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A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Kinesiology

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EFFECTS OF ACUTE SYNCHRONOUS WHOLE-BODY VIBRATION EXERCISE

(Spine Title: Effects of Acute Synchronous Whole-Body Vibration Exercise)

(Thesis Format: Integrated Article)

by

Tom J. Hazell

Graduate Program in Kinesiology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

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THE UNIVERSITY OF WESTERN ONTARIO
School of Graduate and Postdoctoral Studies

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The thesis by

Tom J. Hazell

entitled:

Effects of Acute Synchronous Whole-Body Vibration Exercise

is accepted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

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Date	Chair of the Thesis Examination Board

Abstract

The addition of whole-body vibration (WBV) to body mass resistive exercises results in increased muscle activity. Whether these increases result in any health benefits is not well understood. The purpose of this dissertation was to examine several physiologic responses to acute WBV exercise in an attempt to begin understanding its potential health benefits.

Study 1 demonstrated the addition of WBV to an isometric semi-squat in young healthy men (n = 8) resulted in no further cardiovascular stress than the exercise alone. WBV significantly increased in leg skin temperature (LSK_{temp}; ~2 °C) vs the same exercise without vibration (NoV). There were no increases in heart rate and modest increases in mean arterial pressure (9-10 mm Hg) with no differences between groups. Exercise increased blood flow significantly (NoV: ~90 $ml \cdot min^{-1}$ vs WBV: ~180 $ml \cdot min^{-1}$) but these differences were not significant between treatments.

Study 2 demonstrated the addition of WBV to a 30 min dynamic exercise session (5 sets of 6 upper and lower body exercises) resulted in greater oxygen consumption during (12.0±8.3 L $O_{2)}$ and following (8 h: 30.8±26.2 L O_2 and 24 h: 47.8±39.5 L O_2) the exercise bout compared to NoV in young healthy men (n = 8). These increases suggest WBV exercise could be an effective training method to induce positive body composition changes with chronic exposure.

Study 3 demonstrated the addition of WBV to the same 30 min exercise session resulted in no significant effects on muscle function, soreness, or inflammation in young healthy men (n = 10) compared to NoV. These data suggest the addition of WBV had no significant deleterious effects on muscle.

Study 4 demonstrated both the WBV and NoV exercise sessions had an insulin sensitizing effect (WBV: 9.6±2.4; NoV: 10.4±2.3) in young healthy men (n=8). However, the addition of WBV to the NoV exercise had no effect on blood glucose or plasma insulin values over time.

Together these studies demonstrate moderate intensity WBV exercise composed of body mass resistive exercises with the addition of WBV significant increases oxygen consumption while having small effects on the cardiovascular system, muscle damage, and glucose handling.

KEYWORDS: vertical vibration, metabolism, cardiovascular, acute exercise

Co-Authorship

All of the experimental data presented in this dissertation were collected and interpreted by the author, Tom J. Hazell, under the mentorship of Dr. Peter W.R. Lemon. The first author on all manuscripts is Tom J. Hazell.

Chapter 2 is co-authored by Graeme W.R. Thomas, Jason R. DeGuire, and Peter W.R. Lemon and is published in the *European Journal of Applied Physiology*.

Chapter 3 is co-authored by Peter W.R. Lemon and is in preparation for submission.

Chapter 4 is co-authored by T. Dylan Olver, Craig D. Hamilton, and Peter W.R. Lemon and is in preparation for submission.

Chapter 5 is co-authored by T. Dylan Olver, Craig D. Hamilton, Philip J. Medeiros, and Peter W.R. Lemon and is in preparation for submission.

Dedication

This dissertation is dedicated to the memory of my father, Rick Hazell, who passed away during the 1st year of my PhD. You always pushed me to work extremely hard and do my best. I'm not sure when it happened, but throughout this degree I slowly began to realize how much like you I had become. The characteristics most needed to complete this dissertation were instilled in me by your guidance long before you left us.

Acknowledgements

To my advisor Dr. Peter W.R. Lemon, thank you for your guidance over these 4+ years. Your scientifically rational way of designing experiments and interpreting data as well as your emotionally balanced means of dealing with the highs and lows of academia has helped me mature as both a person and scientist. Your experience and guidance on everything related to school, work, and life will never be forgotten, I am indebted to you for all your help, and of course for giving me the opportunity to pursue this degree. I hope there is continued collaboration in our futures.

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To the Kinesiology faculty and staff, thank you for all your time and expertise, completion of a doctoral degree takes the help of many and you always provided that. I want to particularly thank Jenn (Symmes) Plaskett for all her help over the years.

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To my boys, thanks for always reminding me there was more to life than school or work. Great friends are hard to come by and I have several. Thanks for being there whenever I needed a beverage, a visit, or a road trip.

Thank you to my family for supporting me through this entire process. Especially my moms and pops, I'll never forget your reaction the day I told you I was going to pursue my PhD. Not sure where along the lines of you "advising" me to go to school at McMaster ended up being 11+ years of post-secondary education but my student life has officially come to a close. Thank you for always believing in me and supporting me even when I didn't. Your guidance taught me the value of hard work without which I wouldn't be where I am today. Dad, you are the reason I completed this degree. It's uncanny how much like you I have become over the years. Mom, thank you for being everything and anything you have had to be along the way.

To Andrea, since we met you have been my biggest supporter. Words cannot express the gratitude for all the time you spent listening to my issues at school, my presentations, or anything else school related I have talked your ear off about. Your patience, belief, and love have been more helpful than you could ever imagine. Thank you for always being there (and for coming with me on my next adventure in Montreal!).

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CHAPTER 1

General Introduction

Introduction

There is a growing concern about the current and future health of Canadian across the lifespan from children to seniors. Currently, 36.1% of Canadians are overweight and a staggering 23.1% of those individuals are obese (Tjepkema 2006). While it is well known that conventional forms of exercise training such as strength or endurance are very effective towards improving general health, a large proportion of Canadians do not use either adequately (~50% of Canadians are inactive; Warburton et al. 2007). Further this undesirable situation exists despite Canada's position as a world leader in promoting physical activity (several physical activity guides published since 1998). Very simply, if these existing physical activity guidelines were followed deaths from heart disease, hypertension, stroke, osteoporosis, and Type II diabetes in Canada could be reduced by as much as 33% (Warburton et al. 2007). This problem highlights the need for exercise modes that not only work but that can and will be utilized by a large majority of Canadians.

Recently, whole-body vibration (WBV) exercise has emerged as a new method of training. While the interest in WBV is steadily increasing, little information is known about the mechanisms by which WBV acts, how the human body responds to it, and which exercise intensities (movements and WBV stimuli) are most effective. Research to date has focussed on lower intensity exercise with WBV and greater intensities must also be evaluated to determine if WBV can be effective in improving health. More research is also warranted to investigate how WBV exercise could positively affect various physiological systems (cardiovascular and metabolic) that are important to human health. In addition, with the large percentage of Canadians inactive and unfit, WBV exercise presents a unique exercise modality because it may have much greater adherence rates

than more traditional forms of exercise training (Wilcock et al. 2009). This dissertation was designed to evaluate several physiologic responses to acute vigorous WBV exercise in an attempt to begin to understand some of the potential health benefits of WBV.

Whole-body Vibration Exercise

Whole-body vibration (WBV) exercise involves performing common exercises utilizing body mass as the resistance (i.e. squats, lunges, calf raises, push ups, dips, etc) on a vertically oscillating platform. These exercises can be performed statically or dynamically. Theoretically, the WBV stimulus can be adjusted (both frequency and displacement) to vary the exercise intensity providing an appropriate exercise mode for most individuals ranging from unfit, young adults to institutionalized older individuals. While the image of WBV exercise often evokes an image of a vibrating belt apparatus (Figure 1.1), WBV exercise as studied here is actually quite different (Figure 1.2).

Figure 1.1 – What most people think of when they hear the term whole-body vibration (http://www.geocities.com/sgb345/exercise-belt.jpg)

The Whole-body Vibration Stimulus

The technology behind WBV applied via a ground based platform is really not new as it has been around for more than 50 years s Russian scientists used it in cosmonauts (Rittweger 2010). In practice, WBV platforms generate vertical oscillations via two different commercial designs (Figure 1.2). One platform type generates a side-

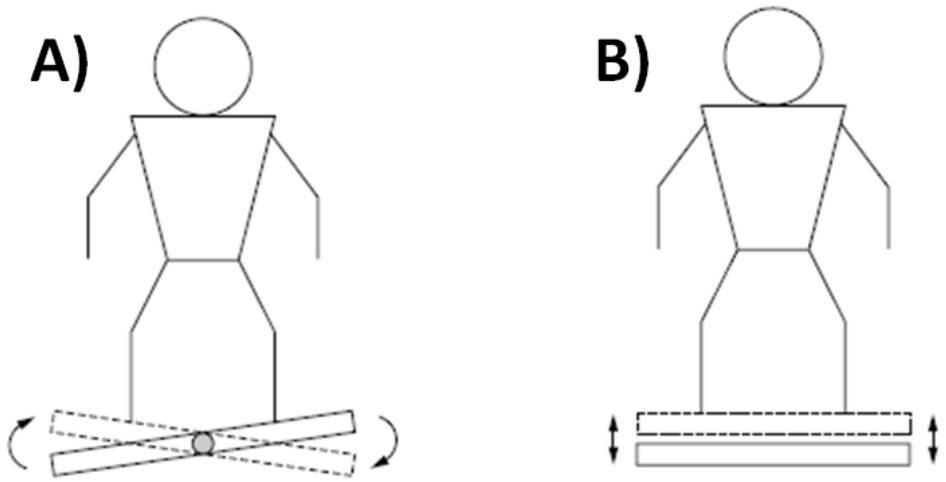

Figure 1.2 – Platform Types – A) oscillates with reciprocating displacements on both sides of a fulcrum; B) strictly vertical oscillations (Cardinale and Wakeling, 2005)

alternating (reciprocating displacement) vibration stimulus as the platform moves around a central mounted fulcrum in a teeter-totter like motion. The second type utilizes a synchronous (vertical) vibration stimulus as the platform oscillates uniformly up and down (Cardinale and Wakeling 2005). Both types of WBV generate a sinusoidal stimulus characterized by both a frequency and a peak-to-peak displacement. Frequency represents the number of oscillations (cycles of motion) per second expressed in Hertz (Hz), ranging between ~15-50 Hz. Peak-to-peak displacement (amplitude) is the size of each deflection expressed in millimetres (mm). Typically, studies utilizing side-alternating platforms report much h igher displacements (~7-10 mm) relative to vertical platforms (~1-4 mm; Mester et al. 2006). At least in theory, greater displacement and/or frequency could increase the vibration stimulus but few supporting data are available, although large displacements with high frequencies seem unlikely from a strictly mechanical standpoint. In support of this possibility, we have determined using high speed video analysis that the vertical displacement of our three platforms (WAVE™

platform [Whole-body Advanced Vibration Exercise], Windsor, Canada) when set at 2 and 4 mm are actually 1 and 2mm (unpublished data). As a result, the stimulus received in many published studies could have varied. Importantly, we have demonstrated that a synchronous/vertical stimulus with frequencies from 35-45 Hz and a reported amplitude of 2-4mm (actually 1-2 mm) resulted in a significant increase in leg muscle activity as measured via electromyography (Hazell et al. 2007). The reported data are further complicated because the range of durations utilized during WBV exercise has varied substantially (5 sec - 9 min). Fortunately there is some consistency with exercise protocol as many WBV exercise studies have utilized a 1:1 work:rest ratio (i.e. 60 sec of exposure separated by 60 sec rest) for a total of 15 min of WBV over a 30 min time period (Rittweger 2010). These between study differences mean that the interpretation of data across studies is difficult.

The Whole-body Vibration Mechanism(s)

While the technology of WBV has been around for almost 50 years, the physiological mechanism(s) by which WBV affects skeletal muscle is still unclear. It is known that whole-body vibration exposure stimulates skeletal muscle by activating a stretch reflex analogous to the tonic vibration reflex (Cardinale and Bosco 2003; Ritzmann et al. 2010; Figure 1.3). As depicted in Figure 3, the mechanical vibrations generated by the WBV platform cause short and rapid changes in extrafusal muscle fibre length which are detected by the intrafusal fibres located inside the muscle spindle, specifically the primary sensory endings (highly sensitive to changes in length; Hagbarth and Eklund 1966; Mester et al. 1999). These vibration-imposed length changes initiate an afferent response within the muscle spindle sending Group 1a sensory neurons to the

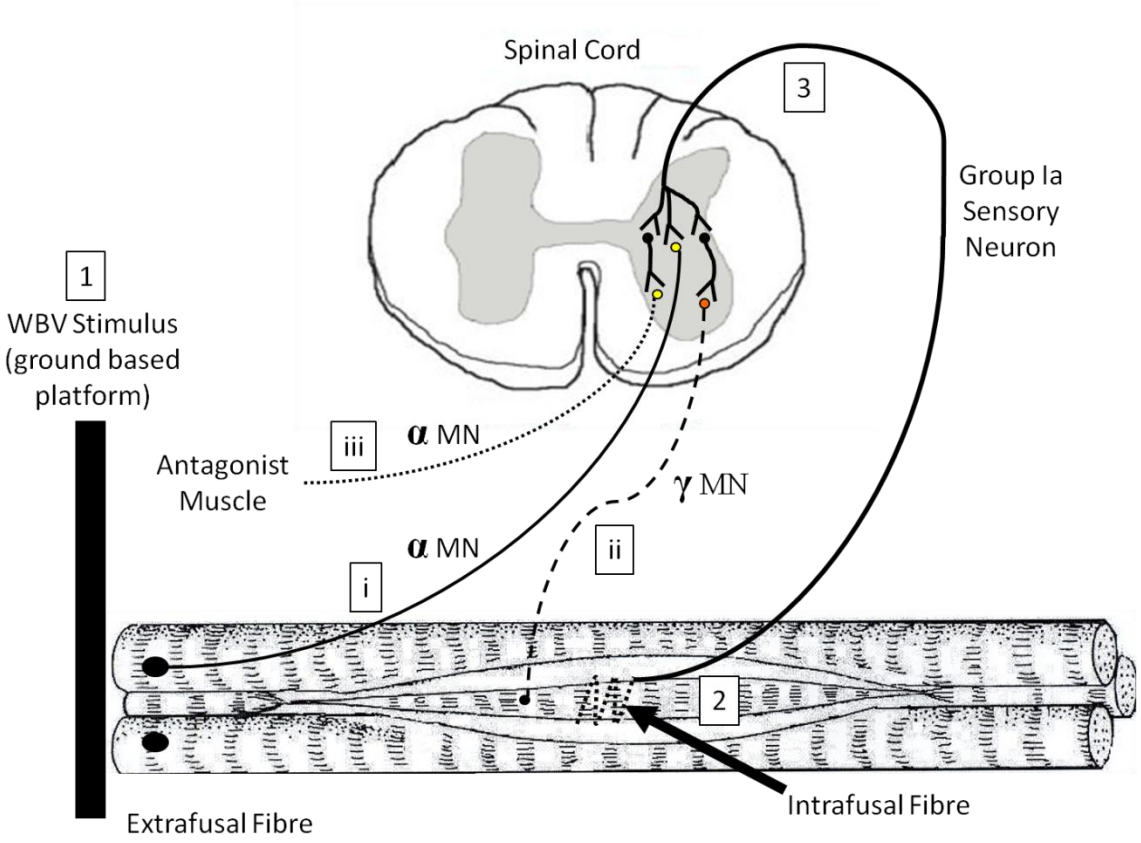

Figure 1.3 – Tonic Vibration Reflex - The vibration stimulus (1) causes short and rapid changes in muscle fibre length that are detected by the muscles spindles (2) which send Ia sensory neurons to the spinal cord (3). In the spinal cord these Ia sensory neurons can : (i) use a mono-synaptic projection (direct) to excite an alpha motor neuron that will stimulate a reflexive muscle contraction in the extrafusal muscle fibre of the same muscle, (ii) use a poly-synaptic projection to inhibit an alpha motor neuron preventing antagonist muscle activity, (iii) use another poly-synaptic projection to activate a gamma motor neuron that will cause the intrafusal muscle fibre of the agonist muscle to maintain its sensitivity to further vibration perturbations.

spinal cord (Matthews 1966) which result in both mono-synaptic and poly-synaptic actions. Excitation of alpha motor neurons (α MN) through monosynaptic projections innervate extrafusal fibres (of the same muscle) resulting in an involuntary reflexive contraction (Hagbarth and Eklund 1966; Mester et al. 1999) in an attempt to control the vibration imposed muscle length change. The sensory afferent information via polysynaptic projections can inhibit α MN preventing antagonist muscle action, or activate gamma motor neurons (γ MN) causing the intrafusal fibre to remain sensitive to

further vibration oscillations (Cardinale and Bosco 2003; Eklund and Hagbarth 1966). The oscillatory perturbations may also stimulate the skin and joint receptors which may provide further sensory input to the γ MN increasing the sensitivity and responsiveness of the muscle spindle to successive WBV perturbations (Cardinale and Bosco 2003; Eklund and Hagbarth 1966; Mester et al. 1999; Ribot-Ciscar et al. 1989).

Although many believe this stretch reflex stimulation to be the primary mechanism of action for WBV, at least two other potential mechanisms could also be involved. One is that WBV elicits a postural control strategy (Abercromby et al. 2007) where the vibration stimulus generates postural instability. The body responds by activating muscles to maintain body balance. If so, this could be advantageous in helping reduce falls in the elderly which is of course a substantial health concern (Abercromby et al. 2007). Furthermore, the vibration oscillations could induce a muscle tuning response in an attempt to minimize the propagation of the vibrations throughout the body (Wakeling and Nigg 2001; Wakeling et al. 2002, 2003). Consequently, the muscles might activate to prevent further transmission of the vibration stimulus through the body similar to the way the body reacts to a heel strike during running (Wakeling and Nigg 2001; Wakeling et al. 2002). Additional study is required to identify the mechanism(s) responsible for the effect of WBV on the musculature.

Regardless, the WBV stimulus results consistently in a significant increase in muscle activity. Both the side-alternating (Abercromby et al. 2007; Cardinale and Lim 2003) and synchronous (Abercromby et al. 2007; Hazell et al. 2007, 2010; Roelants et al. 2006) types of WBV delivered through the feet increase activity in a variety of lower body muscles (vastus lateralis, vastus medialis, rectus femoris, gastrocnemius). In contrast, any stimulus delivered through the feet reaching the upper body musclulature

during either static or dynamic contractions is minimal (Hazell et al. 2007). Perhaps this lack of an upper body affect is due to a reduction in the transmissibility of the signal (Rubin et al. 2003), lack of proximity to the WBV platform, or the number of joints dampening the propagation of the stimulus. Finally, our recent muscle activity work has demonstrated that the WBV can also increase muscle activity during loaded dynamic squats, i.e., those with external loads (Hazell et al. 2010) suggesting WBV exercise could possibly further enhance the response to conventional strength training.

Chronic Whole-body Vibration Exercise

Several chronic studies ranging from 5 days to 12 weeks have reported WBV-induced increases in strength (Delecluse et al. 2003; Roelants et al. 2004; Ronnestad 2004; Savelberg et al. 2007), power (Bosco et al. 1998; Lamont et al. 2008, 2009, 2010), and performance (Bosco et al. 1998; Delecluse et al. 2003; Di Giminiani et al. 2009; Lamont et al. 2008, 2009, 2010; Torvinen et al. 2002) in young healthy adults. However, similar to the acute studies there are several studies demonstrating no benefits with WBV training (Cochrane et al. 2004; de Ruiter et al. 2003; Kvorning et al. 2006). Likely this is due to the considerable variability in exercise movements, durations, rest periods, and WBV stimuli used. Carefully controlled studies documenting the responses to acute WBV exercise are needed in order to determine whether or not chronic WBV exercise is beneficial.

Whole-body Vibration Exercise and Health

Clearly both endurance and strength exercise training produce a variety of health and exercise performance benefits. Although much less studied, WBV is promoted as a training ‘panacea’. This is unfortunate as it may mislead the general public. To date,

there is some evidence that WBV results in positive effects on flexibility, joint stability, and balance (Cochrane and Stannard 2005; Rittweger 2010) suggesting it may help improve activities of daily living in older adults. Other possible health benefits include improvements in energy metabolism, body composition, hormone profiles (ie growth hormone, cortisol), and blood lipids (Bosco et al. 2000; Goto and Takamatsu 2005; Kvorning et al. 2006). However, these results are preliminary and require further investigation to ascertain if they are induced by WBV exercise. Pilot data from our laboratory (n=3) has demonstrated WBV training leads to decreases in fat mass and increase in lean mass; however, future research is necessary to document any potential health outcomes with WBV exercise.

