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Health and Performance-Related Effects of

Whole Body Vibration Training

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Doctor of Philosophy in Exercise Science

at
Lincoln University

by
Nuttaset Manimmanakorn

Lincoln University
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Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Exercise Science.

**Health and Performance-Related Effects of Whole Body Vibration Training**

by

Nuttaset Manimmanakorn

Whole body vibration (WBV) is a relatively new tool used by some practitioners to improve health. Vibration is now widely used in sport science, physiotherapy, and rehabilitation. WBV is applied via a platform which transmits oscillatory movement through the participant’s body. It has been shown that whole body vibration has positive effects on human body systems including the musculoskeletal, neurovascular and endocrine systems. While vibration training stimulates muscle contraction that promotes muscle strength, the evidence for performance benefit is controversial. The effects of WBV are still being uncovered but it is becoming clear that there are a number of areas where WBV may be beneficial. Sport scientists have investigated the effects of WBV on muscle performance, particularly strength and power development, with mixed results. It is also well established that WBV can affect other physiological systems such as the control of blood vessels and the nervous system. Acknowledgement of the beneficial effects on these systems may indicate the use of WBV on patients with disruption to these systems such as diabetics. Improvement in blood perfusion to certain areas via changes in blood vessel diameter resulting from WBV may also prove useful for recovery, and enhanced recovery from strenuous exercise would be beneficial to many sportspeople.

It is the aim of this thesis to indicate clearly the usefulness of WBV for muscular performance benefit. This will be accomplished by a meta-analysis of previous relevant research studies. A second aim is to identify any beneficial changes to the health of type II diabetic patients of WBV training. Finally, the effectiveness of WBV as a means of enhanced recovery from strenuous exercise will be examined in the last study of this thesis.
Chapter 1 introduces WBV and the thesis rationale. In chapter 2, I searched for high quality studies (randomised controlled trials and matched design studies) from Web of Knowledge, Scopus, Google Scholar and SPORTDiscus databases. The overall effect of WBV training from the 14 studies compared to having no additional exercise on countermovement jump height yielded a positive standardised mean difference of 0.82 (95% confidence interval 0.56-1.09). The effect of WBV training on squat jump height was 0.68 (0.08-1.11). Vibration exercise consisting of a higher frequency (> 30 Hz), higher amplitude (> 3 mm), longer exposure duration (> 10 min/session), longer training period (>12 weeks) and among non-athletes had a greater benefit for jump height improvement than a lower frequency (≤ 30 Hz), lower amplitude (≤ 3 mm), shorter exposure duration (≤ 10 min/session), intermediate training period (4-12 weeks), shorter training period (< 4 weeks) and in athletes. The effect of WBV training compared to a standard exercise group from 4 studies was 0.63 (0.10-1.15). This study revealed strong evidence for a beneficial effect of WBV on counter movement jump height.

In chapter 3, I conducted a randomized controlled trial at Srinagarind Hospital Thailand. Type II diabetics (40 patients) were randomized into two groups (WBV and control). The WBV group was given 2 sets of 6 one-minute vibration squats, 3 times per week for 12 weeks. Training load increased progressively from an initial vibration frequency of 30 Hz and platform amplitude shift of 2 mm to 40 Hz and 4 mm. I outlined my findings that indicated that WBV training had little effect overall with no significant difference found between groups for fasting blood sugar (FBS), glycosylated haemoglobin (HbA1c), insulin level and insulin sensitivity (p > 0.05). However, after the patients were dichotomized into groups representing the severity of their diabetes, those with HbA1c ≥ 8 (severe diabetes, 9 patients in WBV and 8 patients in control), WBV produced a significant reduction in FBS by -20.80 ± 18.99% (mean ± 95%CI, p = 0.012) and insulin sensitivity by 4.67 ± 5.19% (p = 0.043). HbA1c and insulin levels also had positive outcomes but did not reach statistical significance. In contrast, there was no significant difference between WBV and controls for all outcomes in the less severe diabetes group (HbA1c < 8). In chapter 3, changes in vascular and nerve function with vibration training were examined and I found a possible beneficial decrease in peak systolic velocity by -3.13 ± 12.70% (p = 0.143) in the WBV compared to the control group. However, the WBV group showed unclear effects in nerve conduction velocity, pain and numbness between the two groups.
Finally in chapter 4, I conducted a randomized controlled crossover study at Lincoln University whereby sixteen male athletes performed 6 sets of 30 sec Wingate tests interspersed with 30 sec of active recovery (40W), and then were subsequently randomized into 2 groups: Group 1, active recovery program (consisting of 10 minutes of cycling and stretching), and Group 2, WBV where athletes completed 1 set of stretching (hamstrings, right quadriceps and left quadriceps) at 30 Hz, 1-2 mm amplitude, for 30 sec, and 2 sets of lateral thigh muscle, hamstrings, quadriceps and calve massage at 40 Hz, 4-5 mm amplitude, for 60 sec. I found little difference in blood lactate removal, anaerobic capacity, anaerobic power, fatigue index, 3-sec maximum voluntary contraction force, jump height, sit and reach distance, rate of perceived exertion score, or muscle soreness score between a traditional active recovery program and WBV. A subset of 6 athletes’ tissue oxygen saturation was measured via near-infrared spectroscopy (NIRS) during exercise and recovery. The WBV program substantially increased muscle oxygenation 10 min post exercise and post recovery (74.50 ± 1.43, 72.19 ± 2.25% respectively) compared to the traditional active recovery (63.73 ± 3.75, 69.46 ± 1.81%) or no recovery (72.95 ± 2.89, 71.93 ± 2.39%). It seems that the WBV program may increase the oxygen availability to tissue but has little performance benefit immediately after or 60 min later.

