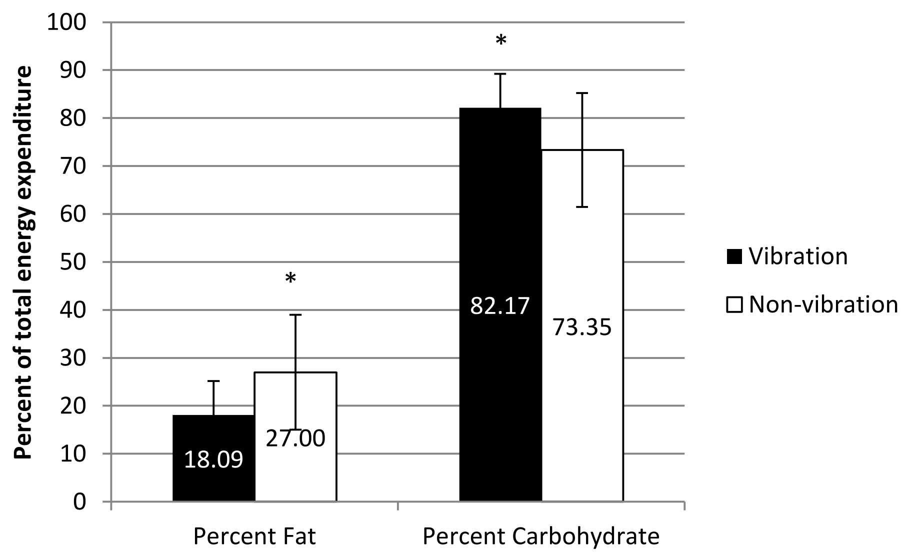
Impact of Multiple Whole Body Vibration Sessions on Fat and Carbohydrate Metabolism

Hypothesis 1a for Research Question One stated that there would be a significant difference in percentage of fat utilization between the vibration intervention and non-vibration control groups. Fat utilization was significantly greater in the non-vibration control group as compared to the vibration intervention group (One-Way ANOVA, $F(1, 22) = 4.845$, $p = 0.039$). As shown in Figure 1, the non-vibration control group used 8.91% more fat than the vibration intervention group.

Hypothesis 1b for Research Question One stated that there would be a significant difference in percentage of carbohydrate utilization between the vibration intervention and

non-vibration control groups. Figure 1 illustrates that carbohydrate utilization was significantly greater in the vibration intervention group as compared to the non-vibration control group (One-Way ANOVA, $F(1, 22) = 4.857$, $p = 0.038$). The vibration intervention group used 8.82% more carbohydrate than the non-vibration control group.

Figure 1. Means (± SD) of percent carbohydrates and percent fats utilized in vibration and non-vibration group during identical exercise sessions (27.9 ± 1.0 min/session)



***** $p < 0.05$ between groups

The scatterplots depicted in *Figures 2 and 3* further illustrate the relationships between relative energy expenditure (kcal/kg/min) and substrate utilization per each group. A bivariate correlational analysis found a very weak *negative* relationship exists between energy expenditure (kcal/kg/min) and % fat utilization for the vibration intervention group ($r = -0.001$, $p = 0.997$) and a very weak *positive* relationship exists for the non-vibration control group ($r = 0.164$, $p = 0.611$). In contrast, a very weak *positive* relationship was found between energy expenditure (kcal/kg/min) and % carbohydrate utilization for the vibration intervention group ($r = 0.001$, $p = 0.997$) and a very weak *negative* relationship for the non-vibration control group ($r = -0.165$, $p = 0.608$).