Summary

While the technology of WBV has been around for decades, the recent surge of investigations (over the last 10 years) has only scratched the surface of the effects of WBV. The vertical oscillations of the platform increase exercise intensity as evidenced by an increase in skeletal muscle EMG activity and this may mean WBV exercise can improve health in ways similar to traditional strength or endurance exercise training. To document these effects as well as any potential adverse effects, more research is needed. In the following chapters, several physiological effects of acute synchronous WBV exercise are presented.

In Chapter 2, data are presented demonstrating that the addition of vibration to a static leg squat results in no further increase in heart rate and mean arterial pressure compared to the same exercise without vibration. Moreover, the WBV exposure did increase leg skin temperature significantly with potential increases in femoral artery

blood flow. These data suggest that the addition of WBV to a static semi-squat has only a mild cardiovascular stress.

In Chapter 3, data are presented demonstrating that a moderate WBV exercise session (including upper and lower body movements) increases oxygen consumption significantly both during and following exercise compared to the same exercise session without vibration. These results suggest regular WBV exercise (training) could produce a significant amount of fat mass loss, assuming constant energy intake.

In Chapter 4, data are presented demonstrating moderate WBV exercise has little effect on muscle damage, soreness, or inflammation compared to the same exercise session without vibration. These results indicate suggest WBV might be a viable training mode for those with low functional capacity but that it may be an insufficient stimulus for more fit individuals.

In Chapter 5, data are presented demonstrating WBV exercise may enhance insulin sensitivity in young healthy mean with normal glucose tolerance. Although subsequent study of individuals with impaired glucose tolerance is necessary this observation could be important because of the current epidemic of diabetes in developed countries.

Finally, in chapter 6 the findings of all four studies are reviewed, practical implications with regard to WBV exercise are provided, and recommendations for future research are discussed.

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CHAPTER 2

Synchronous whole-body vibration does not increase cardiovascular stress to static semi-squat exercise

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Hazell TJ, Thomas GWR, DeGuire JR, & Lemon PWR (2008) Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise. *Eur J Appl Physiol* 104: 903-908

Introduction

Whole-body vibration (WBV) is an increasingly popular method of skeletal muscle training where static or dynamic exercises are performed on a vibrating platform. Research has demonstrated that WBV increases skeletal muscle electromyography (EMG) activity (Cardinale and Lim 2003; Hazell et al. 2007; Roelants et al. 2006) suggesting WBV exposure may be a viable training modality. However, to date equivocal results in terms of strength, power, and performance have been reported with WBV training. Several studies demonstrate increases similar to those derived from more traditional strength training (Delecluse et al. 2003; Roelants et al. 2004a, b; Torvinen et al. 2002) while others suggest little benefit (Cochrane et al. 2004; Delecluse et al. 2005; Kvorning et al. 2006). Although for the most part beneficial in a number of ways, it is known that strength exercise, at least with large muscle mass maximal lifts, results in substantial increases in heart rate and blood pressure (Gaffney et al. 1990; MacDougall et al. 1992).

The cardiovascular response to WBV exercise is less clear. Compared to baseline, Kerschan-Schindl et al. (2001) observed increased popliteal artery blood flow with 9 min of continuous standing in a static semi-squat position (knee flexion = 60-70°) but with no increase in heart rate or blood pressure. However, they could not determine if this was in response to the exercise itself or due to the addition of WBV. In contrast, Lohman et al. (2007) found no increase in leg skin blood flow with 3 min of intermittent squats (1 min on, 1 min off) with or without WBV in any of three static semi-squat positions (knee flexion = 25°, 80°, or 100°). Interestingly, skin blood flow did increase when the subjects rested their calves directly on the WBV platform suggesting that direct vibration can affect even inactive musculature (Lohman et al. 2007) although this could be due a

different mechanism. Rittweger et al. (2000) demonstrated that dynamic squat exercise with an additional load (35-40% body mass) to volitional fatigue increased heart rate, blood pressure, and skin blood flow (foot and leg) versus baseline but also could not distinguish the effects of WBV from the effects of the exercise alone.

To date no study has evaluated the cardiovascular response to a more comprehensive WBV exercise workout, i.e., a series of exercises, repeated for several sets like a typical strength training session, nor has the recovery period been assessed. With no clear understanding of the effect of WBV on the cardiovascular system, manufacturers of WBV platforms have generated a substantial list of contraindications that include both diabetes and cardiovascular disease. This has resulted in considerable apprehensiveness when prescribing WBV exercise to some of the very populations that could benefit most from this type of training such as older adults and people with metabolic syndrome or cardiovascular disease. Therefore, the purpose of this study was to document heart rate (HR), mean arterial pressure (MAP), femoral artery blood flow (FBF), and leg skin temperature (LSk_{temp}) responses during and following a WBV exercise bout compared to the same exercise with no vibration (NoV) as an initial attempt to determine whether such contraindications are necessary.

Methods

Healthy recreationally active men (20-30 y) were recruited to participate in this study. Subjects were required to pass the PAR-Q health survey (Thomas et al. 1992) and had no contraindications to WBV according to the manufacturer's criteria (i.e. diabetes, cardiovascular diseases, epilepsy, gallstones, kidney stones, acute inflammations, joint problems, joint implants, recent thrombosis, tumours, recent operative wounds, intense

migraines, or back problems such as hernia). The Health Sciences Office of Research Ethics at The University of Western Ontario approved this study in accordance with the ethical standards of the 1964 Declaration of Helsinki and all subjects gave their informed written consent prior to participation.

Protocol

All subjects performed a familiarization trial, employing all static positions to be utilized during the experimental sessions. The WBV stimulus was applied with a WAVE™ platform (Whole-body Advanced Vibration Exercise, Windsor, Canada). This platform generates a synchronous (vertical) vibration stimulus whereby the platform oscillates up and down uniformly. The WBV stimulus was set at a frequency of 45 Hz and 2 mm peak-to-peak displacement which we have shown to increase leg skeletal muscle EMG significantly (Hazell et al. 2007). Two conditions were examined, the first was a seated (passive, unloaded) condition and the second condition was a semi-squat (static, loaded) position (both with WBV and without vibration [NoV]). The protocol involved 15 repetitions of one min and one min of seated rest followed by 10 minutes of recovery (total time=40 minutes). Each subject sat quietly in the laboratory for 25-35 minutes before baseline measures were made to allow for acclimation to the environment (room temperature 21.2 ± 0.5°C).

Seated Condition

Eight men (age= 25±3.4 years, height= 178±6.2 cm, body mass= 80±10.3 kg; mean±SD) sat in a chair beside the WBV platform, with their feet on the WBV platform and their knees at 90° flexion. This position was chosen to examine the effect of WBV in a passive, unloaded position. The subjects' feet were secured in contact with the platform by a velcro strap attached at each side of the oscillating plate.

Static Semi-Squat Condition

Five of the same men and three others (age= 25±2.6 years, height= 177±7.0 cm, body mass= 84±12.1 kg) completed both a WBV and NoV trial in a static semi-squat position (knees at 120±5° via goniometer). Trials were conducted in random order and separated by a minimum of 48 hours rest. The combination of these two trials allowed the differentiation of the effects of WBV from the effects of the static-squat itself.

Outcome Measures

Heart rate (bpm) was calculated from R-R intervals of a 3-lead electrocardiograph (Pilot 9200, Collins Instruments, San Antonio, TX). Mean blood pressure (mmHg) was assessed by photoplethysmography with a finger cuff on the middle finger of the right hand (Finometer®, Finapress Medical Systems, Amsterdam, The Netherlands). Both HR and MAP were continuously recorded during all protocols. Blood flow velocity (cm/sec) and vessel diameter (mm) of the common femoral artery were measured using a 2-MHz Doppler ultrasound probe (CFM750, GE/Vingmed, Horten, Norway). The same experienced investigator made all Doppler measurements. Estimates of femoral artery blood flow (FBF; $mL \cdot min^{-1}$) were calculated using common femoral artery blood velocity and cross-sectional area (Hughson et al. 1996; MacDonald et al. 1998; Van Beekvelt et al. 2001). Previous literature indicates that common femoral artery vessel diameter does not change with exercise (Shoemaker et al. 1996). We verified this by measuring common femoral artery vessel diameter at baseline and at the end of exercise (30 min) and observed no significant difference (data not shown). Therefore, the diameter measured at baseline was used to calculate FBF for all subsequent time points. Leg skin temperature (LSK_{temp}; °C) was assessed with a skin temperature probe at a site 2.5 cm superior to the lateral malleolus of the left ankle (MLT409/A, ADInstruments, Colorado Springs, CO).

Blood flow and skin temperature were measured following 5 min of seated rest to establish baseline values and repeated at 8, 16, 24, & 30 min of the protocol which corresponded to the rest periods following the 4^{th}, 8^{th}, 12^{th} , and 15^{th} bouts of exercise. Recovery measurements were made at 32, 35, and 40 min of the protocol (corresponding to 2, 5, and 10 min of recovery (Figure 2.1). Analog signals for all measurements were sampled at 100 Hz, whereas ECG was sampled at 1,000 Hz, and stored with an online data acquisition and analysis package (PowerLab, ADInstruments, Colorado Springs, CO). All data were averaged over a 10 sec period (25-35 sec into the rest interval). This timeline was selected to ensure a stabilization of the leg skin temperature recording and to provide time to locate and optimize the Doppler signal.

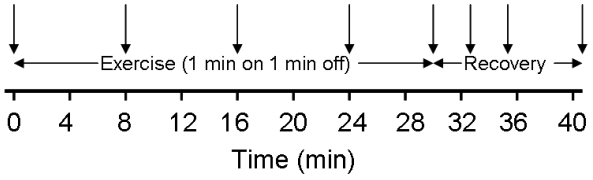

Figure 2.1 – Protocol timeline. All measurements made at 0 min (baseline), 8 min (4^{th} WBV bout), 16 min (8^{th} WBV bout), 24 min (12^{th} WBV bout), and 30 min (15^{th} WBV bout) as well as after 2, 5, and 10 min recovery (32, 35, & 40 min of the protocol). Arrows indicate time points for HR, MAP, FBF, and LSk_{temp}.

Statistical Methods

Two-way repeated measures ANOVAs were used to investigate the differences in HR, MAP, FBF, and LSk_{temp} at all time points. All data are presented as means±SD and the level of statistical significance was set at $p<0.05$. Post hoc tests were performed using Tukey's Honestly Significant Difference tests.

Results

Seated Condition (Passive, Unloaded)

Exposure to WBV during the passive seated condition did not result in any significant effects on HR, MAP, FBF, or LSk_{temp} (Table 2.1) indicating that vibration to unloaded muscles with feet flat on the platform provides a minimal stimulus.

Table 2.1 - Cardiovascular measures during seated condition at baseline, at 8, 16, 24, and 30 min of WBV (1 min on, 1 min off) and after 2,5, & 10 min recovery[1]

Time (min)	HR (bpm)	MAP (mmHg)	FBF ($ml \cdot min^{-1}$)	LSk_{temp} (°C)
0 (Baseline)	66±8	97±9	222±113	29.2±0.9
8 (4^{th} min WBV)	68±12	101±10	208±116	29.2±1.0
16 (8^{th} min WBV)	70±8	100±10	174±52	29.5±1.4
24 (12^{th} min WBV)	69±8	103±10	177±56	29.6±1.6
30 (15^{th} min WBV)	69±7	104±14	195±87	29.1±2.8
32 (2 min Recovery)	70±6	103±15	179±104	30.1±2.0
35 (5 min Recovery)	73±9	106±13	208±91	29.6±1.6
40 (10 min Recovery)	71±10	104±10	206±74	29.7±1.3

HR, heart rate; MAP, mean arterial pressure; FBF, femoral artery blood flow; LSk_{temp}, leg skin temperature; WBV, whole-body vibration
[1]None of the observed changes reached statistical significance

Semi-Squat Condition (Static, Loaded)

Heart Rate

There was no interaction between treatment and time of measure for heart rate (P=0.970). There were also no main effects for treatment (P=0.343) or time of measure (P=0.808; Table 2.2). Heart rate in the NoV (73±13 bpm) and WBV conditions (68±10 bpm) were not different at baseline and there was no effect on HR for either the no-WBV or WBV conditions at any time point (Table 2.2).

Mean Arterial Pressure

There was no interaction between condition and time (P=0.484) for mean arterial pressure. There was also no effect of treatment (P=0.929) but there was a main effect for

time of measure (P<0.001). As expected, baseline MAP in the NoV (98±8 mmHg) and WBV conditions (92±8 mmHg) were similar (Table 2.2). Mean arterial pressure did increase significantly with the exercise vs baseline (P<0.0227) at 24 min (12th exercise bout) and continued through 10 min of recovery (to 40 min time point). The 30 min time point was also significantly increased vs the 8 min (4th exercise bout) time point (P=0.018) as well as the 16 min (8th exercise bout) time point (P=0.040). However, there was no further effect of the addition of WBV to the exercise.

Table 2.2 – Heart rate and mean arterial pressure measures during static-semi squat exercise with and without WBV at baseline, at 8, 16, 24, and 30 min of WBV (1 min on, 1 min off) and after 2,5, & 10 min recovery

Time (min)	HR (bpm)		MAP (mmHg)		
	NoV	WBV	NoV		WBV
0 (Baseline)	73±13	67±10	98±8		92±8
8 (4th min WBV)	73±12	65±10	102±7		96±10
16 (8th min WBV)	73±15	66±12	100±5		96±15
24 (12th min WBV)	73±13	66±17	107±10	*a*	102±16
30 (15th min WBV)	75±14	67±18	103±8	*abc*	106±16
32 (2 min Recovery)	74±14	66±14	105±11	*a*	100±13
35 (5 min Recovery)	73±13	64±12	103±9	*a*	98±18
40 (10 min Recovery)	73±13	67±13	104±9	*a*	100±15

HR, heart rate; MAP, mean arterial pressure; static semi-squat with whole-body vibration (WBV) or without vibration (NoV)
No differences between NoV and WBV
a – increased vs baseline (P<0.002)
b – increased vs 8 min (4th exercise bout; P=0.018)
c – increased vs 16 min (8th exercise bout; P=0.040)

Femoral Artery Blood Flow

There was no interaction between treatment and time of measure (P=0.496) for femoral artery blood flow. There was also no main effect for treatment (P=0.308) but there was a main effect for time of measure (P<0.001). At baseline prior to the semi-squat exercise, femoral artery blood flow was similar for both the NoV (218±65 ml·min^{-1}) and WBV conditions (195±25 ml·min^{-1}; Figure 2.2). The exercise itself increased FBF vs baseline at the 24th min (12th exercise bout) time point (P=0.009) and the 30th min (15th exercise bout) time point (P=0.005). The 24 and 30 min time points were also increased vs the 40 min (10 min recovery) time point (P<0.038) but there was no effect of adding WBV.

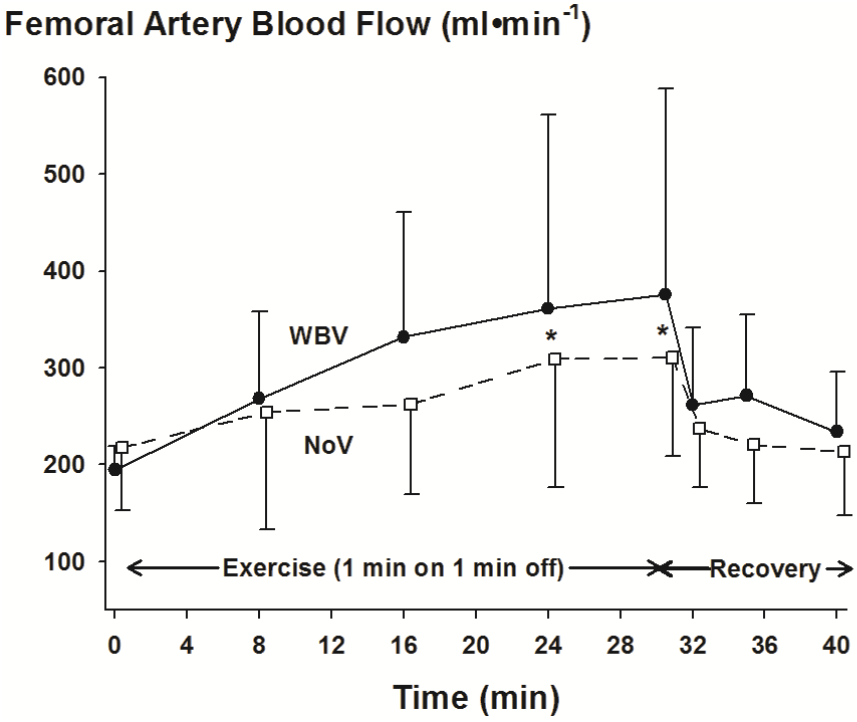

Figure 2.2 – Femoral Artery Blood flow response versus time in the NoV and WBV static semi-squat position (means±SD). There was a main effect (*; P<0.038) of time at 24 (12th exercise bout) and 30 min (15th exercise bout) vs baseline and 40 min (10th min recovery)

Skin Temperature

There was a significant interaction between treatment and time of measure for LSk_{temp} ($p<0.001$). At baseline prior to the semi-squat exercise, leg skin temperature was similar ($P>0.05$) in both the NoV (29.6±0.9 °C) and WBV conditions (29.2±1.6 °C) (Figure 2.3). The NoV condition did not affect LSk_{temp} while the WBV condition increased LSk_{temp} over baseline and the 8 min (4^{th} exercise bout) time point by the 16 min (8^{th} exercise bout) time point and continuing all the way through recovery ($P<0.001$) The increase in LSk_{temp} with WBV was also increased over the NoV condition at 24 min (12^{th} WBV bout; $P=0.017$) and 30 min (15^{th} WBV bout; $P=0.011$) as well as after all recovery time points ($P<0.001$).

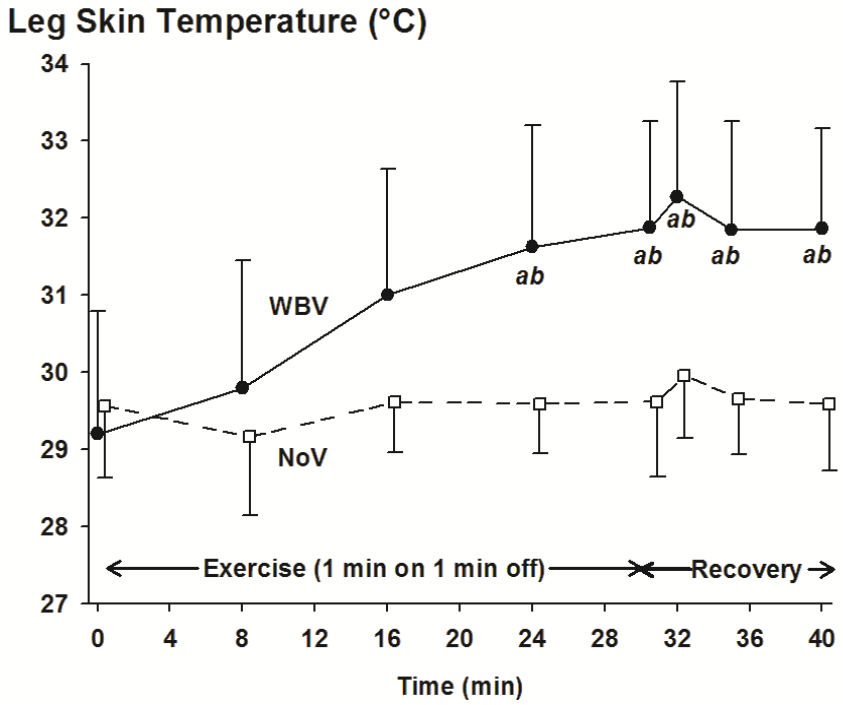

Figure 2.3 – Leg Skin temperature response versus time in the no-WBV and WBV static semi-squat position (means±SD)
a - WBV increased over baseline ($P<0.001$)
b - WBV increased over NoV($P<0.046$)

Discussion

The current study examined the cardiovascular response (HR, MAP, FBF, and LSk_{temp}) during and following a series of acute bouts of vertical WBV in both a seated position (passive, unloaded) and in a semi-squat position (static, loaded). Our main finding was that the addition of WBV to 15, repeated static semi-squats (knee angle = 120°, one min on, one min off) did not increase the cardiovascular stress in young, healthy males. The static semi-squat position itself resulted in a significant increase in MAP at 24 min but with no significant change in HR, FBF, and LSk_{temp}. The addition of WBV to semi-squat exercise caused a small non-significant increase in FBF at 16 min (which had dissipated by 40 min) and a sustained significant increase in LSk_{temp} at 16 min continuing through 40 min. However, these effects are quite small physiologically. Moreover, WBV did not increase HR or MAP versus that observed with the NoV semi-squat. Although previously, we and others have shown dynamic WBV exercise (full squats) increases EMG activity versus the same exercise without the WBV stimulus (Cardinale and Lim 2003; Hazell et al. 2007; Roelants et al. 2006) the present findings indicate that superimposing WBV to a semi-squat (static) exercise session produces minimal additional cardiovascular stress.