In summary WBV training has an effect on a number of systems in the body. It is clear that WBV under particular circumstances (high frequency, high amplitude) has a beneficial effect on the generation of muscle power. We have also provided evidence to indicate that WBV training may be an effective method of controlling some of deleterious outcomes of type II diabetes in the most severe cases only. Finally, vibration training increased muscle oxygenation during recovery and may be useful in restoring oxygen levels to the muscles post exercise training, however we found little evidence to suggest such a recovery technique would benefit subsequent performances completed 1 hour later.

**Keywords:** Whole body vibration, meta-analysis, strength, diabetes, glucose metabolism, blood flow, nerve conduction study, recovery program
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Heartiest thanks to my wife, my children and my friends for all the support, caring and sharing they have given me. I hope the completion of this thesis will signal the end of a major stressful achievement in my life and I look forward to heading home with the knowledge I have made a significant contribution to the research area.
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Thesis organisation

The thesis consists of five chapters and appendices. The chapters are presented in the format of the journal for which they were prepared. The references in APA format for each chapter are retained in the individual chapter and are gathered at the end of the thesis.

Chapter 1 is an introduction and thesis rationale.

Chapter 2 aims to analyze the current evidence for a beneficial effect of WBV training on jump height using meta-analysis. It also aims to identify the vibration parameters that are more effective at increasing jump height.

Chapter 3 aims to investigate the effect of 12 weeks of regular WBV training on fasting blood glucose, HbA1c, fasting insulin, insulin sensitivity, peripheral vascular blood flow and peripheral nerve conduction in type II diabetics using a randomized controlled trial.

Chapter 4 aims to investigate the effect of WBV recovery program following strenuous exercise compared to a traditional recovery program. Parameters to be measured included blood lactate concentration, muscle power, muscle strength, flexibility, muscle oxygenation, rate of perceived exertion and muscle soreness.

Chapter 5 is a general discussion including research limitations, conclusion and proposals for the future research.

Appendix A contains questionnaires which were used in this thesis. Appendices B and C contains subject information, consent form and ethical approval for the two experimental studies. Appendix D contains research photos of two experiment studies.
Whole body vibration (WBV) is an exercise training protocol widely promoted as a modern exercise technique. An oscillatory movement is generated by motors underneath a platform which are subsequently transmitted to the human body. The commercial WBV machine generates a sinusoidal wave form (Jordan, Norris, Smith, & Herzog, 2005) that is different to the vibration wave form generated by motorized vehicles or industrial machines in our environment. The sinusoidal wave form of WBV produces several positive effects on multi-organ systems including skeletal, muscle, peripheral vascular, peripheral nervous and the endocrine systems (Prisby, Lafage-Proust, Malaval, Belli, & Vico, 2008). In the 1970s, the Russian sport scientist, Dr. Vladimir Nazarov, introduced WBV training to prevent demineralisation of bone and muscle loss in astronauts during spaceflight in a weightless environment (O’Sullivan, 2007; VibraTrim, 2010; Wikipedia, 2011). Early Russian researchers also found that WBV improved muscle strength, flexibility and decreased sport injuries. However, this technology remained in Russia until the fall of Communism (O’Sullivan, 2007; VibraTrim, 2010; Wikipedia, 2011). Research into WBV training in the English literature is now a growing field of study.

The first focus of this thesis is the effect of WBV on the muscular system. Vibration training increases muscle power and strength probably by stimulating reflex muscle contraction via the muscle spindle resulting in the activation of alpha motor neurons (Cardinale & Bosco, 2003). The application of vibration causes enhanced electromyographic activity which indicates improved synchronization of motor units (Bosco, Cardinale, & Tsarpela, 1999; Delecluse, Roelants, & Verschueren, 2003). The effects of WBV on muscle performance however remain controversial. Luo et al. (2005) reviewed 14 randomized controlled studies, and concluded that WBV may have a beneficial acute (during vibration), residual (immediately after WBV) and chronic (after regular WBV exercise) effect on strength and power (Luo, McNamara, & Moran, 2005). In contrast, Nordlund and Thorstensson (2007) reviewed 12 studies and reported that WBV had little or no effect on jump performance (Nordlund & Thorstensson, 2007). These contradictory results have led to the emphasis of chapter 2 in which I used a meta-analytic technique to provide a clearer indication of the effect of WBV on muscle performance. As a result of the large variations in study design and effect measurements, I confined the study criteria to studies using only countermovement
jump (CMJ) and squat jump (SJ) as their outcome measure. It was hypothesized that this study would not only provide a stronger indication of the effect of WBV on jump performance but also provide in-depth information on vibration parameters including frequency, amplitude and exposure duration for stimulating muscle contraction and thereby performance enhancement. These parameters were used to provide the WBV stimulus in the next study forming chapter 3.