Figure 2. Scatterplot of energy expenditure (kcal/kg/min) and % fat utilization during an exercise bout in both vibration and non-vibration groups

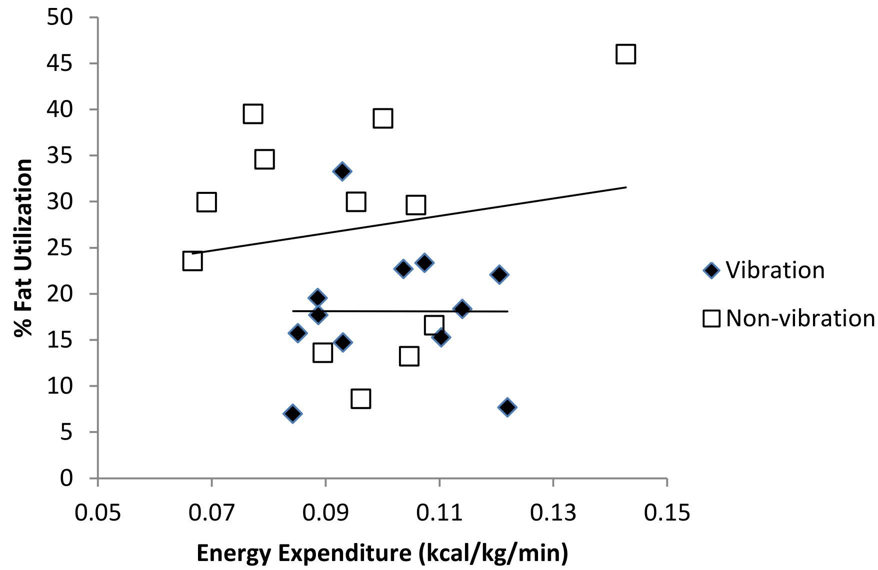
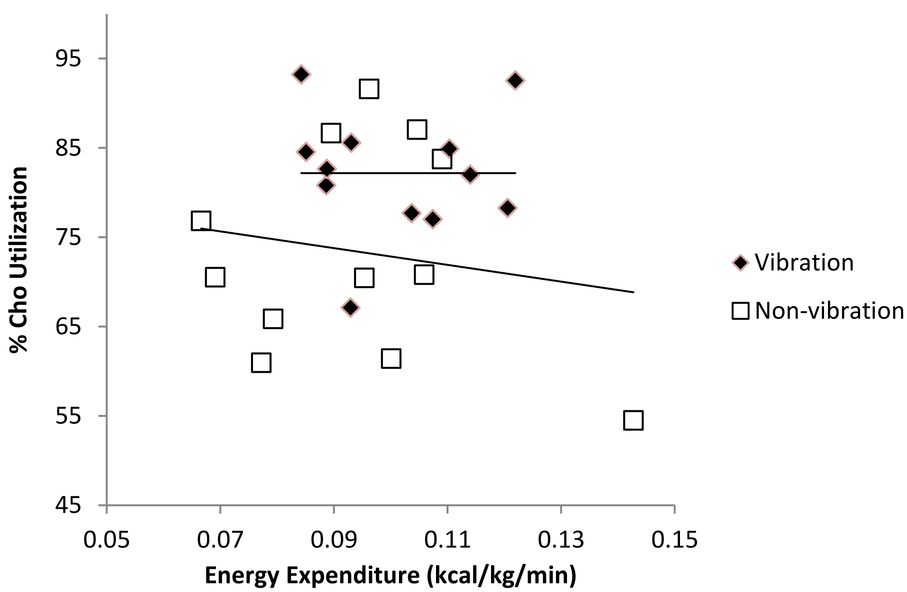


Figure 3. Scatterplot of energy expenditure (kcal/kg/min) and % carbohydrate utilization during an exercise bout in both vibration and non-vibration groups