The seated condition of this study was included to evaluate the effect of a WBV stimulus on inactive muscles not under tension (unloaded) because previous research has suggested that muscles and joints under tension have an increased response to the WBV perturbation (Hagbarth and Eklund 1966; Martin and Park 1997; Mester et al. 1999; Nordin and Hagbarth 1996). To our knowledge this is the first attempt to examine WBV on unloaded muscles in a position similar to typical standing WBV exposure via a ground based platform (feet flat on the platform). Previously, Lohman et al. (2007) have reported

an increased skin blood flow when subjects rested their calves directly on the platform. Perhaps this increase in blood flow results from friction between the skin and platform rather than from vibration per se.

The static semi-squat is a typical position utilized in most WBV training protocols. Our comparison of static squat exercise with and without WBV evaluates the additional effects of vibration providing information not available previously (Kerschan-Schindl et al. 2001; Rittweger et al. 2000). Although, the static semi-squat position itself increased MAP significantly to 107±10 mmHg, importantly, the addition of vibration did not result in a further increase in MAP. Moreover, the increase with static-squat exercise was much less than observed with isometric exercise (25-100% maximal voluntary contraction) which increased MAP to 140±14-161±11 mmHg (Gaffney et al. 1990) or that measured with dynamic strength training (10 repetition maximum) which increased MAP to 109±4-138±5 mmHg (MacDougall et al. 1998).

In terms of blood flow, Lohman et al. (2007) found no increase in skin blood flow with 3 min of intermittent vibration exposure while Kerschan-Schindl et al. (2001) observed an increase in popliteal artery flow after 9 min exposure. Our common femoral artery flow data are consistent with these two studies as we found no increase after 8 min similar to Lohman et al. (2007) but blood flow did increase, albeit modestly, with additional repeats (24 min) which is in line with the observations of Kerschan-Shindl et al. (2001). However, the individual FBF response was variable and the lack of statistical significance could be due to a Type II error. Some increase in blood flow during WBV seems appropriate considering previously described increases in muscle activity in the leg (Cardinale and Lim 2003; Hazell et al. 2007; Rittweger et al. 2000) but regardless, the

response magnitude was small indicating that any cardiovascular effect is minimal in a static position.

We did observe a significant increase in LSk_{temp} after 16 min and throughout the 10 min recovery period during the WBV static semi-squat exercise. This skin temperature increase over the distal leg area (just superior to the lateral malleous) likely reflects skin blood flow. Previous studies by Rittweger et al. (2000) and Kerschan-Shindl et al. (2001) both reported itchiness and redness of the skin in response to WBV in many of their subjects. Several of our subjects also reported experiencing itchiness and redness was visible. Further, another study using direct local vibration has reported a significant increase in skin temperature and also observed skin erythema (Oliveri et al. 1989).

Perhaps the small non-significant increase in FBF we observed is due to a redistribution of blood to leg muscle, skin or both. It is believed that WBV exposure results in changes in muscle fibre length that elicit reflexive muscle contractions (Hagbarth and Eklund 1966). These involuntary reflex contractions could increase muscle temperature necessitating an increased skin blood flow to dissipate heat. Such a response would be expected to increase skin temperature as we observed.

Previous studies have suggested that WBV exposure during static exercises results in increases in oxygen consumption (4.5 $ml \cdot kg \cdot min^{-1}$; Rittweger et al. 2001), energy expenditure (Garatachea et al. 2007), and EMG activity (Cardinale and Lim 2003; Hazell et al. 2007; Roelants et al. 2006). Our current data indicate intermittent semi-squat exercise with WBV when repeated for 15 repetitions (one min on and one min off) increases common FBF and distal LSk_{temp} minimally relative to the same exercise without vibration. Increases in oxygen consumption, muscle activity, and leg blood flow with little effect on heart rate and blood pressure suggest WBV exposure also results in arterial

vasodilation in the exercising limb. Furthermore, if WBV exercise increases oxygen consumption, this should require an increase in cardiac output. Although likely small, together with the current observation of no increase in HR, WBV could, therefore, result in an increase in stroke volume. This might be the result of an increase in venous return though this result and the possible mechanisms responsible for it require further study.

Conclusion

Adding synchronous WBV to static-semi squat exercise results in a significant but small increase in LSk_{temp} with little effect on HR, MAP, and FBF indicating that any imposed stress is minimal. Future studies should investigate the cumulative cardiovascular response to WBV with multiple static and dynamic exercises using both upper and lower body musculature as well as in populations with compromised cardiovascular systems and/or those unable to perform traditional strength exercise, i.e., those in rehabilitation programs, to determine more appropriate contraindications for this new exercise modality.

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CHAPTER 3

Synchronous whole-body vibration increases VO_2

during and following acute exercise

Introduction

Over the past decade or so whole-body vibration (WBV) exercise has been become a popular training modality. The vertical oscillations generated by the platform are theorized to stimulate reflex muscle contractions in a response akin to monosynaptic reflexes (Cardinale and Bosco 2003). Acute whole-body vibration exercise (both synchronous and side-alternating) results in a significant increase in muscle activity, muscle/skin temperature (Abercromby et al. 2007; Cardinale and Lim 2003; Cochrane et al. 2008; Hazell et al. 2007, 2008, 2010; Marin et al. 2009; Ritzmann et al. 2010; Roelants et al. 2006) and has even been reported to increase strength, power, and performance (Bosco et al. 1999; Cormie et al. 2006; Da Silva-Grigoletto et al. 2009; McBride et al. 2010; Ronnestad 2009; Torvinen et al. 2002a). However, there are also data showing little effect (de Ruiter et al. 2003; Erskine et al. 2007; Torvinen et al. 2002b) perhaps indicating that a wide range of exercise intensities are possible with WBV exercise.

Completing static and dynamic squats on a WBV platform (side-alternating) increased VO_2 ~3-5 $ml \cdot kg^{-1} \cdot min^{-1}$ compared to the same exercise without vibration (Rittweger et al. 2001). Recently, we have demonstrated minimal cardiovascular stress (heart rate, blood flow, or mean arterial pressure) with the addition of WBV to a static semi-squat position (Hazell et al. 2008) suggesting that static WBV exercise may not intense enough to result in a meaningful increase in oxygen consumption. However, dynamic WBV squats at least with an external load (35-40% body mass) increase VO_2 significantly (up to ~50% of VO_2max; Rittweger et al. 2000, 2002) indicating that the stimulus with WBV can be considerable. The greatest increase in VO_2 (0.7 $ml \cdot kg^{-1} \cdot min^{-1}$) vs NoV during dynamic squatting was seen while performing a 2 sec squat cycle (1 sec down 1 sec up; Garatachea et al. 2007) compared to slower squatting cadences (4 sec or 6

sec cycles). During five sets of loaded (10 repetition max) dynamic squats (11.5 min), the addition of WBV (side alternating) significantly increased VO_2 (1.7 $ml \cdot kg^{-1} \cdot min^{-1}$) vs the same exercise without vibration and by 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$ during 5 min of recovery (Da Silva et al. 2007). Although these increases in oxygen consumption during and immediately following WBV exercise vs no vibration exercise are small (only ~2.2 L O_2 [~45 kJ]) in 16.5 min they could be underestimates because recovery collections were so brief any anaerobic energy contribution would have been missed. It is unknown whether a more complete whole body dynamic exercise session (multiple exercises targeting both upper and lower body muscle groups) is strenuous enough to generate a significant training stimulus.

The purpose of this study was to quantify VO_2 during and for an extended time period (24 h) following a multiple exercise WBV exercise session vs the same exercise session without the addition of vibration in order to determine the potential of WBV exercise as part of a program to enhance body composition. It was hypothesized that WBV exercise would increase 24 h VO_2 relative to the same exercises without vibration and, of course, to a non-exercise control day.

Methods

Protocol Overview

Oxygen consumption of healthy male Kinesiology students (n=8) was measured for 24 h to assess the effect of a WBV exercise session vs the same exercise session without vibration (NoV). Subjects (26±2.3 y, 180±8.2 cm, 84±10.1 kg, 16.6±6.1% body fat) first completed three separate 24 h VO_2 collections (WBV, NoV, and no exercise [control]) without measurement during exercise. Subsequently, they repeated the two

exercise sessions exactly as before (including the overnight fast and breakfast) but with VO_2 measurement during the exercise. Three subjects were unable to return for the during exercise measurements due to scheduling problems and were replaced with 3 others of matching gender, age, height, body mass, body composition, and fitness levels (during exercise subjects = 26±3.0 y, 179±8.3 cm, 85±7.3 kg, 19.7±6.0% body fat). The treatments were systematically rotated to avoid order effects. No physical activity was performed for at least 24 h prior to participation and both physical activity and diet (see below) were controlled throughout the experiment. All subjects passed the PAR-Q health survey (Thomas et al. 1992) and had no contraindications to WBV according to the manufacturer's criteria (i.e. diabetes, cardiovascular diseases, epilepsy, gallstones, kidney stones, acute inflammations, joint problems, joint implants, recent thrombosis, tumours, recent operative wounds, intense migraines, or back problems such as hernia). The Health Sciences Office of Research Ethics at The University of Western Ontario approved this study and all subjects gave their informed written consent prior to any participation.

Exercise Session

The exercise session involved both upper and lower body dynamic exercises and utilized all major muscle groups. A 1:1 exercise to recovery ratio (30 sec exercise: 30 sec recovery) was used. Specifically, subjects completed a total of six exercises (5 sets of each) paced by a metronome at a rate of 15 reps in 30 sec because a two sec cycle has been shown previously to result in greater increases in oxygen consumption than slower squatting cadences (Garatachea et al. 2007). This resulted in 15 min of exercise over the 30 min protocol. The exercises for the lower body including squats (feet on the platform), single leg lunges for each leg (lead foot on the platform), and hamstring

bridges (laying supine, feet on the platform and repetitions involving elevating the trunk). The upper body exercises included push-ups and triceps dips (hands on the platform). Blocks were utilized for the upper body exercises, lunges, and the hamstring bridges so that the hands and feet that were off the platform remained at the same height as the platform. Body mass was the resistance and range of motion was controlled with a goniometer.

The WBV stimulus was applied using a WAVE™ platform (Whole-body Advanced Vibration Exercise, Windsor, Canada). This platform generates a synchronous (vertical) vibration stimulus whereby the platform oscillates up and down uniformly (Ritzmann et al. 2010). The WBV stimulus was set at a frequency of 45 Hz and a peak-to-peak displacement of 2 mm (verified via single frame analysis of high speed video) which we have shown previously to increase leg skeletal muscle EMG significantly (Hazell et al. 2007, 2010). Importantly, the platform compensates for individual differences in body mass via a load levelling system® so each subject received the same vibration stimulus. Briefly, this works by placing the vibration platform in the same initial position, regardless of body mass, using inflatable air bladders. We have verified system performance with masses up to 180 kg (data not shown). The NoV exercise session was performed on the same platform with the vibration turned off.

Oxygen Consumption

All measurements were made by indirect calorimetry using an online breath by breath gas collection system (Vmax Legacy, Sensor Medics, Yorba Linda, USA). The system was calibrated according to manufacturer's recommendations before testing using gases of known concentration and a 3 litre syringe. Subjects were fitted with a silicone gas collection face mask (7400 series Vmask™, Hans Rudolph Inc., Shawnee, USA) with

an attached seal (Sensa Seal™, Hans Rudolph Inc., Shawnee, USA) to prevent air leakage during the measurement period.

Oxygen consumption was monitored over eight, 30 min periods before, during, and following the exercise session (see below for details). Before and following exercise measures were made while subjects were lying supine in a temperature/humidity controlled chamber (21 degrees C, 11% relative humidity). The first 15 min of the 30 min collection was discarded, breath by breath data were averaged over 30 sec and expressed as litres of $O_2 \cdot min^{-1}$. Exercise measures were taken continuously and also averaged over 30 sec. Heart rate (HR) was measured using a HR monitor (Polar RS200sd™, Polar Electro Inc., Lachine, Canada).

Experimental Protocol

Subjects arrived at the laboratory in the morning (0800 h) after an overnight fast (no food/drink, except water after 2000 h the previous day) having limited their physical activity getting to the laboratory (driven and used the elevator). They remained in the laboratory over the next 9 h. Breakfast (0830-0845 h) and lunch (1230-1245 h) were provided and dinner was reproduced for all 3 conditions (nutrient details below). Oxygen consumption was measured from 0800-0830 h (baseline), from 0845-0915 h (pre-exercise), from 0915-0945 (during exercise), from 0945-1015 h (immediately post-exercise), from 1200-1230 h (2 h post-exercise), from 1245-1315 h (3 h post-exercise), and from 1600-1630 (6 h post-exercise). Subjects relaxed quietly reading between measures. At 1630 h subjects were allowed to leave the laboratory but did not perform any further exercise the rest of the day. Finally, subjects reported back to the laboratory the following morning (0800 h) after another overnight fast and VO_2 was remeasured

(recovery baseline; Figure 3.1). For the control day, subjects repeated the entire protocol exactly but rested quietly from 0915-0945 h.

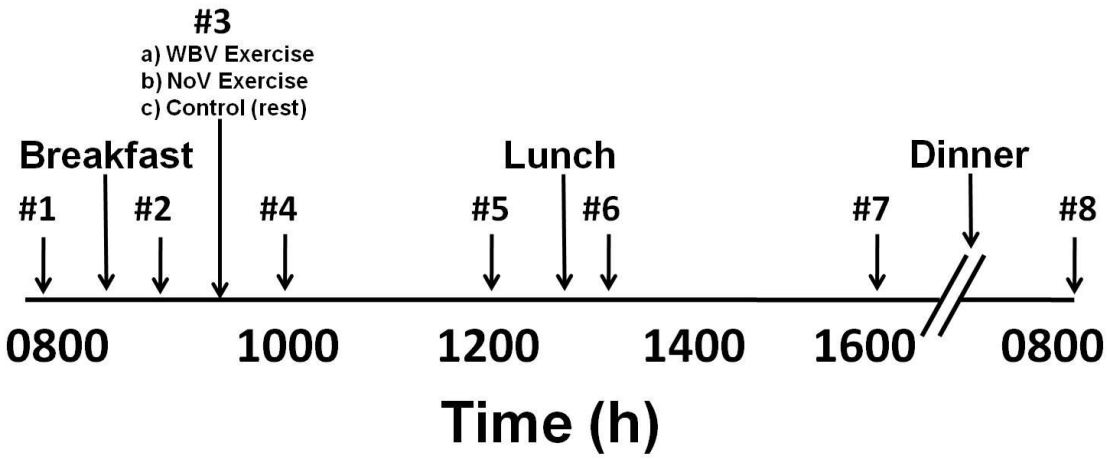

Figure 3.1: Protocol Timeline. Arrows indicate measurement time points. #1 - Baseline (0800-0830 h), #2 – Pre-exercise (0845-0915 h), #3 - During exercise (0915-0945 h), #4 – Immediately post-exercise (0945-1015 h), #5 – 2 h post-exercise (1200-1230 h), #6 – 3 h post-exercise (1245-1315 h), #7 – 6 h post-exercise (1600-1630 h), and #8 - Recovery baseline (0800-0830 h next day). Breakfast was a 29 kJ•kg^{-1} meal at 0830-0845 h, lunch was a 46 kJ•kg^{-1} meal at 1230-1245 h and dinner was a 50 kJ•kg^{-1} meal in the evening.

Total Oxygen Consumed

To determine the total amount of oxygen consumed over 8 h and 24 h, the VO_2 (L·min^{-1}) was plotted at each collection time and the trapezoid method was used to calculate the area under the curve for all 3 treatments (Jacobsen et al. 2005; Melby et al. 1993).

Diet

Dietary control was maintained by providing all subjects with breakfast and lunch in the laboratory. For breakfast subjects consumed 29 kJ·kg^{-1} meal (~72% carbohydrate, 15% fat, and 13% protein) which consisted of yogurt (150 g), orange juice (236 ml), and an appropriate amount of cereal (16 kJ·kg^{-1}) determined by their body mass. For lunch, subjects ate a 46 kJ·kg^{-1} meal (~55% carbohydrates, 27% fat, and 18% protein) consisting

of a "sub" sandwich (6 inch; meatball), 1% chocolate milk (500 ml), and an appropriate amount of cereal bar (16 $kJ \cdot kg^{-1}$) depending on body mass. Further, they recorded their evening food intake (50 $kJ \cdot kg^{-1}$ meal; ~39% carbohydrate, 30% fat, and 31% protein) on the first day and consumed that same food intake for the subsequent treatments.

Familiarization

Prior to any data collection each subject completed a familiarization trial, with all exercises that were to be utilized during the experimental sessions while wearing the VO_2 collection mask. As part of this session each subject's body composition was assessed (via air displacement), as described previously (Noreen and Lemon 2006).

Statistical Methods

All data were analyzed using Sigma Stat for Windows (version 3.5). One-way repeated measures analyses of variance (ANOVA) were used to determine differences among the three treatments (WBV exercise session, NoV exercise session, and control) for total 8 & 24 h VO_2, as well as for average HR and total VO_2 during the exercise sessions. Separate, two-way repeated measures ANOVA (treatment X time) were used to investigate the differences in VO_2 and respiratory exchange ratio (RER) at all measurement time points. All data are presented as means±SD, and the level of statistical significance was set at $p<0.05$. Post hoc tests were performed using Tukey's HSD tests.

Results

Exercise Oxygen Consumption

WBV increased the average exercise VO_2 throughout the full exercise session by 19% vs the NoV exercise session (2.082±0.399 vs 1.689±0.272 $L \cdot min^{-1}$; P<0.001). The total exercise session oxygen consumption (including between rep and set recovery) was also greater with WBV by 23% vs NoV (62.5±12.0 vs 50.7±8.2 L O_2; P=0.002; Figure 3.2).

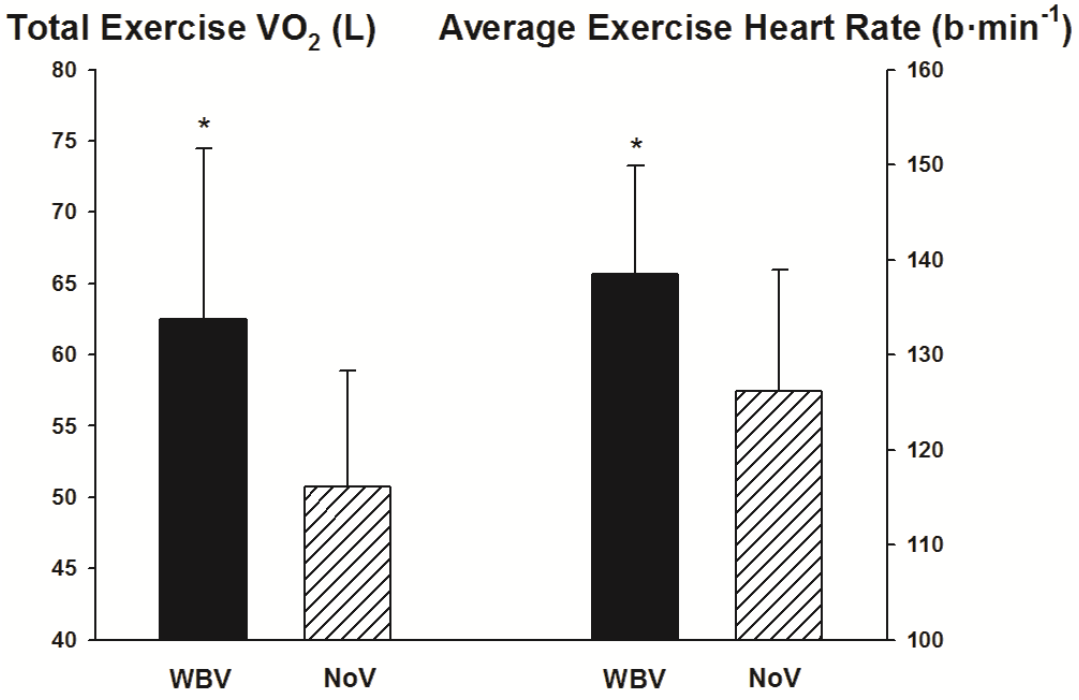

Figure 3.2: Total oxygen consumed (L) and average heart rate (bpm) during the WBV and NoV exercise sessions. Subjects performing the WBV exercise session consumed more oxygen (+12 L; P=0.002) and had greater heart rates (+10 bpm; P=0.068) compared to the NoV.

Average Exercise Respiratory Exchange Ratio

Exercise RER appeared to be greater with WBV compared to NoV however, the observed difference only approached statistical significance (WBV = 0.99±0.05 vs NoV = 0.95±0.03; P=0.068).

Average Exercise Heart Rate

The WBV exercise session elicited a greater HR compared to the NoV exercise session (137±11vs 127±13 $b \cdot min^{-1}$; P=0.022; Figure 2).

Oxygen Consumption

There was a significant (P<0.001) interaction (treatment X time) for VO_2. Both exercise sessions increased VO_2 vs CTRL over time; however, only the exercise (0915-0945) and the immediately post-exercise measures (0945-1015 h) were statistically significant (Figure 3.3). At both these time points, WBV VO_2 was greater than NoV (P=0.003) and CTRL (P<0.001) while NoV VO_2 was greater than CTRL (P<0.042).

Respiratory Exchange Ratio

There was a significant (P<0.001) interaction (treatment X time) for RER; however, only the immediately post-exercise measure (0945-1015 h) was significantly affected (Figure 3.4). At this time point, the WBV (0.68±0.06) RER was significantly lower than both NoV (0.72±0.05; P=0.017) and CTRL (0.86±0.04; P<0.001) and NoV RER was significantly lower than CTRL (P<0.001).

8 h Total Oxygen Consumption

Total VO_2 over 8 h was increased by 15% for WBV vs NoV (240.5±28.3 vs 209.7±22.9 L O_2; P=0.004) and by 59% over the CTRL day (151.4±20.7 L O_2; P<0.001; Figure 3.5i). The NoV condition was 39% greater than CRTL (P<0.001).

24 h Total Oxygen Consumption

Total VO_2 over 24 h was increased (P=0.01) by 10% for WBV (518.9±61.2 L O_2) vs NoV (471.1±43.7 L O_2) and by 25% (P<0.001) vs CTRL (415.2±51.6 L O_2; Figure 3.5ii). NoV was 14% greater than CTRL (P=0.003).

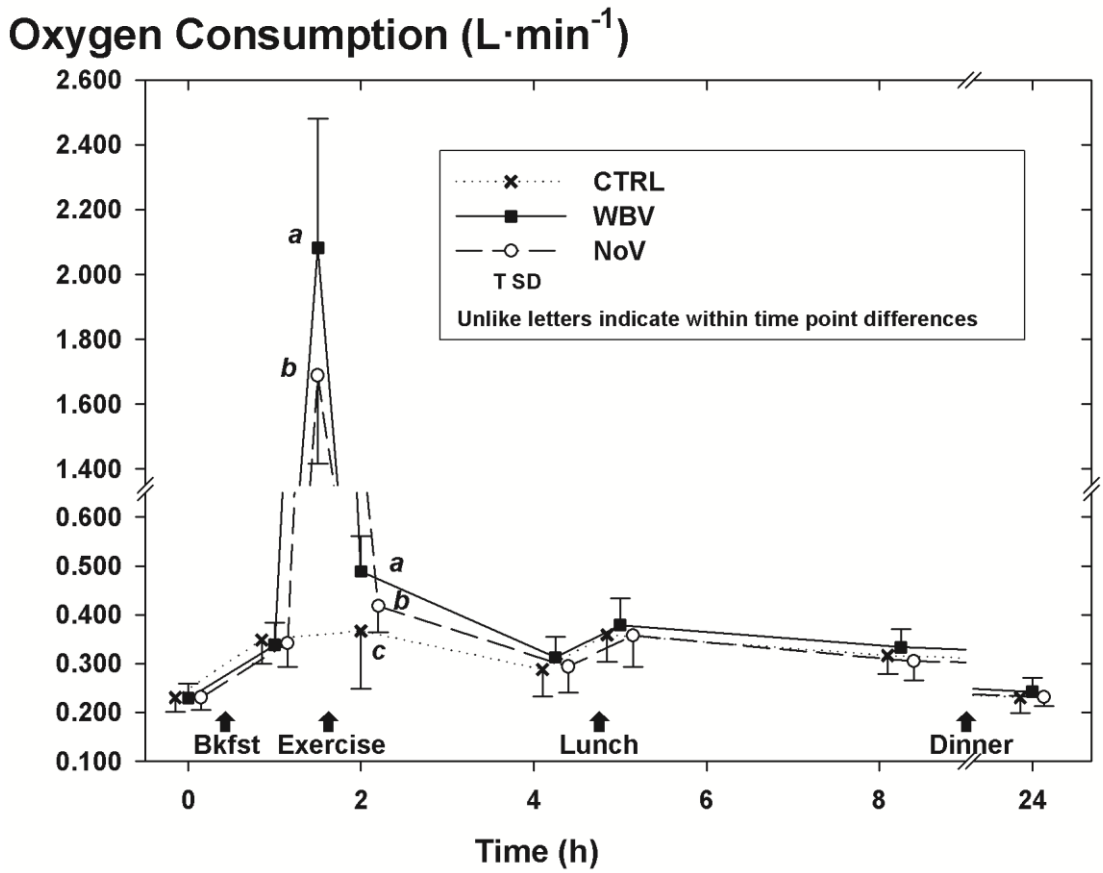

Figure 3.3: Oxygen consumption ($L \cdot min^{-1}$) before, during, and following treatments for CTRL, WBV, and NoV. The VO_2 during WBV was increased vs NoV ($P<0.001$). Immediately post-exercise WBV was increased vs NoV ($P=0.003$) and CTRL ($P<0.001$) at 2 h. The VO_2 immediately post-NoV exercise was also greater ($P<0.001$) than CTRL at 2 h. No other time points reached statistical significance.

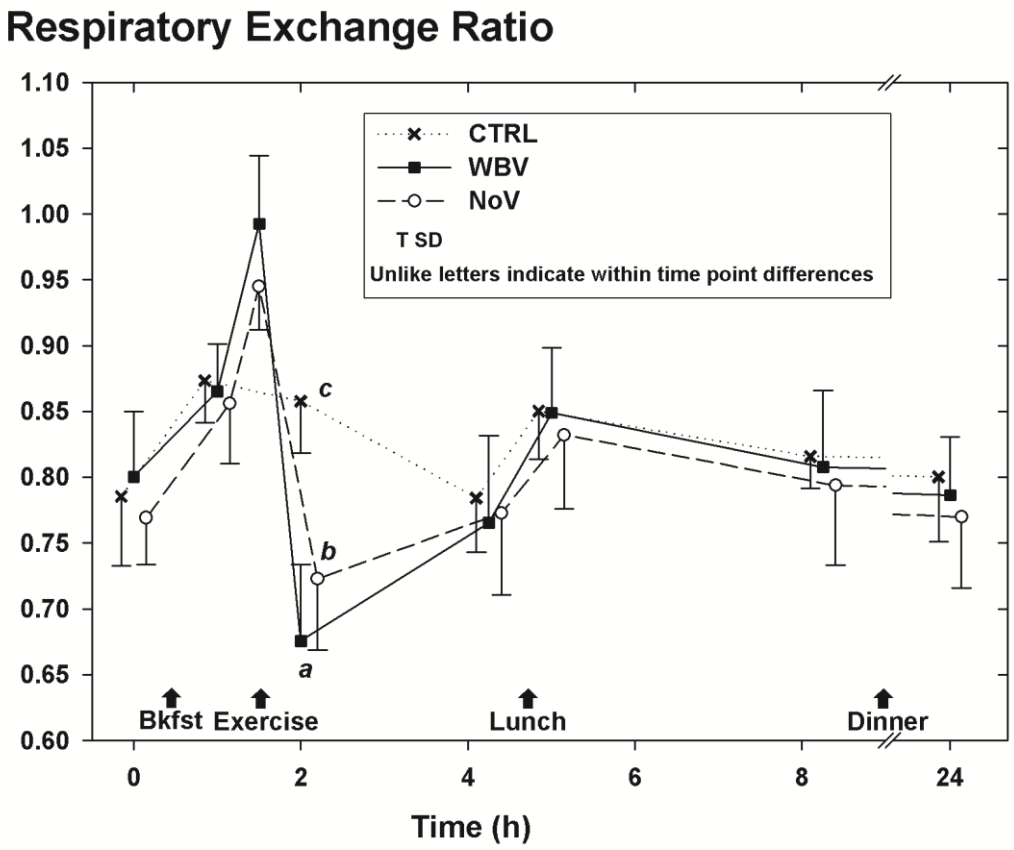

Figure 3.4: Respiratory exchange ratio before, during, and following treatments for CTRL, WBV, and NoV. The RER immediately post-WBV exercise was lower vs NoV exercise ($P=0.017$) and CTRL ($P<0.001$) at 2 h. The RER immediately post-NoV exercise was also lower ($P<0.001$) vs CTRL at 2h. No other time points reached statistical significance.

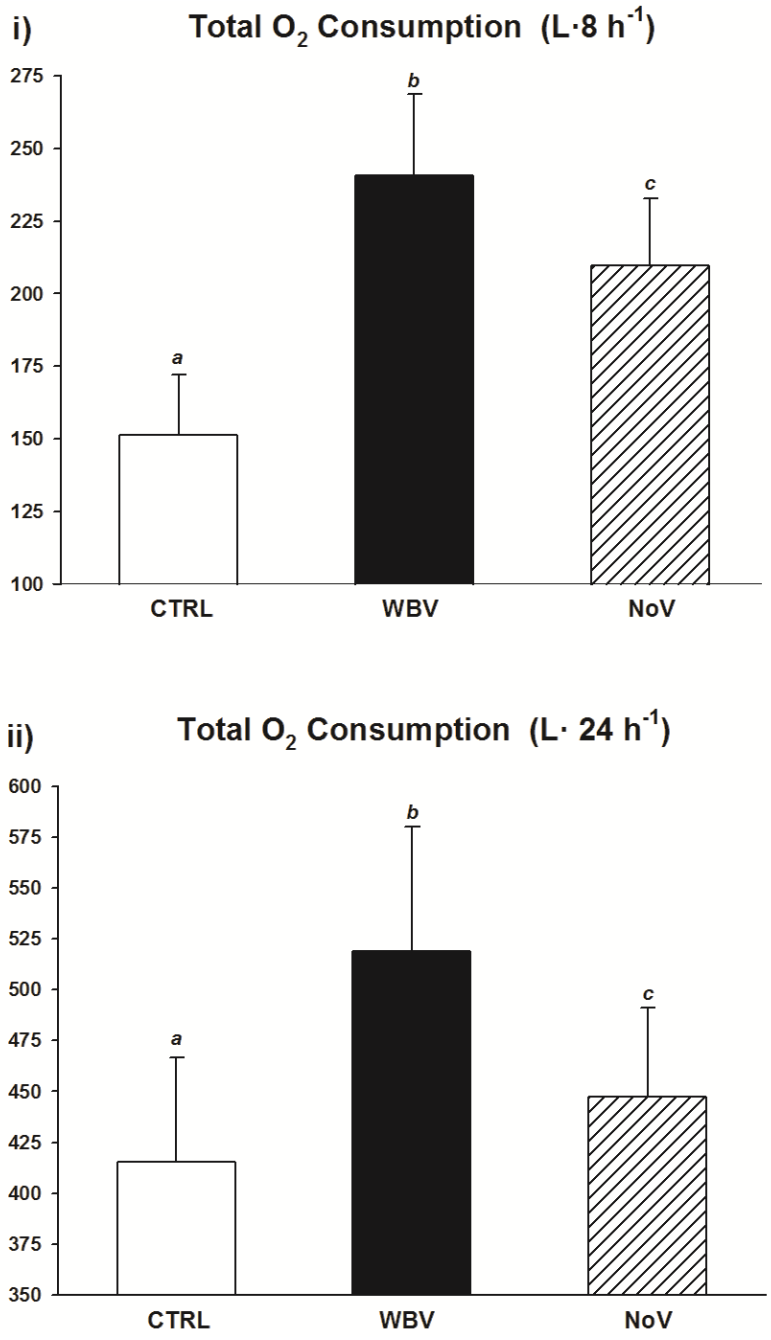

Figure 3.5: i) Total oxygen consumed (L) over 8 h for CTRL, WBV, and NoV. The total VO_2 was greater with WBV exercise vs NoV exercise (by 31 L; P=0.004) and CTRL (by 89 L; P<0.001) while NoV was also greater than CTRL (by 58 L; P<0.001). Unlike letters indicate time point treatment differences. ii) Total oxygen consumed (L) over 24 h for CTRL, WBV, and NoV. The total VO_2 was greater with WBV exercise vs NoV exercise (by 48 L; P=0.010) and CTRL (104 L; P<0.001) while NoV was greater than CTRL (by 56 L; P=0.003). Unlike letters indicate treatment differences.

Discussion

The purpose of this study was to quantify VO_2 during and following (24 h) a WBV exercise session compared to the same session without vibration (NoV) in order to evaluate the potential of chronic WBV exercise as a body fat loss treatment. The WBV exercise session resulted in a significantly greater VO_2 during and following exercise (8 and 24 h) vs both NoV exercise and control. Although prior studies have demonstrated that exposure to WBV during both static and dynamic movements results in VO_2 increases compared to the same exercises without vibration, these investigations used single exercises (or sets of a single exercise) for very short time periods and the increases observed were modest (~1-10 L O_2; Da Silva et al. 2007; Rittweger et al. 2000, 2001, 2002). Further, no one has studied upper body exercises on a ground based platform or made prolonged recovery measures so the earlier data are likely underestimates as much of any anaerobic contribution would have been missed. Our study was designed to extend these findings by examining a more complete whole body exercise session (multiple sets of both upper and lower body exercises) and to incorporate prolonged (24 h) recovery measures to more completely assess if chronic WBV exercise has the potential to alter body composition.

Our exercise session was quite strenuous as indicated by both HR and RER responses during the WBV (~71% predicted HRmax; 0.99±0.05) and NoV (~65% predicted HRmax; 0.95±0.03) exercise sessions. Total oxygen consumed during the WBV exercise session was increased by 23% in comparison to NoV. This increase in VO_2 amounted to ~12 L more oxygen (~265 kJ) than NoV.

Although only statistically significant at the immediate post-exercise measure (0945-1015 h), VO_2 appeared to be systematically greater throughout the remainder of the

day following WBV exercise vs NoV exercise. When totalled over 8 h, VO_2 with the WBV treatment was significantly increased compared to both NoV and control by 15 and 59%, respectively. These significant increases in VO_2 totalled 31 L (~550 kJ) vs NoV and 89 L (~1690 kJ) vs control. As the subjects remained in the laboratory this entire time and food intake was controlled these data suggest that acute dynamic WBV exercise causes a significant increase in metabolic rate that continues for at least 30 min into recovery and perhaps much longer. Over 24 h, total VO_2 was also increased with WBV treatment vs both NoV (by 10%) and control (by 25%). These significant increases in VO_2 totalled 48 L (~970 kJ) and 104 L (~1960 kJ) over NoV and control, respectively. Further, because the treatment differences were smaller at 24 h than at 8h and because we extrapolated linearly from 8 to 24 h it is possible that differences following the 8 h time point were actually underestimated over this 16 h time period. Consequently, the 24 h differences in energy expenditure reported here represent a conservative estimate of the difference among WBV, NoV, and control.

Relative to body composition changes, these acute observations could be important. For example, assuming constant energy intake and similar expenditure differences with a 4 sessions·wk^{-1}, 16 week training program one would expect about a 4 kg fat loss with WBV vs only ~2 kg fat loss with NoV (see table 3.1). Unfortunately this estimate cannot be substantiated as yet, because to date, only a few studies have examined the effect of chronic WBV exercise and fat mass loss and the results are equivocal. In untrained young women, 24 wk (3 sessions·wk^{-1}) of WBV training (squat, lunges, biceps curls) resulted in no changes in body composition (Roelants et al. 2004), while 24 wk (3 sessions·wk^{-1}) of WBV training (squats and lunges) in postmenopausal women caused a

Table 3.1 – Fat loss estimate (calculation)[1]

Exercise Type	L O2 vs CTRL	kJ vs CTRL	kJ· wk^{-1} (4 sessions)	kJ·16 wk^{-1} (64 sessions)	Total Fat (kg)
WBV	+104	+2184	+8736	+139,776	-4.3
NoV	+56	+1176	+4704	+75,264	-2.3

[1]Assuming energy intake remains constant, 1 L VO_2 = ~21 kJ of energy, 1 kg of fat = 32,232 kJ

significant 0.6 kg decrease in fat mass (Verschueren et al. 2004). Supplementing conventional resistance training exercises with three WBV exercises (squats on the platform, sitting on platform performing shoulder extension/flexion with straps attached to the platform, standing on the ground performing wrist curls with straps attached to the platform) over 32 wk (3 sessions·wk^{-1}) in postmenopausal women resulted in a 0.7 kg greater fat loss vs strength training alone (Fjeldstad et al. 2009). In contrast, adding three WBV exercises (heel rise, one-legged squat, leg abduction) to a combined endurance and strength training over 72 wk (2 sessions·wk^{-1}) demonstrated no effect on body composition (von Stengel et al. 2010). Consequently, while the current study demonstrates that moderate intensity WBV exercise could enhance body composition in young adults, low intensity WBV exercise is likely insufficient. Moreover, in all these training studies diet was not controlled (and in some cases insufficient description of the exercise program was provided) so, although our results are promising, a definitive conclusion regarding the effects of chronic WBV exercise on body composition change must await future studies that document carefully both the food intake and the exercise program used.

WBV could increase VO_2 in part by inducing increased postural control (Abercromby et al 2007) but the primary mechanism responsible for the increased VO_2

during the WBV exercise session is likely the increased exercise intensity resulting from the vibration stimulus (Abercromby et al. 2007; Cardinale and Lim 2003; Hazell et al. 2007, 2010; Marin et al. 2009; Ritzmann et al. 2010; Roelants et al. 2006). Our data demonstrating a greater VO_2 and HR during the WBV exercise session compared to NoV are consistent with this. While the specific mechanisms responsible for the prolonged increases in VO_2 ie. cost of glycogen resynthesis, oxidation of lactate, hormone and/or catecholamine-induced increases in metabolism and lipolysis, thermic effect of exercise and food, increased muscle protein turnover (muscle damage/repair), etc were not measured in this study, all have been documented previously to play a role (see comprehensive reviews, (Borsheim and Bahr 2003; LaForgia et al. 2006). Specifically, increases in temperature (Cochrane et al. 2008; Hazell et al. 2008) and lactate formation (Rittweger et al. 2000) have been shown with WBV exercise.

Recently in animals, chronic, daily exposure to vibration reduced fat accumulation (Luu et al. 2009; Maddalozzo et al. 2008) apparently by reducing the differentiation of precursor cells to adipocytes (Rubin et al. 2007). If so, chronic vibration exercise could produce even greater fat losses than estimated from our acute metabolic measures.

The significantly lower RER immediately after both exercise sessions compared to control is interesting and likely indicative of CO_2 retention in response to the intensity of the exercise completed (perhaps to replenish bicarbonate stores; Laforgia et al. 1997). Although the amount of lactate produced was not measured in our study, the WBV exercise was more strenuous than the NoV and the lower observed immediate post-exercise RER is consistent with the need to buffer hydrogen ions. However, with no other RER differences between treatments over the rest of the 24 h period it appears unlikely that either exercise session resulted in any prolonged change in fuel utilization.

Although having to replace 3 subjects for the during vibration aspect of our study may appear to limit our data we do not believe this is the case because we matched the subjects quite closely (gender, age, height, body mass, body composition, and fitness levels). Further and importantly, when only the subjects who completed both the entire experiment are examined (n=5), the WBV data are also significantly increased vs the NoV (WBV: 544.0±59.5 L O_2 vs NoV 490.5±37.7 L O_2; $P<0.05$). In fact, when converted to fat loss this expenditure totals a 2.3 kg greater fat mass loss with WBV vs 2 kg when all 8 subjects are included). Therefore, if anything having to replace 3 subjects actually reduced the observed treatment differences.