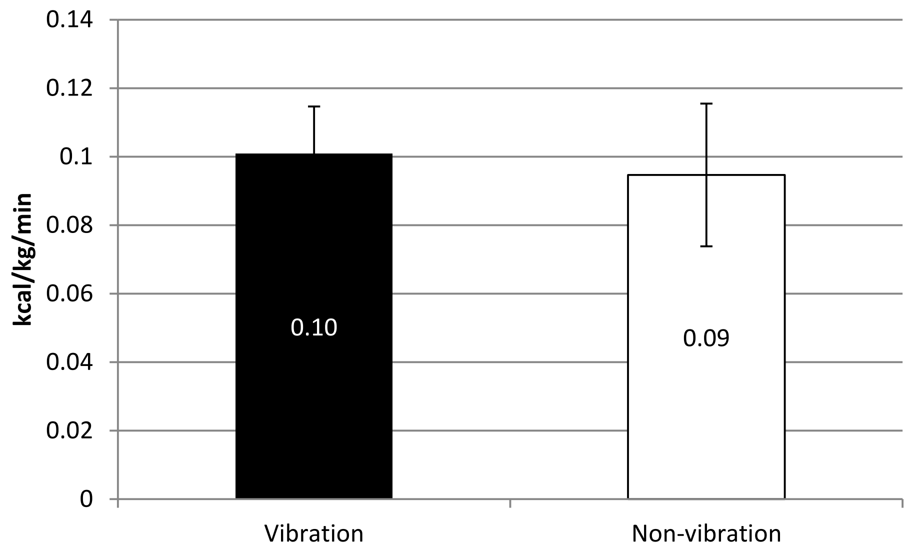


Impact of Multiple Whole Body Vibration Sessions on Energy Expenditure

The hypothesis for Research Question Two stated that energy expenditure (kcal/min) would be greater in the vibration intervention group as compared to the non-

vibration control group. As shown in Figure 4, an independent-samples t-test determined that there was no significant difference between energy expenditure between the two groups ($t[22] = 0.865$, $p = 0.396$).

Figure 4. Mean (± SD) energy expenditure (kcal/kg/minute) in both vibration and non-vibration groups



CHAPTER FIVE

Discussion

The primary purpose of the present study was to observe if vibration exposure influenced substrate preference during a single exercise session in their last week of WBV training. A secondary purpose was to determine how WBV training impacts energy expenditure in a healthy adult population after an eight week training habituation period. A significant difference was found between percentage of fats and carbohydrates utilized in the vibration intervention and non-vibration control group ($p = 0.037$). A significant difference was also found between percentage of carbohydrates utilized in the vibration intervention and non-vibration control group ($p = 0.037$). No significant difference was found between energy expenditure in the vibration intervention and non-vibration control groups ($p > 0.05$). The following discussion focuses on the aforementioned results followed by a review of limitations in the study.

Impact of Multiple Sessions of WBV on Energy Expenditure

The present study found that energy expenditure is not significantly increased during a WBV exercise session after an eight week training habituation period when compared to an identical exercise session not using WBV. A possible explanation for why the present study failed to find a significant difference in energy expenditure between groups despite HR increases in the vibration group is that results may have been confounded by the extra isometric component of exercise in the vibration intervention group due to exercises being performed on an unstable surface. Because isometric contractions impede blood flow, heart rate must increase in order to maintain cardiac output. Furthermore, previous studies have demonstrated that the vibration stimulus elicits involuntary muscular contractions due to neuromuscular reflexive action, as well as increases muscular activation in order to dampen vibratory waves (Cardinale and Lim 2003; Cardinale and Wakeling 2005; Issurin 2005; Martin and Park 1997; Roelants et al. 2006). Thus, blood flow may have been obstructed to a greater degree in the vibration intervention group as compared to the non-vibration control group. Furthermore, impaired blood supply during isometric muscular work impedes lactate clearance and oxygen delivery, thus preventing fat metabolism and increasing carbohydrate metabolism (Ahlborg et al. 1972). Thus, the increased carbohydrate utilization observed in the present study may have been partly due to impaired blood flow. However, a study by Hazell et al. (2008) found that the addition of vibration to static squats did not significantly raise heart rate or impede femoral artery blood flow. Kerschel-Schindl et al. (2001) postulated that WBV may induce vasodilation of vessels and subsequently increase blood flow. Because the current study did not measure blood flow, it is unclear if circulation was impeded in the vibration intervention group.