Finally, from a practical standpoint, our participants seem to enjoy vibration workouts relative to more traditional strength exercises. Although many factors might be ongoing including the novelty of this form of exercise, a recent review paper compiled data from nine WBV training studies and reported that only 1 of 266 subjects dropped out (Wilcock et al. 2009). While the reason(s) for this very high adherence rate to an exercise program is(are) unclear, the potential effectiveness of WBV exercise to promote fat loss combined with a very low dropout rate suggests that this training modality has considerable fat loss potential. Future study is certainly warranted to determine if this potential can be achieved.

Conclusion

The present study demonstrates a significant increase in VO_2 both during and following a WBV exercise session compared to the same exercise session without vibration. Although previous WBV data indicate little effect on fat loss with training these studies used a much more limited exercise session, many at lower exercise

intensities, and did not control food intake (Fjeldstad et al. 2009; Roelants et al. 2004; Verschueren et al. 2004; von Stengel et al. 2010). Our results illustrate the significant potential of WBV exercise as a component of programs designed to reduce fat mass. However, because an adaptation to WBV exercise training is possible over time, additional study is needed to verify that these fat losses do occur with training.

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CHAPTER 4

Does synchronous whole-body vibration exercise cause muscle damage and inflammation?

Introduction

Whole-body vibration (WBV) is a popular method of skeletal muscle exercise where body mass resistive exercises are performed on a vertically vibrating platform. The vertical oscillations generated by the platform are theorized to induce short and rapid changes in muscle fibre length which result in reflexive muscle contractions in a response akin to monosynaptic reflexes (Cardinale and Bosco 2003; Hagbarth and Eklund 1966; Ritzmann et al. 2010). Further, the vibration perturbations may affect postural control positively by increasing the need to maintain balance (Abercromby et al. 2007) or cause a muscle tuning response via one's attempt to dampen the transmission of the vibration signal (Wakeling and Nigg 2001). Regardless of the underlying mechanism responsible, WBV exposure can increase muscle contractile activity significantly although a wide range of intensities appear possible (Abercromby et al. 2007; Cardinale and Lim 2003; Hazell et al. 2007, 2010; Marin et al. 2009; Ritzmann et al. 2010; Roelants et al. 2006).

The increases in muscle contractions with WBV (synchronous and side-altering) have resulted in acute increases in strength, power, and performance (Bosco et al. 1999; Cormie et al. 2006; Da Silva-Grigoletto et al. 2009; McBride et al. 2010; Ronnestad 2009; Torvinen et al. 2002) as well as increases in oxygen consumption/energy expenditure (Chapter 3; Da Silva et al. 2007; Rittweger et al. 2000, 2002) and skin temperature (Hazell et al. 2008). Consequently, WBV exercise may have potential as a training/rehabilitation tool especially for those individuals who cannot or will not participate in other forms of exercise (i.e. traditional strength exercise), although much more information about the responses to it are needed.

Traditional exercise (strength or endurance) can cause structural injury (i.e. muscle fibre tears) resulting in functional decrements in muscle performance (Clarkson and Hubal 2002). Typically, this is preceded by an "acute phase response" including the production of cytokines. Often these are described as 'inflammatory' or 'pro-inflammatory' (e.g. IL1-β, IL-6), although IL-6 is perhaps better classified as an 'inflammation-responsive' cytokine (Pedersen et al. 1998). Other cytokines may act as biological inhibitors of the inflammation (anti-inflammatory; e.g. IL-1ra, IL-10; Richards et al. 1991). Significant inflammatory responses can occur with exercise, especially when there is a substantial eccentric component (Hellsten et al. 1997; Ostrowski et al. 1999; Peake et al. 2005; Pedersen et al. 1998). Although the dynamic body mass resistance exercises performed typically on the WBV platforms are characterized by both concentric and eccentric muscle contractions (Rittweger 2010), the heart rate, blood flow, mean arterial pressure, and oxygen consumption data reported in Chapters 2 and 3 of this dissertation indicate that it should be classified as mild to moderate rather than intense exercise. Consequently, whether such WBV exercise causes any significant muscle damage or inflammation is of interest.

The purpose of this study was to quantify the muscle damage, soreness and inflammation following an acute WBV exercise session (upper and lower body dynamic exercises) versus the same exercise session without vibration.

Methods

Study Overview

Healthy male Kinesiology students (25±3.5 y, 179±7.2 cm, 81±7.9 kg; n= 10) were recruited for two separate 24 h study periods incorporating a WBV exercise session

or the same exercise session without vibration (NoV). Subjects did not perform any physical activity for 48 h prior to any data collection period, refrained from alcohol or caffeine for 24 h, and recorded their energy intake during the initial treatment in order to repeat this intake for the second treatment period (nutrient details below). All subjects were deemed healthy as assessed with the PAR-Q health survey (Thomas et al. 1992) and had no contraindications to whole body vibration (WBV) according to the manufacturer's criteria (i.e. diabetes, cardiovascular diseases, epilepsy, gallstones, kidney stones, acute inflammations, joint problems, joint implants, recent thrombosis, tumours, recent operative wounds, intense migraines, or back problems such as hernia). The Health Sciences Office of Research Ethics at The University of Western Ontario approved this study and all subjects gave their informed written consent prior to participation.

Exercise Session

The exercise session involved both upper and lower body dynamic exercises and utilized all major muscle groups. A 1:1 exercise to recovery ratio (30 sec exercise: 30 sec recovery) was used. Specifically, participants completed 5 sets of each of a total of six exercises paced by a metronome at a rate of 0.5 reps·sec^{-1} resulting in 15 min of exercise over the 30 min protocol. The exercises for the lower body included squats (feet on the platform), single leg lunges for each leg (lead foot on the platform), and hamstring bridges (laying supine, feet on the platform and repetitions involving elevating the trunk) and for the upper body (hands on the platform) push-ups and triceps dips. Body mass was the resistance and range of motion was controlled with a goniometer.

The WBV stimulus was applied using a WAVE™ platform (Whole-body Advanced Vibration Exercise, Windsor, Canada). This platform generates a synchronous/vertical vibration stimulus whereby the platform oscillates up and down

uniformly (Rittweger 2010). The WBV stimulus was set at a frequency of 45 Hz and a peak-to-peak displacement of 2 mm (verified via single frame analysis of high speed video) which we have shown previously to increase leg skeletal muscle EMG significantly (Hazell et al. 2007, 2010). Importantly, the platform has a load levelling system® based on body mass so each subject received the same vibration stimulus. Regardless of body mass this places the vibration platform in the same initial position using inflatable air bladders. We have verified system performance with masses up to 180 kg (data not shown). The NoV exercise session was performed on the same platform but with the vibration turned off.

Experimental Protocol

Subjects completed two separate 24 h data collection periods separated by 3 weeks (WBV exercise session vs NoV). The treatments were rotated systematically to avoid order effects. Subjects ate breakfast (0800h), arrived at the lab (0900 h), had a resting blood sample taken from a forearm vein, completed baseline (pre-exercise) assessments of muscle function (knee and elbow extensors), and filled out a muscle soreness questionnaire (see below). The subjects then completed the 30 min exercise session with or without vibration (0930-1000 h) and the same measurements were repeated (Figure 4.1) immediately post-exercise (1000 h); 4 h post-exercise (1400 h); and 24 h post-exercise (0900 h next day). During the recovery data collection (measures #3-4), subjects were allowed to leave the laboratory but refrained from any exercise until all measures were completed the next day. Lunch (between 1200 - 1300 h) and dinner (1700 – 1800 h) were eaten at the same time on both testing days by the subjects. They recorded all food intake on the first day and consumed the same food intake for the subsequent test day (139 $kJ \cdot kg^{-1} \cdot d^{-1}$, ~26%, protein, ~48% carbohydrate, 26% fat).

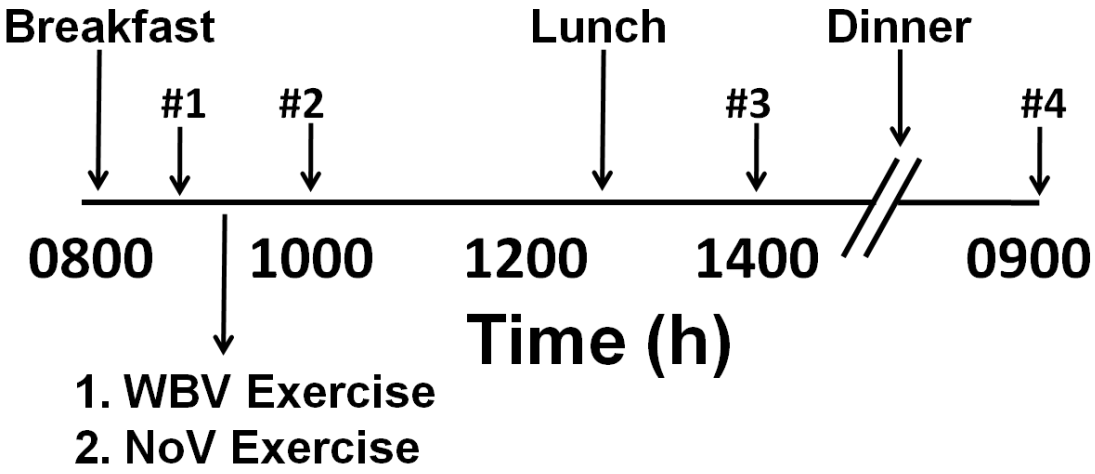

Figure 4.1 – Protocol Timeline. Arrows refer to measurement time points. #1 - Baseline (0900-0930 h), #2 – Immediately post-exercise (1000-1030 h), #3 – 4 h post-exercise (1400-1430 h), #4 – 24 h post-exercise (0900-0930 h). Exercise occurred from 0930-1000 h. Daily nutrient intake was 139 $kJ \cdot kg^{-1} \cdot d^{-1}$ (~26%, protein, ~48% carbohydrate, 26% fat).

Familiarization

Prior to any testing subjects performed a familiarization session to acclimate to the sensation of WBV. This session consisted the dynamic exercises to be used in the experimental exercise session. Subjects were given a demonstration of proper technique and were allowed practice time until they performed the exercises correctly.

Muscle Function Tests

The muscle function (strength/power) measures consisted of maximal voluntary isometric (MVC) and isokinetic contractions for both the knee and elbow extensors using a Biodex Multi-Joint System 3 dynamometer (Biodex Medical, Shirley, USA). To test the knee extensors, subjects performed 3 maximal isometric knee extensions at 90° of knee flexion. Each repetition was held for 3 sec and 120 sec of passive rest was provided between repetitions. Five min of passive rest was allowed between the isometric and isokinetic tests. The isokinetic contractions (60° to 180°) were performed at two

velocities: $60°\cdot s^{-1}$ and $240°\cdot s^{-1}$. Subjects performed 5 maximal contractions at each angular velocity separated by 3 min of passive rest. Torque was recorded throughout the entire range of motion (60° to 180°). The elbow extensors testing used a similar protocol, except that the isometric tests were performed at 60° of elbow flexion.

Muscle Inflammation

At each testing time point (pre-exercise, post-exercise, 4 h post-exercise, and 24 h post-exercise) 6ml blood samples (BD Vacutainer® K_2 EDTA Blood Collection Tube [lavender top]; Becton, Dickinson and Company, Franklin Lakes, USA) were collected from a forearm vein. Samples were immediately centrifuged at 3500 rpm for 15 min at 4°C (Allegra™ 21R, Beckman Coulter™, Brea, USA). Plasma supernatant aliquots were transferred to polypropylene freezer vials and frozen/stored at -80° C for later analyses. Cytokines were determined by ELISA kits (enzyme linked immunosorbent assay, Millipore™, Massachusetts, USA).

Muscle Soreness

To measure muscle soreness, subjects rated their perceived degree of soreness for both the knee and elbow extensors at all 4 time points, using a linear 0-10 point scale (Betts et al. 2009; Thompson et al. 1999). A rating of 0 indicated no soreness and a rating of 10 indicated extreme soreness.

Statistics

Two-way repeated measures ANOVAs (treatment X time) were used to investigate the differences in muscle function, soreness, and the markers of muscle inflammation at all measurement points. Post hoc tests were performed using Tukey's Honestly Significant Difference tests, where necessary. All data are presented as means±SD and the level of statistical significance was set at $p<0.05$.

Results

Isometric Muscle Function

There was no significant interaction for quadriceps muscle function over time (P=0.963; Figure 4.2i) or main effect for exercise mode (P=0.775) but there was a main effect for time of measure (P=0.025). Both the immediate post-exercise measure (P=0.037) and the 24 h post-exercise measure (P=0.042) were significantly lower than the pre-exercise measure.

For triceps muscle function, there was also no significant interaction (P=0.972; Figure 4.2i) or main effect for exercise mode (P=0.710) but there was a main effect for time of measure (P=0.008). The immediate post-exercise time point was significantly lower than both the pre-measure (P=0.019) and the 24 h post-exercise measure (P=0.016).

Isokinetic Muscle Function ($60°\cdot sec^{-1}$)

There was no significant interaction for quadriceps isokinetic muscle function (P=0.974; Figure 4.2ii) and there were no main effects for exercise mode (P=0.658) or time point of measure (P=0.317).

Similarly, in terms of triceps isokinetic muscle function, there was no significant interaction (P=0.443; Figure 4.2ii and no main effects for exercise mode (P=0.768) or time of measure (P=0.067).

Isokinetic Muscle Function ($240°\cdot sec^{-1}$)

There was no significant interaction for quadriceps muscle function at $240°\cdot sec^{-1}$ (P=0.950; Figure 4.2iii) and no main effects for exercise mode (P=0.705) or time of measure (P=0.066).

For triceps muscle function at $240°\cdot sec^{-1}$, there was no significant interaction (P=0.690; Figure 4.2iii) or main effect for exercise mode P=0.960) but there was a main

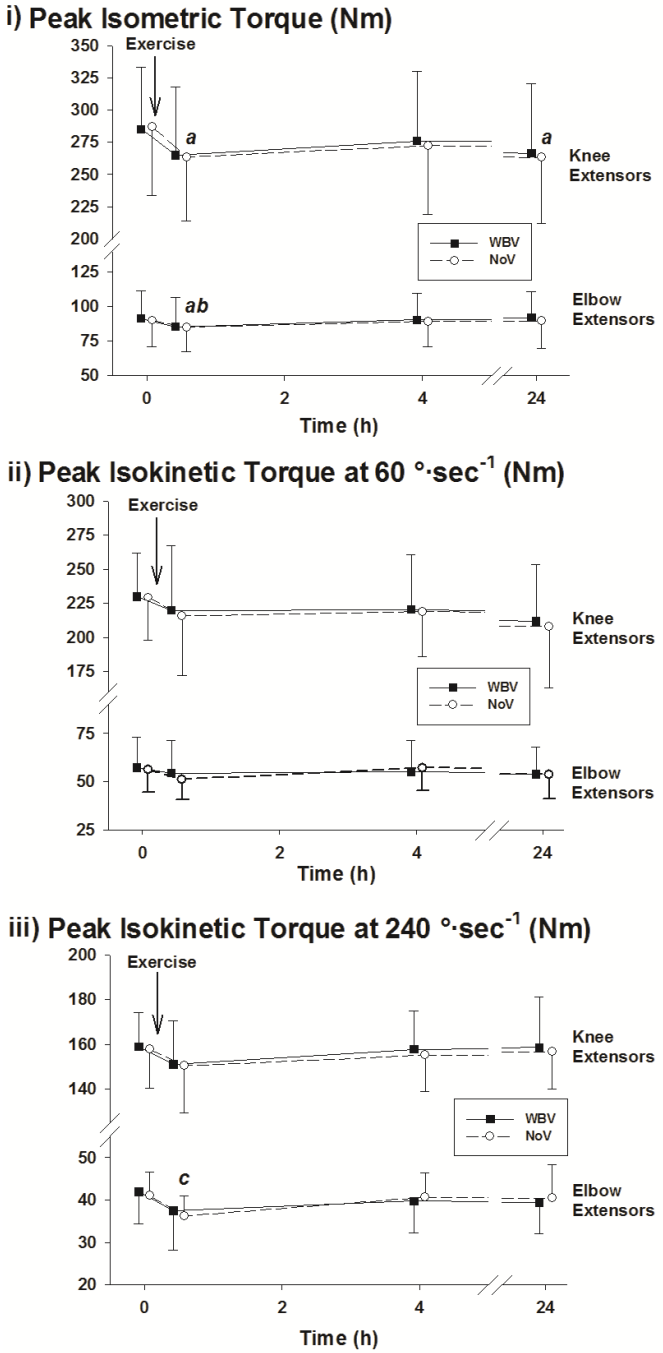

Figure 4.2 – i) Knee and elbow extensor peak isometric torque (Nm) during the WBV and NoV treatments. There was a main effect of time immediately post-exercise (P=0.037) and at 24 h post (P=0.042) vs pre (*a*) for knee extensors and immediately post vs pre (P=0.019; *a*) and 24 h post (P=0.016; *b*) for elbow extensors. ii) Knee and elbow extensor peak isokinetic torque at 60°·sec^{-1} (Nm) during the WBV and NoV treatments. There were no differences at any time point or between treatments. iii) Knee and elbow extensor peak isokinetic torque at 240°·sec^{-1} (Nm) during the WBV and NoV treatments. There was a main effect of time immediately post-exercise vs pre (P=0.002), 4 h post (P=0.029), and 24 h post (P=0.045) for elbow extensors (*c*).

effect for time of measure (P=0.003). The immediate post-exercise measure was significantly lower than pre-exercise (P=0.002), 4 h post-exercise (P=0.029), and the 24 h post-exercise measure (P=0.045).

Muscle Soreness

There was a significant interaction (P=0.007; exercise mode X time) for quadriceps muscle soreness (Figure 4.3i). The WBV exercise session increased muscle soreness at 24 h post-WBV exercise (2.0±1.5; P<0.001) vs the 24 h time point with NoV (0.7±0.7). This 24 h time point with WBV exercise was also significantly greater than all previous time points (P<0.037). The NoV exercise session had no effect on quadriceps muscle soreness.

There was also a significant interaction (P=0.011; exercise mode X time) for triceps muscle soreness (Figure 4.3ii). The WBV exercise session increased muscle soreness at 24 h post-WBV exercise (2.2±1.7; P<0.001) vs the 24 h time point with NoV (0.6±0.9). This 24 h time point with WBV exercise was also significantly greater than all previous time points (P<0.001). The NoV exercise session had no effect on triceps muscle soreness.

Interleukin-1β

There was no significant interaction for IL-1β (P=0.994; Figure 4.4i) and there was no effect of exercise mode (P=0.875) but there was a main effect for time of measure (P=0.041). However, post hoc analysis failed to locate any difference.

Interleukin-6

There was no significant interaction for IL-6 (P=0.332; Figure 4.4ii) and there was no effect of exercise mode (P=0.092) but there was a main effect for time of measure

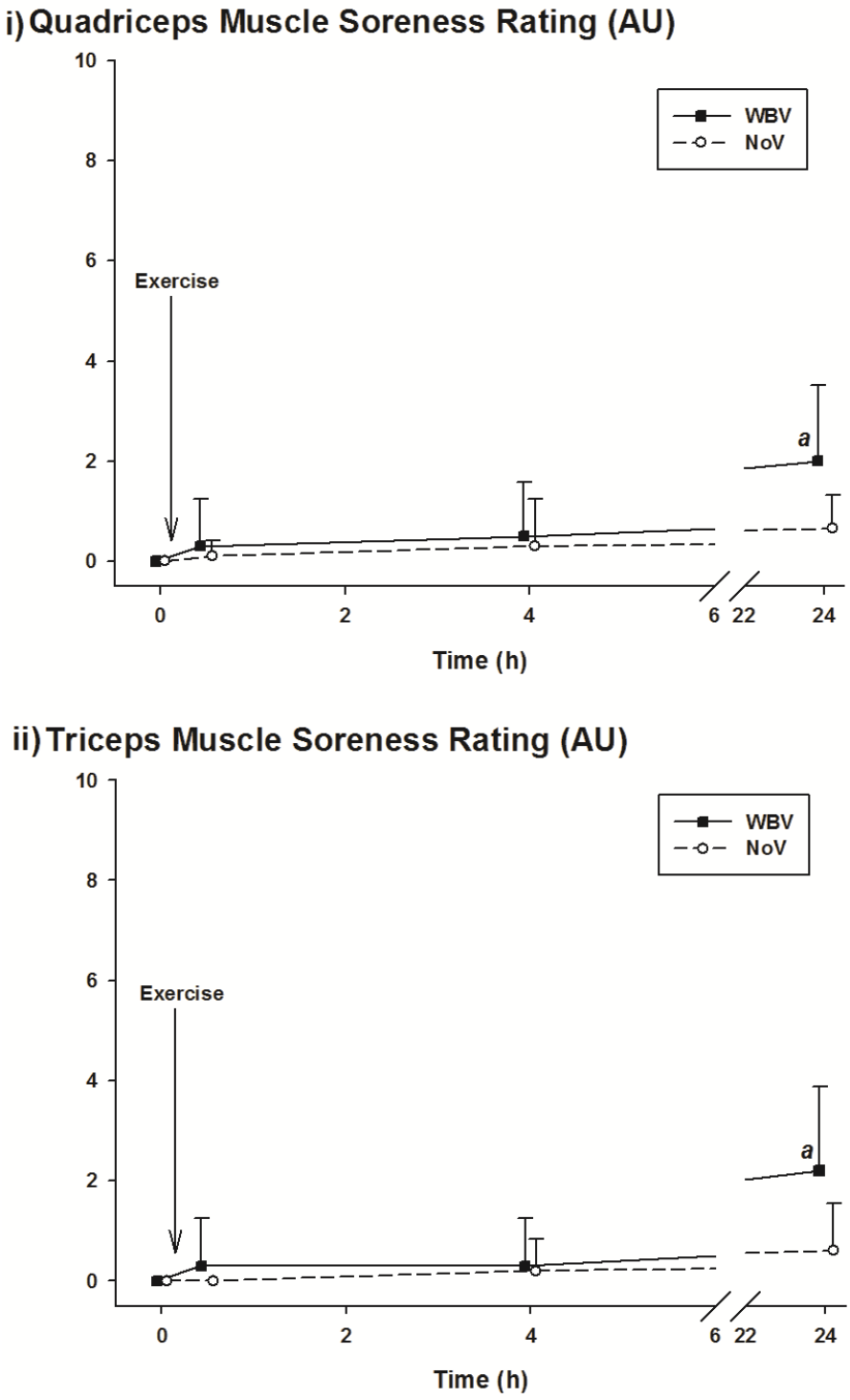

Figure 4.3 – (i) Knee and (ii) elbow extensor subjective ratings of perceived muscle soreness (AU) for WBV and NoV treatments.
a – Significantly increased vs NoV ($P<0.001$).

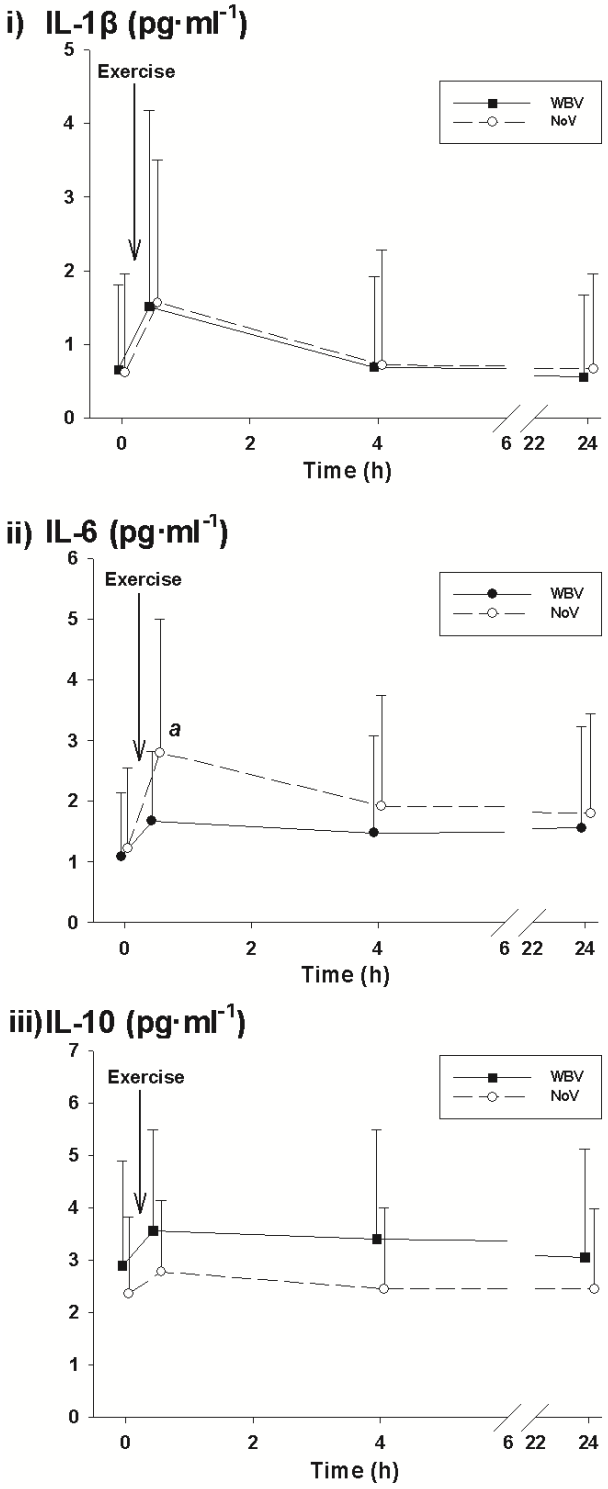

Figure 4.4 – i) Interleukin-1β response for WBV and NoV. There were no differences at any time point. ii) Interleukin-6 response for WBV and NoV. There was a main effect for time immediately post ($P<0.001$) vs pre (*a*). iii) Interleukin-10 response for WBV and NoV. There was a main effect for exercise mode ($P=0.029$) as WBV was significantly increased vs NoV (*****).

(P<0.001). The immediately post-exercise measure was significantly increased compared to the pre-exercise measure (P<0.001).

Interleukin-10

There was no significant interaction for IL-10 (P=0.422; Figure 4.4iii) and no effect for time of measure (P=0.381) but there was a main effect for exercise mode (P=0.029). The WBV exercise session was significantly increased vs the NoV exercise session (P=0.029).

Discussion

Previously we have demonstrated that exposure to synchronous WBV increases the intensity of the exercises performed as evidenced by an increase in skeletal muscle activity (Hazell et al. 2007, 2010), skin temperature, oxygen consumption, and heart rate (see Chapter 2 & 3). The current results demonstrate that the addition of WBV to a dynamic exercise routine (upper and lower body) results in minimal effects on muscle function/damage, inflammation, and soreness.

We did observe a small decrease in muscle function immediately post-exercise (isometric knee and elbow; isokinetic $240°\cdot sec^{-1}$); however, none of these decreases were significant between exercise modes indicating that this effect is due to the exercise not the vibration. While the addition of vibration to the dynamic exercises performed increases oxygen consumption and heart rate, it appears this increased intensity of exercise has no negative effects on muscle performance. Muscle function is often considered the best indirect measure of muscle damage (Clarkson and Hubal 2002), however, these very small decreases immediately post-exercise are more likely muscle fatigue-related (Clarkson et al. 1992).

In contrast, several previous WBV investigations have demonstrated a potential improvement in muscle strength/power immediately following shorter (<15 min) intermittent exposures during static exercises with both synchronous (Cormie et al. 2006; Da Silva-Grigoletto et al. 2009; McBride et al. 2010) and side-alternating (Bosco et al. 1999) WBV. It is believed that WBV results in a neuromuscular potentiating effect (post activation potentiation) where the WBV-induced increases in muscle activity enhance muscle force output via increased motor neuron excitability or the phosphorylation of muscle contractile elements (Bosco et al. 1999; McBride et al. 2010). However, other previous studies have found no strength/power benefit from similar WBV protocols (de Ruiter et al. 2003; Erskine et al. 2007) making the potentiating effects of WBV exposure unclear. These variable findings may be due to the wide range of exercise intensities, durations, and exercises used. Regardless, the present results demonstrate that adding WBV to a longer exercise routine (>30 min) containing dynamic exercises with body mass as the resistance has little effect on muscle function in young men. Greater intensities are possible with WBV, especially if external weights are used, and more work is required to elucidate fully the effects of WBV on muscle function.

In terms of muscle soreness, we did observe a statistically significant but small increase in muscle soreness at 24 h post-WBV exercise (rating of ~2 out of 10 in both the quadriceps and triceps). This observation is consistent with the minimal muscle function/damage effects and indicates that WBV exercise of sufficient intensity to significantly increase oxygen consumption and heart rate causes only a small degree of discomfort and not until the morning following the exercise bout. This may demonstrate the potential for WBV exercise to be completed more frequently in a training program, however, muscle soreness can peak ~1-3 days post-exercise (Smith 1991) and whether

this small degree of muscle soreness seen in response to the WBV exercise session would increase at 48 or 72 h remains to be determined. Further, we do not believe this soreness is due to the novelty of the WBV stimulus as all subject's participated in a familiarization session prior to the study and several had participated in prior WBV exercise but further study with novice exercisers and with repeated bouts of WBV exercise would be helpful in understanding this stimulus.

The observed small change on inflammatory markers is also consistent with the minimal effects on muscle damage/function and soreness. The minimal effect on the pro-inflammatory marker IL-1β suggests both exercise sessions were not strenuous enough to elicit a marked inflammatory response. However, while the exercise sessions did result in a small increase in IL 6 (~2-3 $pg \cdot ml^{-1}$) immediately post-exercise, there was no difference between treatments. IL-6 is an inflammation responsive cytokine released with increasing exercise intensity, duration, and muscle mass involvement (Pedersen 2007; Pedersen et al. 1998). This increase is much less than reported with running a marathon (~80 $pg \cdot ml^{-1}$; Ostrowski et al. 1999) or with traditional strength exercise (~5-6 $pg \cdot ml^{-1}$; Izquierdo et al. 2009) suggesting that the exercise bout studied was not overly strenuous. For IL-10, there was no effect for time of measure but there was a main effect for the type of exercise. The WBV exercise session resulted in a greater overall response than the NoV exercise session. However, consistent with the other inflammation markers, the IL-10 values (<3.7 $pg \cdot ml^{-1}$) were small vs strength exercise (~5 $pg \cdot ml^{-1}$; Izquierdo et al. 2009). As IL-10 is an inhibitor of other inflammatory cytokines (Richards et al. 1991), its increase with WBV may have prevented any potential increase in the other markers of muscle inflammation measured (IL-1β and IL-6). Furthermore, an increase in IL-10 is has been seen in concert with an increased catecholamine response (Peake et al. 2005).

While, we did not assess sympathetic stress here it is interesting to note that WBV has been demonstrated to cause increases in oxygen consumption for up to 24 h following an exercise session (Chapter 3). Perhaps part of this increase in oxygen consumption could be a result of a lingering anti-inflammatory/catecholamine response. However, it appears that the exercise intensity of both exercise sessions (NoV and WBV) were insufficient to elicit a marked inflammatory response. While this may seem like a positive result, it may mean that the stimulus is too low for any significant muscle adaptations. Perhaps WBV exercise with body mass resistive exercises as studied here is not strenuous enough to result in an increase in muscle protein synthetic rate as little muscle repair is necessary. For WBV exercise to be a truly beneficial training modality, increases in muscle hypertrophy are certainly desirable.

Conclusion

The present results demonstrate that a the addition of WBV to an exercise session containing dynamic exercises for the upper and lower body which increases skeletal muscle activity, VO_2, heart rate, and skin temperature causes little effect on muscle function/damage, soreness or muscle inflammation.

Acknowledgements

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CHAPTER 5

Synchronous whole-body vibration exercise increases insulin sensitivity but does not improve glucose tolerance in healthy young men

Introduction

In recent years, whole body vibration (WBV) exercise has been commercialized as an effective training modality to improve health and fitness and many of these claims lack scientific evidence. However, with the large number of people from North America suffering from diabetes (Dinca-Panaitescu et al. 2010) many of these individuals could be tempted to engage in this form of exercise. Currently, it is unknown how the WBV stimulus will affect healthy and unhealthy individuals such as those with impaired glucose handling or diabetes.

There is no doubt that more conventional modes of exercise enhance glucose disposal (Henriksen 2002; Winett and Carpinelli 2001) and it is quite possible that the addition of WBV to standard resistive body mass exercise could do so as well. The mechanical oscillations generated by the platform result in an increased amount of muscle activity (Abercromby et al. 2007; Cardinale and Lim 2003; Hazell et al. 2007, 2010, 2010; Marin et al. 2009; Roelants et al. 2006). This increase in muscle activity may be because the vibration stimulus induces short and rapid changes in muscle fibre length stimulating reflexive muscle contractions via a response akin to monosynaptic reflexes (Cardinale and Bosco 2003; Ritzmann et al. 2010). Moreover, the vibration perturbations may also increase muscle activity by positively affecting postural control by increasing the need to maintain balance (Abercromby et al. 2007) or cause a muscle tuning response via one's attempt to dampen the transmission of the vibration signal (Wakeling and Nigg 2001). These increased muscle contractions with WBV have previously been demonstrated to result in increases in skin temperature (Hazell et al. 2008), blood flow (Kerschan-Schindl et al. 2001), and oxygen consumption (Da Silva et al. 2007;

Garatachea et al. 2007; Rittweger et al. 2000, 2001, 2002; Vissers et al. 2009; Chapter 3) but little is known about its effects on glucose tolerance.

At present many WBV platform manufacturers contraindicate WBV exercise for a variety of health concerns including diabetes but this is not based on data. This is unfortunate as it may unnecessarily preclude groups of individuals who might benefit from it most. The reasons for these contraindications are unclear. Therefore, the purpose of this study was to examine the effect of WBV exercise on glucose tolerance in young, healthy men using the same 30 min WBV session studied in chapters 3 & 4.

Methods

Subject Information

Eight healthy male Kinesiology students (27±2.4 y, 179±7.7 cm, 83±10.6 kg) were recruited for 3 separate testing sessions. All subjects were deemed healthy as assessed with the PAR-Q health survey (Thomas et al. 1992) and had no contraindications to whole-body vibration (WBV) according to the manufacturer's criteria (i.e. diabetes, cardiovascular diseases, epilepsy, gallstones, kidney stones, acute inflammations, joint problems, joint implants, recent thrombosis, tumours, recent operative wounds, intense migraines, or back problems such as hernia). The Health Sciences Office of Research Ethics at The University of Western Ontario approved this study in accordance with the ethical standards of the 1964 Declaration of Helsinki and all subjects gave their informed written consent prior to participation.

Familiarization

Prior to any testing subjects performed a familiarization session to acclimate to the sensation of WBV. This session consisted of static and dynamic forms of the exercises to

be used in the experimental exercise session. Subjects were given a demonstration of proper technique for all exercises and were allowed practice time until they performed the exercises correctly.

Experimental Design

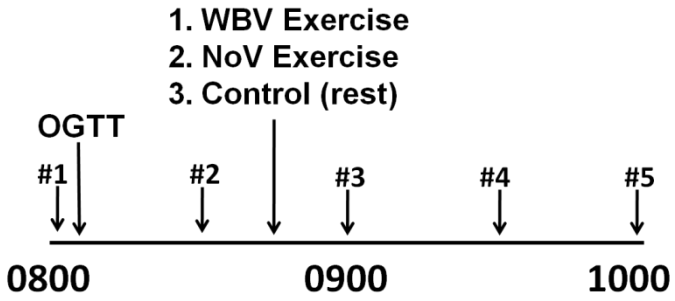

Figure 5.1 – Protocol Timeline. Arrows refer to measurement time points. #1 – Baseline (0755 h), #2 – Pre-exercise (0830 h), #3 – Immediately post-exercise (0900 h), #4 – 30 min post-exercise (0930 h), #5 – 60 min post-exercise (1000 h). The oral glucose load) was consumed between 0755-0800 h. Exercise occurred from 0830-0930 h.

Each subject performed 3 separate oral glucose tolerance tests (OGTT; Figure 5.1) incorporating no exercise, a WBV exercise session, or the same exercise session without vibration (NoV). Each session was rotated systematically to avoid any order effects. Subjects arrived at the laboratory at 0800 h after an overnight fast (12 h) where a fasted blood sample (vein in the antecubital space) and finger prick blood sample were taken (Time point #1; Baseline fasted). Subjects then ingested a glucose drink (75 g glucose in 900 mL of water) over a 5 min time period. Thirty min after ingestion additional venous and finger prick blood samples were withdrawn (Time point #2 - pre-exercise). Subjects then rested for 30 min (sat in the lab reading) or performed the WBV exercise session or the same exercise session with no vibration (0830-0900 h). Immediately at the end of 30 min venous and finger prick blood samples were withdrawn (Time point #3; immediately post-exercise). Two more venous and finger pricks blood samples occurred (Time point #4 - 30 min post-exercise, 90 min post-drink and Time point #5 – 60 min post-exercise, 120 min post-drink). Therefore, all

subjects underwent a total of 5 venous and 5 finger prick blood samples over a 2 hr OGTT.

Exercise Session

The exercise session involved both upper and lower body dynamic exercises and utilized all major muscle groups. A 1:1 exercise to recovery ratio (30 sec exercise: 30 sec recovery) was used. Specifically, participants completed 5 sets of each of a total of six exercises paced by a metronome at a rate of 0.5 reps·sec^{-1} resulting in 15 min of exercise over the 30 min protocol. The exercises for the lower body included squats (feet on the platform), single leg lunges for each leg (lead foot on the platform), and hamstring bridges (laying supine, feet on the platform and repetitions involving elevating the trunk) and for the upper body (hands on the platform) push-ups and triceps dips. Blocks were utilized for the upper body exercises, lunges, and the hamstring bridges so that the hands and feet that were off the platform remained at the same height as the platform. Body mass was the resistance and range of motion was controlled with a goniometer.

Whole-Body Vibration Stimulus

The WBV stimulus was applied using a WAVE™ platform (Whole-body Advanced Vibration Exercise, Windsor, Canada). This platform generates a synchronous/vertical vibration stimulus whereby the platform oscillates up and down uniformly (Rittweger 2010). The WBV stimulus was set at a frequency of 45 Hz and a peak-to-peak displacement of 2 mm (verified via single frame analysis of high speed video) which we have shown previously to increase leg skeletal muscle EMG significantly (Hazell et al. 2007, 2010). Importantly, the platform has a load levelling system® based on body mass so each subject received the same vibration stimulus. Regardless of body mass this places the vibration platform in the same initial position

using inflatable air bladders. We have verified system performance with masses up to 180 kg (data not shown). The NoV exercise session was performed on the same platform but with the vibration turned off.

Blood Draws

At each testing time point (#1-5) 6ml blood samples (BD Vacutainer® Sodium Heparin Blood Collection Tube [green top]; Becton, Dickinson and Company, Franklin Lakes, USA) were taken from a forearm vein. Samples were immediately centrifuged at 3500 rpm for 14 min at 4°C (Allegra™ 21R, Beckman Coulter™, Brea, USA)., The plasma aliquots were transferred to polypropylene freezer vials and frozen/stored at -80°C for later analyses.

Blood Sample Analysis

Plasma samples were thawed at room temperature and plasma insulin concentrations were determined by ELISA kits (enzyme linked immunosorbent assay, Alpco Diagnostics, Salem, USA) using a microplate reader (Model 680, BioRad Laboratories Ltd., Mississauga, Canada). The finger prick blood sample was performed with a Blood Lancet (EZ-Lets, Hannover, Germany). After each prick the first blood drop was discarded and the second drop was used for analysis (Strasinger and Di Lorenzo 1996). This blood sample was analyzed using a One Touch® Ultra® Glucometer (LifeScan Inc., Burnaby, Canada).

Capillary Blood Glucose Area under the Curve

To determine glucose tolerance over 2 h, the capillary blood glucose values ($mmol \cdot L^{-1}$) were plotted at each collection time and the trapezoid method was used to calculate the area under the curve (AUC) for all 3 treatments (Le Floch et al. 1990; Potteiger et al. 2002).

Whole-body Insulin Sensitivity

Whole-body insulin sensitivity (composite) was calculated using an index of insulin sensitivity that has been previously demonstrated to be highly correlated with the rate of whole-body glucose disposal during the euglycemic insulin clamp (Matsuda and DeFronzo 1999). The calculation used was (10,000/square root of [(fasting glucose x 18) x fasting insulin] x [mean glucose x mean insulin during OGTT]) (Matsuda and DeFronzo 1999).