In the present study, the non-significant difference in energy expenditure of 0.75 kcal/min (6.87 to 7.62 kcal/min) is similar to findings from Da Silva et al. (2007) who stated that the addition of whole body vibration to half squat exercises resulted in a significant increase in energy expenditure by approximately 0.66 kcal/min (3.84 to 4.50 kcal/min). It is possible that Da Silva et al. (2007) found statistical significance due to a more powerful statistical design (effect size of -0.19 in the current study as compared to 0.40 in Da Silva et al’s (2007) study) despite the smaller increase in energy expenditure as compared to the present study. If the current study had utilized a repeated measures protocol similar to Da Silva et al. (2007), it is possible that the differences in energy expenditure may have been significant as well. Because the exercise program of the current study resulted in greater total energy expenditure due to a more intense exercise protocol, the results of the present study are unique. The exercise intensity of the current study depicts the intensity of a moderately difficult exercise session, demonstrating the potential of WBV training as an exercise modality.

Conversely, Garatachea et al. (2007) noted an increase in energy expenditure by approximately one kcal/min in the vibration group. The variation of results may be partially due to methodological differences between these three studies. The present study and Da Silva et al. (2007) both allowed for habituation periods, while Garatachea et al. (2007) collected energy expenditure data just once, during the initial introductory session, thereby not allowing for any habituation period. However, Da Silva et al. (2007) used a two week habituation period (of approximately 11.5 minutes/session) while the present study allowed eight weeks of habituation (approximately 35 minutes/session). Therefore the methodology of the present study allowed for a longer assessment of the impact of whole body vibration on energy expenditure. To our knowledge, the present study is the first to demonstrate that an eight week habituation period utilizing vibration exposure (30-60 sec, 30-40 Hz) to the WBV system does not significantly increase energy expenditure.

Impact of Multiple Sessions of WBV on Fat Metabolism

The present study found that a single WBV exercise session following an eight-week habituation period resulted in less reliance on fat as an energy source when compared to a non-vibration control group performing the same exercise protocol. These findings compare favorably to Garatachea et al. (2007) who reported a mean decrease of 66.3 % in fat utilization ($p < 0.05$) for the vibration condition performing squats when compared to the non-vibration condition performing squats. Similarly, Roelants et al. (2004) found that 24 weeks of WBV training was not an effective intervention for weight reduction ($p > 0.05$) or loss of percent body fat ($p > 0.05$) in untrained females.

Findings from the present study suggest that habitual use of WBV may attenuate fat utilization in favor of carbohydrate. Since the exercise HR for the vibration intervention group was significantly higher than the HR of the non-vibration control group (151.2 ±12.23 bpm vs. 132.96 ± 17.55 bpm, $p = 0.007$, respectively), it appears that the vibration subjects in the intervention group may be exercising at a greater intensity as a result of the addition of the vibration stimulus. Exercising at a greater intensity causes substrate utilization to shift from fat towards carbohydrate utilization. However, if exercise intensity was the sole reason that substrate usage shifted towards carbohydrates, then energy expenditure should increase along with greater exercise intensity. Because the present study did not detect significantly greater energy expenditure in the vibration group versus the non-vibration group (6.87 ± 2.25 kcal/min vs 7.62 ± 1.62 kcal/min, respectively), the vibration stimulus alone may have impacted the metabolic properties of the muscle fibers. This supposition is supported by Pietrangelo et al. (2009) who concluded via muscle biopsies that 12 weeks of locally applied vibration of the quadriceps group stimulated glycolytic and glycogen dependent metabolism as well as shifted muscle fiber type composition towards a larger proportion of fast glycolytic fibers. Therefore, WBV over an extended period of time may result in a reliance on carbohydrates rather than fats as a fuel source during a single exercise bout on the WBV machine. Because fat utilization is important for achieving fat loss, long term WBV training may not be the most efficacious method for fat loss when used as the sole form of exercise training in a weight management program (Saris, 1998).

Impact of Multiple Sessions of WBV Sessions on Carbohydrate Metabolism

Although total energy expenditure (kcal/min) was not significantly impacted by WBV exposure after the user became habituated to WBV training, carbohydrate reliance was significantly greater in WBV users as compared to non-users. Since Type II (fast twitch) muscle fibers rely on carbohydrates as a fuel source, habituated WBV subjects may have been recruiting a larger proportion of fast twitch fibers in comparison to the subjects not using WBV training. This concurs with other studies that reported WBV training is especially beneficial for strength and power gains since Type II muscle fibers produce both strength and power (Bosco 1985; Issurin et al. 1994; Bosco et al. 1998; Bosco et al. 1999; Rittweger et al. 2002; Cardinale and Bosco 2003; Nordlund and Thorstensson 2007; Paradisis and Zacharogiannis 2007)

According to the size principle, motor units are recruited in order of size; the smaller Type I fibers first and the larger Type II fibers are recruited last (Sale, 1988). Since WBV appears to increase recruitment of Type II fibers, WBV would therefore increase the total number of muscle fibers recruited. Also, some research suggests Type II fibers are less energetically efficient during repeated submaximal muscular contractions since more energy is required to equal the ATP production from Type I (slow twitch/endurance) muscle fibers (Barstow et al. 1996, Coyle et al. 1992). Therefore it may seem that the present study should have observed a greater increase in energy expenditure. However, WBV training potentiates the neuromuscular system by stimulating the muscle spindles which invoke a reflexive activation of motor neurons. Because WBV training induces reflexive muscular action, while simultaneously overriding the inhibitory effects of the Golgi tendon organ (which cause muscular relaxation), the energy requirement during a WBV exercise session after a period of training may be lessened due to increased neuromuscular potentiation (Cardinale and Bosco, 2003; Cochrane and Stannard, 2005).

WBV training also augments the efficiency of the stretch shorten cycle, which increases mechanical efficiency by utilizing elastic energy (Bosco et al. 1985; Belli and Bosco 1992). Elastic energy furnished by the stretched myosin cross-bridges will not cost the muscle any energy expenditure; thus the total energy expenditure required to do a task is reduced (Hunter et al. 1998). Therefore, less energy is required to perform exercises that utilize the stretch shorten cycle, allowing the individual to become more energy efficient (Jordan et al. 2005). Because the current study's protocol employed exercises that utilized the stretch shorten cycle, it may be that the combination of greater neuromuscular efficiency, along with an increased energy requirement due to an increase in Type II fiber recruitment, explains the absence of a significant increase in energy expenditure. It is possible that the results from this study may have been different if the current study had utilized a different type of exercise program (less emphasis on explosive/plyometric activities and more emphasis on strength specific exercises).

The greater carbohydrate utilization in the present study is in accordance with findings from Baum et al. (2007) and Pietrangelo et al. (2009). Previous studies suggest that WBV training recruits Type II fibers, which are highly glycolytic and rely on carbohydrates as a fuel source (Romaiguere 1993; Rittweger et al. 2000; Rittweger et al 2003; Paradisis and Zacharogiannis 2007). The findings of the present study not only agree with previous findings, but suggest that Type II fibers may continue to be heavily recruited even after a period of habituation.

The design of current study was unable to detect any weight loss potential after eight weeks of WBV use. However, the potential benefit may exist for facilitating strength and power due to increased Type II muscle fiber activation. Because Type II muscle fibers are recruited heavily during strength and power activities, the findings from this study help support previous findings which state that WBV training is an effective exercise intervention for increased strength and power abilities (Bosco 1985; Rittweger et al. 2002; Cardinale and Bosco 2003; Issurin 2005). Furthermore, even though less fat was metabolized in the vibration intervention group, the utility of this training may be for increasing muscle fiber activation, which not only could lead to increased strength and power, but also a long-term increase in resting metabolic rate.