Statistics

All data were analyzed using Sigma Stat for Windows (version 3.5). One-way repeated measures analyses of variance (ANOVA) were used to determine differences among the three treatments (WBV exercise session, NoV exercise session, and control) for capillary blood glucose AUC and whole-body insulin sensitivity. Separate, two-way repeated measures ANOVA (treatment X time) were used to investigate the differences in capillary blood glucose and plasma insulin values at all measurement time points. All data are presented as means±SD, and the level of statistical significance was set at $p<0.05$. Where appropriate, post hoc tests were performed using Tukey's HSD tests.

Results

Capillary Blood Glucose

There was no interaction between treatment and time ($P=0.274$) and no main effect for exercise session ($P=0.778$; Figure 5.2) but there was a main effect for time of measure ($P<0.001$). As expected, the ingestion of the glucose beverage significantly raised blood glucose values at time point #2 vs all other measurement time points

(P<0.001). Thereafter, blood glucose returned to near fasting concentrations regardless of treatment.

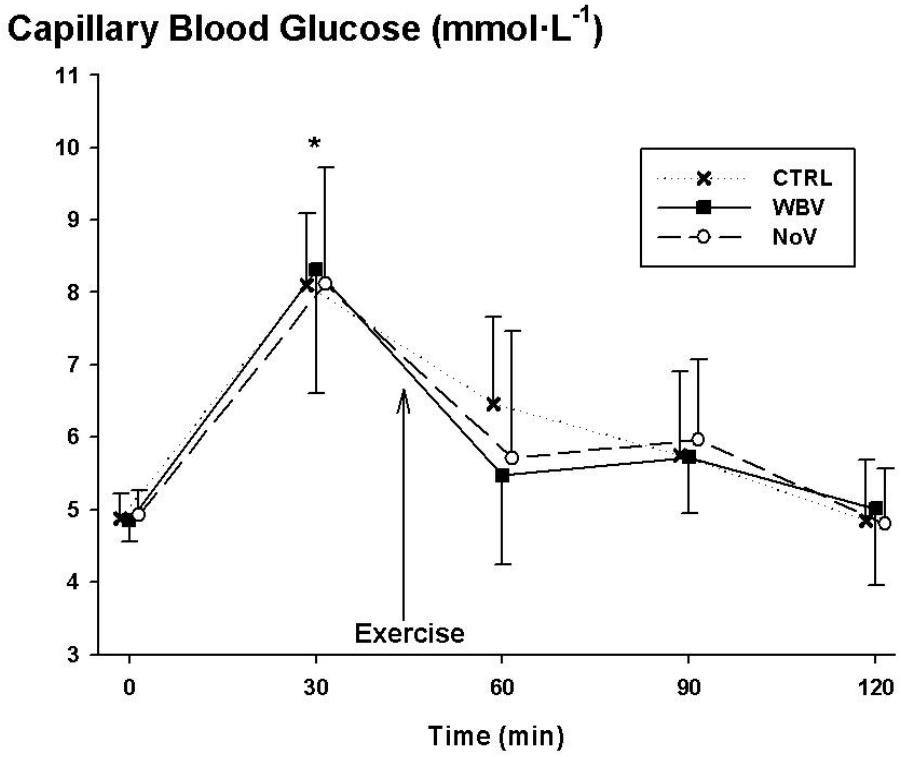

Figure 5.2 – Capillary Blood Glucose Concentrations vs Time.
* = Main effect for time. Time point 2 increased vs all other time points (P<0.001).

Blood Glucose Area under the Curve

There was no difference between treatments for blood glucose area under the curve (P=0.703; Figure 5.3).

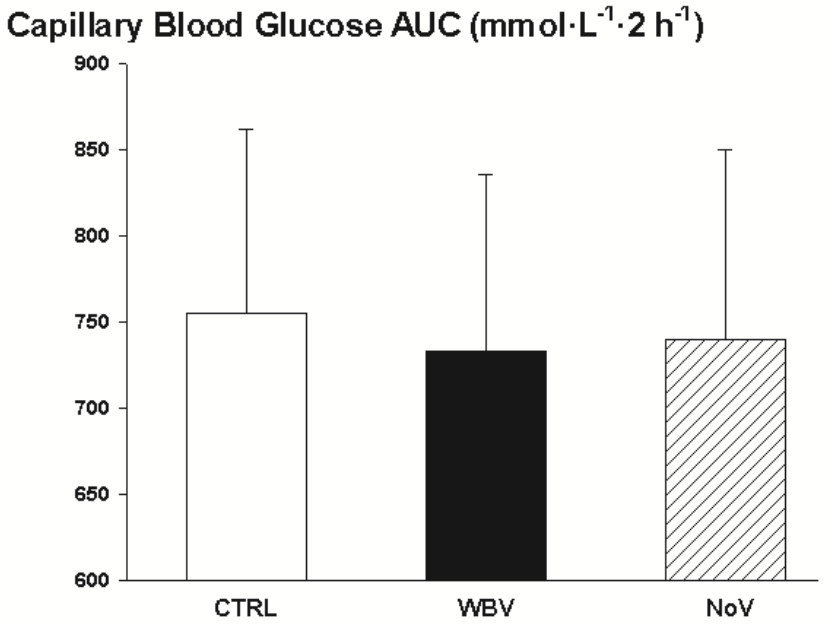

Figure 5.3 – Capillary Blood Glucose Area Under the Curve. No significant effects were observed among treatments.

Plasma Insulin

There was no interaction effect (treatment x time; P=0.102; Figure 5.4) and no main effect for exercise session (P=0.174) but there was a main effect for time of measure (P<0.001). As expected, the ingestion of the glucose significantly increased insulin concentration at time point #2 vs all other measures (P<0.001). Thereafter, insulin returned to near fasting concentrations with all treatments.

Whole-body Insulin Sensitivity

There was a treatment effect (P=0.007; Figure 5.5). Both the NoV (P=0.007) and WBV (P=0.05) where more insulin sensitive than CTRL.

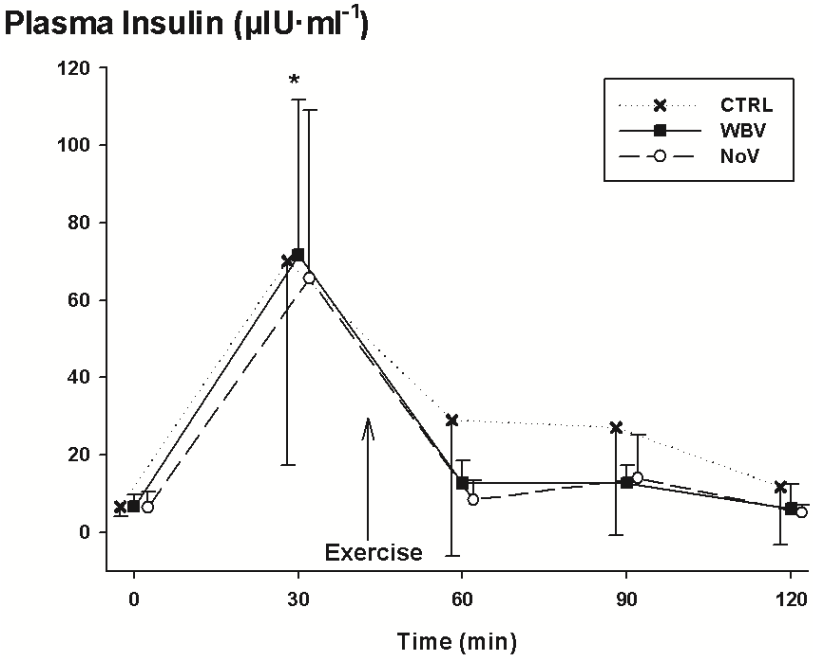

Figure 5.4 – Plasma Insulin Concentrations vs Time. * = Main effect for time. Time point 2 increased vs all other time points (P<0.001).

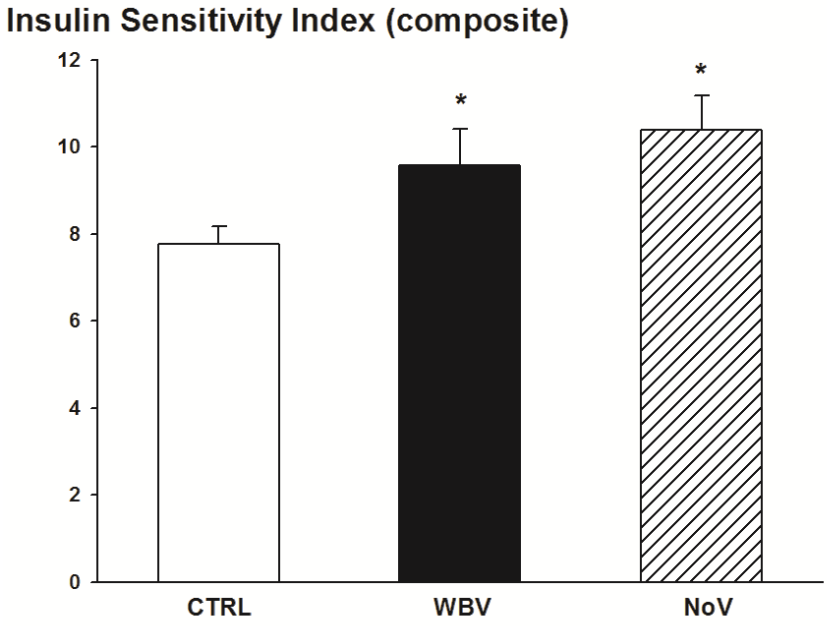

Figure 5.5 – Insulin Sensitivity Index. * - Increased vs CTRL (P<0.05.

Discussion

The contraindications from vibration platform manufacturers include many health conditions where the vertical oscillations could have deleterious effects ie. diabetes. However, those with insulin resistance or even diabetics may benefit from the WBV-induced increases in muscle activity as it is quite possible the muscle contractions with WBV could enhance glucose disposal. Thus, as a first attempt to examine the effect of WBV exercise on glucose tolerance we studied young, healthy men using the same 30 min WBV exercise session studied in chapters 3 & 4.

While there is no doubt that more conventional modes of exercise enhance glucose disposal (Henriksen 2002; Winett and Carpinelli 2001), it is quite possible that the addition of WBV to standard resitive body mass exercise could do so as well. This WBV exercise session has already demonstrated significant increases in skin temperature, oxygen consumption, and heart rate (Chapter 2 and 3) with little effect on skeletal muscle inflammation, soreness, or function (Chapter 4) but its effect on glucose tolerance is unknown.

In the fasted state, all of the current subjects had normal capillary blood glucose concentrations (~4.9 $mmol \cdot L^{-1}$). With the ingestion of the 75 g glucose beverage the subjects blood glucose values increased significantly to (~8.2 $mmol \cdot L^{-1}$), as expected. However, all 3 treatments (control, WBV exercise, and NoV exercise) returned to near baseline values by 60 min (time point 3) and remained so for the duration of the study. Consistent with this observation was the similar total area under the 2 h curve for glucose among the 3 groups. These healthy young men have normal glucose tolerance and the addition of the WBV stimulus to the exercise session did not affect glucose handling significantly.

The fasting plasma insulin values (~6.0 μIU·ml^{-1}) were also within the normal range for all individuals studied. As expected, the ingestion of the glucose load increased plasma insulin concentrations significantly (up to ~65 μIU·ml^{-1}; Magkos et al. 2010) and like the results for blood glucose, insulin returned to near baseline values by 60 min with all 3 treatments (control, WBV exercise, and NoV exercise). Importantly, both the WBV and NoV exercise sessions increased insulin sensitivity compared to control (no exercise). Although not a large response in these healthy subjects, this effect could be important for individuals with impaired fasting blood glucose or type II diabetics. Interestingly, in a single subject with slightly elevated overnight fasted blood glucose (6.5-7.0 mmol·L^{-1}), we have observed a 13-19% reduction in 2 h glucose area under the curve with WBV (unpublished data). This suggests the positive effects on glucose tolerance are greater in those with elevated blood glucose and highlights the need for future research utilizing WBV exercise in individuals with impaired fasting blood glucose or diabetes to assess whether the WBV stimulus can be used as a treatment strategy for this epidemic disease. However, considerable care must be taken because diabetes involves a variety of complications such as retinopathies, neuropathies, etc and how/whether these are affected by WBV is unknown. Finally, because previous WBV studies have demonstrated a number of beneficial effects from a wide range of exercise intensities from mild to intense (Abercromby et al. 2007; Cardinale and Lim 2003; Hazell et al. 2007, 2008, 2010; Marin et al. 2009; Rittweger et al. 2000, 2001, 2002; Ritzmann et al. 2010; Roelants et al. 2006) it is possible that WBV exercise could be utilized by individuals with impaired glucose tolerance, diabetes, or even in those who are not fit enough to benefit from more traditional endurance or strength exercise.

Conclusion

The present results suggest that synchronous WBV exercise improves insulin sensitivity in young, healthy men. Future studies on men and women with impaired glucose tolerance are needed to determine whether WBV exercise, like other more conventional forms of exercise, might be part of a treatment strategy to normalize glucose metabolism.

Acknowledgements

Whole-body Advanced Vibration Exercise, (WAVE™; Windsor, Canada) donated the platform.

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CHAPTER 6

DISCUSSION

Whole-body vibration (WBV) exercise involves performing standard body mass resistive exercises on a vertically oscillating platform. The vertical oscillations generated by the ground based platform stimulate reflex muscle contractions via a response akin to monosynaptic reflexes (Cardinale and Bosco 2003; Ritzmann et al. 2010). These muscle contractions have been demonstrated with significant increases in muscle activity via surface electromyography (Abercromby et al. 2007; Cardinale and Lim 2003; Hazell et al. 2007, 2010; Marin et al. 2009; Ritzmann et al. 2010; Roelants et al. 2006). However, whether this enhanced muscle activity increases the exercise intensity enough to result in any positive health outcomes is currently unknown. In this dissertation, several physiological responses to acute synchronous WBV exercise were examined in an attempt to assess whether WBV exercise has any potential to improve health or fitness.

The cardiovascular stress study (Chapter 2) demonstrated that while the static semi-squat resulted in a small increase in mean arterial pressure, it had no effect on heart rate, femoral artery blood flow, or leg skin temperature. The addition of WBV resulted in a significant increase in leg skin temperature but had no further effects on heart rate or mean arterial pressure. There appeared to be a WBV-induced increase in femoral artery blood flow but this response was quite variable and not significant perhaps due to a Type II error. Some increase in blood flow during WBV seems reasonable considering previously described increases in leg muscle activity (Cardinale and Lim 2003; Hazell et al. 2007; Rittweger et al. 2000) but regardless, the response magnitude was small. If real, any increase in blood flow could be due to a redistribution of blood to leg muscle, skin or both. If femoral artery blood flow did increase coupled with the increase in leg skin temperature this could also be the cause of the increased skin erythema (redness) that occurs in some subjects with WBV exposure. These data indicate that the addition of

WBV to a static semi-squat imposes minimal cardiovascular stress suggesting future research should examine the responses to other more strenuous WBV exercises (multiple static and dynamic exercises using both upper and lower body musculature) to assess whether they can enhance health or fitness.

The oxygen consumption study (Chapter 3) demonstrated that a WBV exercise protocol (involving both upper and lower body dynamic exercises) with dietary control increased oxygen consumption (VO_2) both during the exercise session as well into recovery (8 and 24 h) vs the same exercise session without vibration. The increased muscle contractions with WBV exercise also resulted in an increased heart rate. These results suggest that a regular program of dynamic WBV exercises could produce significant fat mass loss (assuming constant energy intake). The exercise intensity used in this study was moderate but it could be adjusted up or down for other populations. For example, for the less fit, more static exercises with increased rest periods could provide an adequate stimulus. Similarly, WBV exercise could also be performed with external loads to increase the intensity and accommodate even very fit populations. Whether loaded WBV training would result in greater fat mass losses and possibly even increases in lean muscle mass needs to be assessed. Furthermore, the potential for this novel exercise session to affect muscle strength, power, and function needs to be evaluated systematically.

The muscle damage/inflammation study (Chapter 4) demonstrated that the same dynamic WBV exercise session resulted in no significant effects on muscle damage/function, soreness, or inflammation compared to the same exercise session without vibration. While there was a slight decrease in muscle function (indirect measure of muscle damage) immediately post-exercise, this was not different between exercise

sessions (WBV vs NoV) suggesting it was likely muscle fatigue-related. There was also only a very small effect on muscle soreness with the WBV exercise causing a slight increase at 24 h post-exercise. Moreover, with little or no effects on muscle damage/function and soreness it was not surprising that neither exercise session had any large effects on markers of muscle inflammation (IL-1β, IL-6, IL-10). While this may seem like a positive result, it may mean that the stimulus is too low for any real compensatory adaptation in muscle. In summary, the increased muscle activity with vibration did not result in any deleterious effects on muscle, although whether WBV exercise sessions of lower or higher intensity would have similar affects in less fit (sedentary or older adults) or more fit (trained individuals) respectively, requires future investigation. Future research should also examine any potential for the use of vibration in the rehabilitation setting.

The glucose tolerance study (Chapter 5) demonstrated that WBV exercise improved insulin sensitivity in young healthy men. As expected, 30 min following ingestion of the 75 g glucose load there was a significant elevation in both blood glucose and insulin concentrations. Both exercise sessions were effective in lowering blood glucose with less insulin immediately post-exercise (insulin sensitizing effect). Although not a large response in these healthy subjects, this effect could be important for individuals with impaired fasting blood glucose or even type II diabetics. Future research utilizing WBV exercise in individuals with impaired fasting blood glucose or diabetes to assess whether the WBV stimulus can be used as a treatment strategy for this disease is certainly necessary. However, diabetes involves a variety of complications such as retinopathies, neuropathies, etc so future research with this population should proceed with caution.

Summary

Together these studies demonstrate that moderate intensity WBV exercise composed of traditional body mass resistive exercises significantly increases oxygen consumption while having small effects on the cardiovascular system, muscle function/damage, and glucose tolerance. Further, the 24 h VO_2 results indicate that regular WBV dynamic exercise has considerable body fat loss potential and the glucose tolerance data demonstrate WBV exercise has an insulin sensitizing effect that could have considerable potential for those who are glucose intolerant. Therefore, given the range of intensities possible, WBV exercise could be a beneficial training modality for a variety of population groups. More work is recommended to document fully the effects of WBV exercise on both health and performance.

Limitations

While the interest and participation in WBV exercise is growing rapidly, there is a dearth of scientific data supporting the claims made by many in the vibration industry. In the present studies every effort was made to control confounding variables but with free living human subjects this is always challenging.

In the cardiovascular study (Chapter 2), blood flow could not be measured continuously during the exercise protocol as this is a limitation of the Doppler ultrasound methodology. This drawback means it was impossible to determine whether the blood flow changed during the actual WBV exposure or in the immediate post-exercise period. Further research using other methodologies is warranted to determine the time course of any increases in blood flow with WBV exercise. Perhaps an animal model using microspheres may provide valuable information.

In the oxygen consumption study (Chapter 3), we could not measure during exercise VO_2 on the same day as the recovery VO_2 measures due to methodological difficulties. However, the exercise sessions were reproduced exactly so it is likely the increases measured would have been similar if measured on the same day. Moreover, we could not obtain during exercise data on 3 subjects who completed the 24 h recovery protocol. However, the replacement subjects were matched closely (age, height, weight, body fat %, and fitness level). Importantly, the data on the 5 subjects that completed the complete protocol (both exercise and recovery) actually showed a slightly greater oxygen consumption than with all 8 subjects.

In the muscle damage/inflammation study (Chapter 4), non-invasive techniques to determine muscle damage such as magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), or diffusion tensor MRI (DT-MRI) or minimally invasive approaches such needle muscle biopsies to examine ultrastructural muscle fibre damage would have enhanced the results observed.

In the glucose tolerance study (Chapter 5), we examined the effects of WBV exercise on blood glucose concentration and insulin release in young healthy men to provide a first step in understanding this response. Studying individuals with impaired fasting glucose concentration might have yielded more impressive results.

Future Studies

While the current studies demonstrate several physiologic effects of WBV exercise, many questions remain.