Limitations

The present study has a few limitations that need to be acknowledged. No true resting data was recorded due to technician error. Future studies need to include this information to better verify a resting fasted state. Since subjects self-reported their fasted state, there is a possibility that this was under reported. To counter this, pre-exercise RER values were monitored to verify fasted conditions (RER values 0.69-0.88). Since RER was averaged due to the Cosmed's breath by breath analysis method, there is no assurance steady state was attained. Therefore, the results should be viewed with caution. Self-reported accuracy regarding abstinence from exercise and caffeine were other potential limitations.

It is unclear if the use of oral contraceptives may have impacted the substrate utilization results. In the present study, three women in the vibration and four in the non-vibration reported using oral contraception, but the exact formulations were not reported. However, because several research reports failed to find a significant difference between oral contraceptive and non-oral contraceptive use in regards to substrate utilization during prolonged exercise at 65% VO_2 max (Anderson 2004; Casazza et al. 2004), it is likely that oral contraceptive use was not a major limitation. .

Variability in menstrual cycle phase is another factor that may impact substrate utilization and energy expenditure. However, several studies reported no significant impact of menstrual cycle phase (luteal or follicular) on substrate utilization when exercise intensity was between 50-75% VO2 max (Kanaley et al. 1992; Hackney et al. 1994; Bailey et al. 2000; Horton et al. 2002). Women in the current study were either in the luteal (cycle days 19-24) or follicular (cycle days 1-8) menstrual cycle phase (Bailey et al. 2000), therefore it is unlikely menstrual cycle phase was a confounder in this present study.

CHAPTER SIX

Summary and Conclusions

Summary

The purpose of this study was to determine if WBV exposure influenced substrate utilization during a single exercise session during their last week of WBV training. A secondary purpose of this thesis was to determine how WBV training impacts energy expenditure in a healthy adult population after a period of habituation to the WBV training stimulus. Metabolic data was analyzed using subjects who had been habituated to WBV training over a period of eight weeks. Energy expenditure, carbohydrate and fat utilization comparisons were made with subjects who had been following the same training exercise protocol without the use of WBV.

The study did not find evidence that WBV signficiantly enhances caloric expenditure during a WBV exercise session after the user has become habituated with the training intervention. Carbohydrate utilization did appear to be enhanced during the WBV exercise bout. Because WBV users relied more on carbohydrates than non-users, it appears that prominantly Type II fibers are recruited during WBV training. Thus, this study seems to confirm the findings of previous studies that WBV training is an effective exercise intervention when used to improve strength and power measures, both of which utilize Type II muscle fibers.

Conversely, fat utilization diminished during WBV exposure. Because WBV users utilized a lower percentage of fats as compared to non-users, it appears that long-term implementation of WBV training may not be an effective fat loss exercise intervention for non-obese, recreationally active users. These findings will help active healthy WBV users formulate realistic expectations when implementing WBV in a long term training program.

Conclusions

Based on the results of the present study, the following research questions and hypotheses were addressed:

Research Question One. How does a WBV training session impact carbohydrate and fat utilization after habituation to multiple WBV exercise sessions?

Hypothesis 1a. There will be a significant difference in fat utilization between the vibration intervention and non-vibration control groups.

This hypothesis was accepted because the One-Way ANOVA showed that the vibration intervention group utilized significantly less fats than the non-vibration control group.

Hypothesis 1b. There will be a significant difference in carbohydrate utilization between the vibration intervention and non-vibration control groups.

This hypothesis was accepted because the One-Way ANOVA showed that the vibration intervention group utilized significantly more carbohydrates than the non-vibration control group.

Research Question Two. How does energy expenditure (kcal/min) respond to a WBV training session after habituation to multiple WBV exercise sessions?

Hypothesis 2. Energy expenditure will be greater in the vibration intervention group as compared to the non-vibration control group.

This hypothesis was rejected because an independent samples t-test showed there was no significant difference between energy expenditure in the vibration intervention group compared to non-vibration control group.

Practical Application and Suggestions for Future Research

To the knowledge of the investigators, this is the first study to examine substrate utilization and energy expenditure during a WBV exercise bout after an extended period of habituation. Further research is warranted before any definitive conclusions can be made regarding the effect of habitual WBV training on energy expenditure and substrate utilization during an exercise bout. In light of the findings from the present study, future studies should use a repeated measures experimental protocol to compare energy expenditure and substrate utilization both before and after a long term WBV training program. In order to validate the impact of WBV training on muscle fiber recruitment (both quantity of fibers and fiber type), future studies should use EMG testing in combination with collection of metabolic data.

The findings of the present study suggest that WBV training may not be a more effective fat loss intervention than exercise not involving WBV. Although WBV did not significantly increase caloric expenditure in this study involving recreationally active adults after an eight week habituation period, it is possible that WBV may increase Type II muscle fiber activation which could potentially increase resting metabolic rate. Future studies should consider the impact of other factors (i.e. gender, fitness level, previous training, age fiber type activation, resting metabolic rate) in order to determine the effect of WBV training on caloric expenditure and substrate utilization in healthy homogenous populations.

Furthermore, future studies should look at how energy expenditure is impacted by a chronic WBV training program using different forms of exercise (i.e. isometric/stabilization, strength, plyometric/explosive). In order to verify a steady state condition, future studies should consider minute by minute recording of RER rather than breath by breath. To substantiate the impact of WBV on body composition in relation to substrate usage, future studies training studies should employ tests that observe changes in both variables due to WBV training. For example, whole-body DEXA scans would be useful for a 4-compartment body composition analysis, and measurement of circulating glucose and lactic acid in addition to ventilatory measurements would enable review of metabolic parameters.

APPENDIX 1

Questionnaire

Subject's ID Number:____________________ Date:________________

Birthdate:_____________________ Height:______________ Weight:____________

Because food, drink, exercise, and for women, menstrual status, can affect carbohydrate and fat usage, please answer the following questions:

1. Have you consumed any food within the last four (4) hours? __________
   a. If so, what?______________ b. How long ago?___________

   c. How much?________
2. Caffeine within the past twelve (12) hours? ____________
3. Have you exercised at all within the past four (4) hours? ____________
   a. If so, what did you do?

      ____
   b. For how long?__________ (minutes)
4. Please rate your physical activity below:
   a. No regular exercise (0 or 1)
   b. Regular, recreational exercise (2 or 3)
   c. Regular exercise, moderate to high intensity (4, 5, 6, or 7)

(Reference: Baumgartner TA, Jackson AS. Measurement for Evaluation in Physical Education and Exercise Science, 5th Ed. Madison: Brown & Benchmark, p 289, 1995)

Women Only (Optional):

5. What was the date of your last menstrual period? _________(first day)
6. Do you currently use oral contraceptives? **Yes or No** (please circle one)