Cardiovascular effects during dynamic squats with WBV

While the cardiovascular study (Chapter 2) demonstrated no greater cardiovascular stress with WBV during static exercise, the effects of dynamic exercise should also be examined. A future study utilizing similar methodology but with dynamic squatting could be informative. Further, as standing on the vibration platform has little effect on upper body musculature, the cardiovascular effects of the WBV exercise session utilizing both upper and lower body exercise should also be examined. Also, as mentioned, other techniques to assess blood flow could be helpful.

Chronic WBV exercise on body composition

To confirm or extend the results of the oxygen consumption study (Chapter 3) doubly-labelled water or metabolic chamber techniques could be used to assess 24 h energy expenditure. Further, a WBV training study should be undertaken while monitoring energy intake carefully to determine whether the fat loss predictions made based on these acute data are accurate.

Muscle function and damage with loaded WBV exercise

Future studies should examine more strenuous WBV exercise (using external loads) and non-invasive measures of muscle damage (MRI, MRS, DT-MRI) to extend the findings from our muscle damage/inflammation study. Several studies have demonstrated the potential effectiveness of loaded WBV exercise although whether this loaded form of WBV exercise would cause significant effects on muscle function and inflammation has not been evaluated.

Glucose tolerance and insulin release with WBV exercise in unhealthy subjects

In chapter 5 it was demonstrated that a WBV exercise had no effects on glucose tolerance but did result in an increase in insulin sensitivity in young healthy men.

Consequently, it is possible that regular WBV exercise would enhance glucose tolerance in individuals with elevated blood glucose (impaired fasting glucose or diabetics) but this needs verification. Both acute and chronic studies with glucose intolerant individuals are necessary to confirm this hypothesis.

Heat production and dehydration with WBV exercise

The effects of WBV exercise on heat production, core temperature, and body water stores should be investigated as the potential heat production from the WBV-induced muscle contractions could result in body temperature issues as well as dehydration. If WBV exercise is to be promoted to unfit and unhealthy populations this is critical because heat illness can be life threatening.

Conclusion

Whole-body vibration (WBV) exercise is promoted widely as a health/fitness 'panacea' despite a dearth of research data. Several platforms are advertised and available for purchase in stores, on the internet, and on television. While the breadth of scientific evidence regarding the effects of WBV exercise is increasing much more research is necessary to understand how the WBV stimulus affects the body and how the body adapts over time to this novel stimulus. The studies comprising this dissertation evaluated acute WBV exercise from several physiological perspectives focusing on the cardiovascular and metabolic systems in humans. The results suggest that WBV exercise increases muscle activity, oxygen consumption, heart rate, leg skin temperature, and insulin sensitivity without affecting muscle damage/function. Although more work is necessary to understand WBV exercise fully, the present results provide initial evidence that the addition of WBV to traditional body mass resistive exercises produces a moderate, acute

exercise stimulus that, if repeated regularly, could have some positive health effects, especially on fat loss and glucose tolerance.

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APPENDICES

Appendix A – *Ethics Approval*

Study 1

Office of Research Ethics

The University of Western Ontario
Room 00045 Dental Sciences Building, London, ON, Canada N6A 5C1
Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. P.W.R. Lemon
Review Number: 12805E **Review Date:** November 8, 2006 **Revision Number:**
Protocol Title: The Effects of Whole Body Vibration on Femoral Artery Blood Flow, Leg Volume, and Leg Temperature During Seated, Static and Dynamic Muscle Contraction.
Department and Institution: Kinesiology, University of Western Ontario
Sponsor:
Ethics Approval Date: November 22, 2006 **Expiry Date:** June 30, 2007
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted expedited approval to the above named research study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

This approval shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

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Study 2

Office of Research Ethics

The University of Western Ontario
Room 4180 Support Services Building, London, ON, Canada N6A 5C1
Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. P.W.R. Lemon

Review Number: 15468E **Revision Number:** 1

Review Date: July 03, 2009 **Review Level:** Expedited

Protocol Title: The Effect of an acute whole-body vibration exercise training session on resting metabolic rate and 24 hour energy expenditure across the lifespan.

Department and Institution: Kinesiology, University of Western Ontario

Sponsor:

Ethics Approval Date: July 10, 2009 **Expiry Date:** December 31, 2010

Documents Reviewed and Approved: Revised study end date, co-investigators, administrative changes, study methods, participant recruitment and eligibility of subjects. Letter of Information.

Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

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Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. P.W.R. Lemon
Review Number: **16850E** **Review Level:** Expedited
Review Date: February 10, 2010 **Approved Local # of Participants:** 20
Protocol Title: The effects of whole-body vibration exercise on muscle inflammation, soreness, and function
Department and Institution: Kinesiology, University of Western Ontario
Sponsor: WAVE EXERCISE
Ethics Approval Date: March 24, 2010 **Expiry Date:** August 31, 2011
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent.
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

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Study 4

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Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. P.W.R. Lemon
Review Number: 17139E **Review Level:** Expedited
Review Date: June 02, 2010 **Approved Local # of Participants:** 20
Protocol Title: The effects of whole-body vibration on glucose tolerance
Department and Institution: Kinesiology, University of Western Ontario
Sponsor: WAVE MANUFACTURING INC.
Ethics Approval Date: October 29, 2010 **Expiry Date:** August 31, 2011
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent, Advertisement.
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

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Appendix B – *Par-Q Health Survey*

PAR-Q & YOU

Physical Activity Readiness
Questionnaire – PAR-Q (Revised 1994)

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below.

If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with you doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2. Do you feel pain in your chest when you do physical activity?
☐	☐	3. In the past month, have you had chest pain when you do physical activity?
☐	☐	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7. Do you know of any other reason why you should not do physical activity?

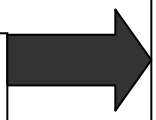
If you answered

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.



DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of temporary illness such as a cold or a fever – wait until you feel better, or
- If you are or may be pregnant – talk to your doctor before you start becoming more active

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if no doubt after completing this questionnaire, consult your doctor prior to physical activity.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

SUBJECT #: _____

You are encouraged to copy the PAR-Q but only if you use the entire form
© Canadian Society for Exercise Physiology Société canadienne de physiologie de l'exercice
Health Canada Santé Canada

Appendix C – *Permission from the European Journal of Applied Physiology*

Title: Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise

Author: Tom J. Hazell

Publication: European Journal of Applied Physiology

Publisher: Springer

Date: Jan 1, 2008

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Licensed content date	Jan 1, 2008
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CURRICULUM VITAE

Name: **Tom J. Hazell**

Position: PhD Candidate
Exercise Nutrition Research Laboratory
School of Kinesiology, Rm 2235 3M Centre
The University of Western Ontario
London, Ontario, N6A 3K7

Education:

2006 – present	PhD	The University of Western Ontario Department of Kinesiology Advisor: Peter W.R. Lemon Doctoral Thesis: *The Effects of Acute Synchronous Whole-body Vibration Exercise*
2004 – 2006	MHK	University of Windsor Department of Kinesiology Advisors: Kenji A. Kenno & Jennifer M. Jakobi Master's Thesis: *The Effects of Whole-body Vibration on Muscle Activity*
1999 – 2004	BKin (Hons)	McMaster University Department of Kinesiology Kinesiology (Minor in Classics)

Honours and Awards:

2010	Department of Kinesiology Travel Award, $700
2010	Faculty of Health Sciences Travel Award, $500
2010	The University of Western Ontario Kinesiology Graduate Thesis Research Award, $562
2010	Society of Graduate Students Travel Subsidy, $400
2009	Faculty of Health Sciences Travel Award, $500
2009	Department of Kinesiology Travel Award, $462

2009	The University of Western Ontario Kinesiology Graduate Thesis Research Award, $370
2007	University of Windsor Human Kinetics Outstanding Graduate Research Award – Applied Human Performance, $250

Funding:

2009 – 2010	Ontario Graduate Scholarship	$15,000
2008 – 2009	Ontario Graduate Scholarship	$15,000

Professional Memberships:

Canadian Society of Exercise Physiology
American College of Sports Medicine

Professional Service:

Reviewer - number in parentheses

American Journal of Clinical Nutrition (1)

Biomed Central Geriatrics (1)

International Journal of Sports Nutrition and Exercise Metabolism (3)

Journal of Aging and Physical Activity (1)

Medicine and Science in Sports and Exercise (2)

Scandinavian Journal of Medicine and Science in Sports (1)

Committees

Departmental

2009-2010	Chair, Kinesiology Graduate Board, The University of Western Ontario
2008-2009	VP Student Affairs, Kinesiology Graduate Board, The University of Western Ontario

Conference Organization

2007 Student Member, Canadian Society for Exercise Physiology (CSEP) Conference Organizing Committee. The University of Western Ontario.

2006-07 Member, Ontario Exercise Physiology (OEP) Conference Planning Committee. The University of Western Ontario.

Scholarly Activity:

Summary:
Articles in peer-reviewed journals: 6
Invited book chapters: 1
Published abstracts from professional meetings: 12
Oral presentations at professional meetings: 6
Poster presentations at professional meetings: 5
Other Oral Presentations: 11

ARTICLES IN PEER-REVIEWED JOURNALS:

MacPherson REK, **Hazell TJ**, Olver TD, Paterson DH, & Lemon PWR. (2011). Run sprint interval training improves aerobic performance but not max cardiac output. *Medicine and Science in Sports and Exercise*. 43, 115-112.

Hazell TJ, MacPherson REK, Gravelle BMR, & Lemon PWR. (2010). 10 or 30-s sprint interval training bouts enhance both aerobic & anaerobic performance. *European Journal of Applied Physiology*. 110, 153-160.

Hazell TJ, Kenno KA, & Jakobi JM. (2010). Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. *Journal of Strength and Conditioning Research*, 24, 1860-1865.

Hazell TJ, Thomas GWR, DeGuire JR, & Lemon PWR. (2008). Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise. *European Journal of Applied Physiology*, 104, 903-908.

Hazell TJ, Jakobi JM, & Kenno KA. (2007). The effects of whole-body vibration on upper- and lower- body EMG during static and dynamic contractions. *Applied Physiology, Nutrition and Metabolism*, 32, 1156-1163.

Hazell T, Kenno K, & Jakobi J. (2007). Functional benefit of power training for older adults. *Journal of Aging and Physical Activity*, 15, 349-359.

INVITED BOOK CHAPTERS:

Hazell TJ, & Lemon PWR. "Protein" In *Nutritional Concerns in Recreation, Exercise, and Sport*. I. Wolinsky & J.A. Driskell, eds. CRC Press, Boca Raton, 2009, 75-90.

PUBLISHED ABSTRACTS AT PROFESSIONAL MEETINGS:

Hazell TJ, Olver TD, Hamilton CD, & Lemon PWR. (2010) Vertical whole-body vibration exercise induces some muscle soreness but does not adversely affect muscle function compared to the same exercises without vibration. *Applied Physiology, Nutrition, and Metabolism*, 35(S1): S40.

OIver TD, **Hazell TJ**, Hamilton CD, Lemon PWR. (2010) Obesity impairs leg blood flow and glucose tolerance in young women. *Applied Physiology, Nutrition, and Metabolism*, 35(S1): S79.

Hazell TJ, & Lemon PWR. (2010) Vertical whole-body vibration exercise increases energy expenditure versus the same exercise without vibration. *Medicine and Science in Sports and Exercise*, 42(5): S305.

Olver TD, **Hazell TJ**, Hamilton CD, & Lemon PWR. (2010) Following a sprint interval session VCO_2 decreases more rapidly than VO_2. *Medicine and Science in Sports and Exercise*, 42(5): S22.

Hazell TJ, & Lemon PWR. (2009) Acute whole-body vibration exercises increases 24 h energy expenditure vs the same exercises without vibration. *Applied Physiology, Nutrition, and Metabolism*, 34(S1): S39.

Olver TD, **Hazell TJ**, MacPherson REK, Hamilton CD, & Lemon PWR. (2009) Four acute, 30-s sprint interval repeats elicit near maximal VO_2, but total session aerobic energy expenditure is still less than traditional endurance training. *Applied Physiology, Nutrition, and Metabolism*, 34(S1): S71.

MacPherson REK, **Hazell TJ,** Olver TD, Paterson DH, & Lemon PWR. (2009) Run sprint interval training enhances body composition, VO_2max, and endurance performance, but has little effect on maximal cardiac output. *Applied Physiology, Nutrition, and Metabolism*, 34(S1): S59.

Hazell TJ, MacPherson REK, Gravelle BMR, & Lemon PWR. (2009) Importance of sprint interval training duration and recovery time on endurance and power performance. *Medicine and Science in Sports and Exercise*, 41(5): S102.

MacPherson REK, **Hazell TJ,** Gravelle BMR, Thomas GWR, & Lemon PWR. (2008) Six sessions of 10 or 30 sec sprint interval training produce improvements in VO_2peak, Wingate, and 5km cycle time trial performance. *Applied Physiology, Nutrition, and Metabolism*, 33(S1): S63.

Hazell TJ, Thomas G, DeGuire JR, & Lemon PWR. (2008) Addition of whole-body vibration to static semi-squat exercise has minimal affect on selected cardiovascular responses. *Medicine and Science in Sports and Exercise*, 40(5): S435.

Hazell TJ, Jakobi JM, & Kenno KA. (2007) Evaluation of muscle activity during whole-body vibration for loaded and unloaded dynamic squats. *Applied Physiology, Nutrition and Metabolism*, 32(1): S43.

Hazell TJ, Jakobi JM, & Kenno KA. (2007) Skeletal muscle EMG changes during whole-body vibration: The influence of frequency and amplitude. *Medicine and Science in Sports and Exercise*, 39(5): S62.

ORAL PRESENTATIONS AT PROFESSIONAL MEETINGS:

Hazell TJ, & Lemon PWR. Acute whole-body vibration exercises increases 24 h energy expenditure vs the same exercises without vibration. *CSEP Annual Scientific Conference*, Vancouver, November 2009.

Hazell TJ, MacPherson REK, Gravelle BMR, & Lemon PWR. Importance of sprint interval training duration and recovery time on endurance and power performance. *ACSM Annual Scientific Conference*, Seattle, May 2009.

Hazell TJ, Gravelle BMR, MacPherson REK, Thomas G, & Lemon PWR. Effects of sprint interval training bout duration on VO_2max, Wingate, 5 km cycle time trial, body composition, and resting metabolic rate. *Ontario Exercise Physiology (OEP) Meeting*, Barrie, 2008.

Hazell TJ, Scherer JA, Jakobi JM, & Kenno KA. Whole-body vibration during loaded dynamic squats enhances leg muscle activity. *Ontario Exercise Physiology (OEP) Meeting*, Barrie, 2007.

Hazell TJ, Jakobi JM, & Kenno KA. Assessment of whole-body vibration with electromyography. *Ontario Exercise Neurophysiology Group (OENG) Meeting*, St. Catharine's, 2006.

Hazell TJ, Jakobi JM, & Kenno KA. The effect of whole-body vibration on upper- and lower- body muscle activation. *Ontario Exercise Physiology (OEP) Meeting*, Barrie, 2006.

POSTER PRESENTATIONS AT PROFESSIONAL MEETINGS:

Hazell TJ, Olver TD, Hamilton CD, & Lemon PWR. Vertical whole-body vibration exercise induces some muscle soreness but does not adversely affect muscle function compared to the same exercises without vibration. *Canadian Society of Exercise Physiology Annual Scientific Conference*, Toronto, November 2010.

Hazell TJ, & Lemon PWR. Vertical whole-body vibration exercise increases energy expenditure versus the same exercise without vibration. *American College of Sports Medicine Annual Scientific Conference*, Baltimore, June 2010.

Hazell TJ, Thomas G, DeGuire JR, & Lemon PWR. Addition of whole-body vibration to static semi-squat exercise has minimal affect on selected cardiovascular responses. *American College of Sports Medicine Annual Scientific Conference*, Indianapolis, May 2008.

Hazell TJ, Jakobi JM, & Kenno KA. Evaluation of muscle activity during whole-body vibration for loaded and unloaded dynamic squats. *Canadian Society of Exercise Physiology Annual Scientific Conference*, London, November 2007.

Hazell TJ, Jakobi JM, & Kenno KA. Skeletal muscle EMG changes during whole-body vibration: The influence of frequency and amplitude. *American College of Sports Medicine Annual Scientific Conference*, New Orleans, May 2008.

OTHER ORAL PRESENTATIONS:

Hazell TJ. The Effects of Acute Synchronous Whole-Body Vibration Exercise. *Open Lecture, McGill University*, Montreal, Quebec, September 2010.

Hazell TJ. The Effects of Acute Whole-body Vibration Exercise. *Kinesiology 605/505y Graduate Bioscience Seminar Series, The University of Western Ontario*, London, Ontario, March 2010.

Hazell TJ. Ultrasound & Vibration Exercise: Waves of the Future? *Community Exercise Nutrition Symposium – Body Transformation Do's and Don'ts, The University of Western Ontario*, London, Ontario, March 2010.

Hazell TJ. High Performance Nutrition for Elite Hockey Players. *Ontario Hockey Association High Performance Program*, London, Ontario, June 2009.

Hazell TJ. Good Vibrations - Is Whole Body Vibration Exercise Effective? *Community Exercise Nutrition Symposium – Fit or Fat, The University of Western Ontario*, London, Ontario, March 2009.

Hazell TJ, & Thomas GWR. Why Your Diet Doesn't Work. *Fitness and Wellness Conference, Fanshawe College*, London, Ontario, May 2008.

Hazell TJ. Chemistry in the Kitchen: Designing Your Own Supplements. *Fitness and Wellness Conference, Fanshawe College*, London, Ontario, May 2008.

Hazell TJ, & Thomas GWR. Effective Nutrition for Hockey Players. *Ontario Hockey Association High Performance Program*, Kitchener, Ontario, July 2007.

Hazell TJ, & Thomas GWR. Eating to Achieve. *Fitness and Wellness Conference, Fanshawe College*, London, Ontario, May 2007.

Hazell TJ. Sports Supplements: The Science Behind the Hype. *Fitness and Wellness Conference, Fanshawe College*, London, Ontario, May 2007.

Hazell TJ, & Thomas GWR. Importance of Nutrition for Elite Hockey Performance. *Ontario Hockey League Under 16 Program of Excellence*, Kitchener, Ontario, May 2007.

TEACHING AND MENTORSHIP EXPERIENCE:

Teaching

2008	Lecturer	Introduction to Exercise Physiology (KIN2230) Intersession The University of Western Ontario Teacher Rating: 6.0/7 - The physiological basis of muscular exercise and training examining metabolic, cardio-respiratory and muscular adaptations to acute and chronic exercise.
2008	Lecturer	Exercise Nutrition (KIN3339) Distance Studies The University of Western Ontario Teacher Rating: 5.3/7 - Investigation of the important food/food components for individuals involved in chronic (regular) exercise programs and/or competition, i.e., athletes.
2007	Teaching Assistant	Exercise Physiology Laboratory (KIN3330) The University of Western Ontario - This course focuses on experiments designed to highlight the physiological response to exercise and to introduce basic techniques for fitness evaluation.
2006	Teaching Assistant	Exercise Nutrition (KIN3339) The University of Western Ontario - Investigation of the important food/food components for individuals involved in chronic (regular) exercise programs and/or competition, i.e., athletes.
2006	Teaching Assistant	Hockey Skills (KIN2208) The University of Western Ontario - The development of skilled performance in ice hockey activities as well as a study of key principles in teaching these activities in physical education.

2006	Teaching Assistant	Scientific Basis of Conditioning (95-370) University of Windsor - Examination of current concepts in conditioning and physiological evaluation including assessment techniques, program design, and other factors affecting physical performance.
2005	Teaching Assistant	Physiology of Fitness (95-260) University of Windsor - Introduction to the physiological response to exercise and training including metabolic and cardio-respiratory responses to exercise energy demands, body composition, and training principles.
2005	Teaching Assistant	Cardiovascular Physiology (95-460) University of Windsor - The study of the cardiovascular system, anatomy, electrophysiology, mechanics, and responses to stressors.
2004	Teaching Assistant	Scientific Basis of Conditioning (95-370) University of Windsor - Examination of current concepts in conditioning and physiological evaluation including assessment techniques, program design, and other factors affecting physical performance.

Mentorship

2006-Present I have assisted my advisor Dr. Lemon in mentoring both junior graduate (7) and undergraduate (7) students. This mentorship involves designing research methodology, data collection, analysis, and dissemination of results (conference abstracts, manuscripts, etc).

2007-Present As a Ph.D. candidate, I aid our Graduate Chair and undergraduate counsellors engage undergraduate students during an information session on futures in graduate education.