   If yes, please list the brand name:____________________________________

APPENDIX 2 Exercise Routine

Exercise	Week	Time (s)	Execution	Amplitude	Hz	Rest (s)	Sets	Support	Notes
Quad/ Hip Flexor Stretch	1	30	passive	low	30	0	1	both hands	
	2	30	active	low	30	0	1	both hands	
	3	30	active	low	30	0	1	both hands	1
	4	30	active	low	30	0	1	both hands	2
	5	30	active	low	30	0	1	both hands	3
	6	30	integrated	low	30	0	1	both hands	
	7	30	integrated	low	30	0	1	both hands	
	8	30	dynamic	low	30	0	1	both hands	
Hamstring Stretch	1	30	passive	low	30	0	1	both hands	
	2	30	active	low	30	0	1	both hands	
	3	30	active	low	30	0	1	both hands	
	4	30	active	low	30	0	1	both hands	
	5	30	active	low	30	0	1	both hands	
	6	30	active	low	30	0	1	both hands	
	7	30	dynamic	low	30	0	1	both hands	
	8	30	dynamic	low	30	0	1	both hands	
Single Leg Squat (SLS)/Romanian Dead Lift(RDL)	1	30	static	low	35	30	1	both hands	4
	2	45	static	low	35	45	1	no support	5
	3	45	static	low	35	45	1	no support	6
	4	45	static	high	35	30	1	one hand	7
	5	45	static	high	35	45	1	one hand	8
	6	45	static	high	35	45	1	no support	9
	7	60	dynamic	high	35	60	1	no support	10
	8	60	dynamic	high	40	30	2	no support	11
Deep Squat	1	30	static	low	35	30	2	both hands	
	2	45	static	low	35	45	2	no support	
	3	45	static	high	35	45	2	no support	
	4	45	dynamic	high	40	30	2	no support	
	5	60	dynamic	high	40	60	2	no support	
	6	60	dynamic	high	40	60	2	no support	
	7	60	explosive	high	40	60	2	no support	
	8	60	explosive	high	40	60	2	no support	
Lunge	1	30	static	low	35	30	2	no support	
	2	45	static	low	35	45	2	no support	
	3	45	static	high	35	45	2	no support	
	4	45	dynamic	high	40	30	2	no support	
	5	60	dynamic	high	40	60	2	no support	
	6	60	dynamic	high	40	60	2	no support	
	7	60	explosive	high	40	60	2	no support	
	8	60	explosive	high	40	30	2	no support	
Calf Raises	1	30	static	low	35	30	2	both hands	
	2	45	static	low	35	45	2	both hands	
	3	45	static	high	35	45	2	both hands	
	4	45	dynamic	high	40	30	2	both hands	
	5	60	dynamic	high	40	60	2	both hands	
	6	60	dynamic	high	40	60	2	both hands	
	7	60	explosive	high	40	60	2	both hands	
	8	60	explosive	high	40	60	2	both hands	
Planks	1	30	static	low	35	30	2	elbows on plate	
	2	45	static	low	35	45	2	elbows on plate	
	3	60	static	low	35	60	2	elbows on plate	
	4	45	static	high	35	45	2	12	
	5	60	static	high	35	60	2	12	
	6	60	static	low	35	60	2	13	
	7	60	dynamic	low	35	60	2	14	
	8	60	dynamic	high	35	60	2	15	
Lateral Planks	6	30	static	low	35	30	1/side	elbow on plate	
	7	45	static	low	35	45	1/side	elbow on plate	
	8	30	static	low	35	30	1/side	16	
Quadricep and Hamstring Massages	1	30	passive	low	35	30	2		
	2	30	passive	low	40	30	2		
	3	30	passive	high	35	30	2		
	4	30	passive	high	35	30	2		
	5	30	passive	high	35	30	2		
	6	30	passive	high	35	30	2		
	7	30	passive	high	35	30	2		
	8	30	passive	high	35	30	2		

*Highlights indicate exercise performed when wearing Cosmed

Passive- stretching without any muscular activation
Active- stretching while concurrently activating agonist muscle to the stretched muscle
Integrated- arms are held straight out from body and body is twisted away from back leg
Static- exercise position was held constant for the duration of the exercise time period
Dynamic-subjects move at a constant cadence (two counts of both eccentric and concentric movement)
Explosive-movement is as rapid as possible

1-arm on same side as back leg is extended straight above the head

2-both arms are extended straight above the head
3-one arm on same side as back leg is extended straight above the head while the subject leans from the hips to the side that is opposite of the extended back leg

4-SLS

5-SLS (opposite leg to front)

6-opposite leg to side)

7-progress to RDL (upper body and back leg in straight line parallel to floor)

8-RDL(add one arm front reach)

9-RDL(arms raised in Y above head)

10-RDL(simultaneously lift one arm and opposite leg until both are parallel to floor)

11-RDL(simultaneously lift one arm and opposite leg until both are parallel to floor)

12-reverse plank (elbows on floor, feet on plate)

13-elbows on plate, alternating arm raise (per 10 seconds)

14-elbows on plate, alternating arm and opposite leg raise (per 10 seconds)

15-elbows on plate, alternating arm and opposite leg raise (per 10 seconds)

16-raise both arm and leg perpendicular to floor

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