The second area of interest outlined in this thesis is what effect WBV has on type II diabetes and glucose metabolism. A previous study in healthy male subjects revealed that plasma glucose level was reduced by 1% after 10 series of 1 min duration of WBV training (30 Hz, 4 mm) (Di Loreto, et al., 2004). In type II diabetic patients fasting blood glucose was reduced by 6.3% and glycosylated haemoglobin (HbA1c) decreased by approximately 3% after 12 weeks of training (30-35 Hz, 2 mm) (Baum, Votteler, & Schiab, 2007). However, WBV effects on diabetics remain unclear since Baum et al. (2007) also observed decreases in fasting blood glucose in the control groups and the changes in HbA1c did not reach statistical significance. Chapter 3 was therefore designed to investigate the effect of 12 weeks of regular WBV training (with greater WBV training load than Baum et al. (2007) protocol at 40 Hz, 4 mm) on fasting blood sugar, HbA1c, fasting insulin and insulin sensitivity in diabetics. The ideal vibration protocol used to study the effect of WBV training on various physiological systems in type II diabetes was gained from the results of chapter 2 (the meta-analysis).

Scientists have also been interested in the effect of WBV on controlling diabetic peripheral vascular and nerve complications. WBV may improve vascular blood supply, and this may reduce the ischemic processes underlying these complications. Several studies have found WBV increased tissue blood flow during training (Kerschan-Schindl, et al., 2001; Lohman, Petrofsky, Maloney-Hinds, Betts-Schwab, & Thorpe, 2007; Lythgo, Eser, De Groot, & Galea, 2009). However, vascular adaptation after chronic use of WBV has not been investigated. In addition, previous research has found a positive effect of WBV on peripheral nerves. In a rhesus monkey animal model, one hour of 1 g WBV at 6 and 8 Hz produced a decrease of approximately 5.51 and 2.45 % in nerve conduction time (latency) (Floyd, Broderson, & Goodno, 1973). Chapter 3 will therefore also investigate the effect of regular WBV training on nervous and vascular changes in diabetic patients.

Whole body vibration has been suggested to increase tissue blood flow by vasodilatation processes via an increase in endothelium-derived vasodilators and a reduction in the release of
a vasoconstrictor substance (Lythgo, et al., 2009; Nakamura, et al., 1995). If this is indeed true, such training may be useful for recovery after strenuous exercise since a greater vasodilatation would occur, allowing more blood to be circulated around body. A number of previous studies have found a positive vascular effect during WBV training. Kerschan-Schindl et al. (2001) revealed that the mean blood flow velocity in the popliteal artery increased from 6.5 to 13.0 cm.s\(^{-1}\) after 9-min of WBV training (26 Hz, 3 mm) (Kerschan-Schindl, et al., 2001). Lythgo et al. (2009) found the mean blood velocity in common femoral artery increased five-fold after 45 seconds of WBV training (20-30 Hz, 4.5 mm) (Lythgo, et al., 2009). Additionally, Lohman et al. (2007) showed that 3 minutes of WBV (30 Hz, 5-6 mm) increased skin blood flow by 147% (Lohman, et al., 2007). Chapter 5 will therefore explore the acute effect of WBV on increasing blood flow that may be applied for promoting performance recovery in athletes. WBV may enhance lactic acid and waste product elimination leading to an increase in the ability of the athlete to perform in subsequent exercise bouts and reduce the potential for delayed onset of muscle soreness (DOMS). Edge et al. (2009) found no statistical difference in metabolic (oxygen consumption, respiratory exchange ratio, blood lactate concentration), muscle damage (creatine kinase) or performance levels (3 km time trial) after 1 day recovery from high intensity exercise training between WBV (12 Hz, 6 mm, 2 sets of 15 min exposure) and a control group (Edge, Mundel, Weir, & Cochrane, 2009). In contrast, the stretching group on an iTonic WBV machine (35 Hz, 2 mm twice a day for 3 days after a strenuous resistance exercise) had significantly lower perceived pain score than control group (Rhea, Bunker, Marin, & Lunt, 2009). To date, the short term effect of WBV (approximately 1 hour after strenuous exercise) on blood lactate clearance and performance recovery has not been investigated. In chapter 4, I have investigated the short term effect of WBV on performance recovery and I discuss possible mechanisms behind any observed changes.

Vibration for prolonged periods may also cause adverse health effects. For example, hand arm vibration syndrome (Raynaud's phenomenon, numbness, tingling and pain in the hands) is common in miners who work up to 3 hours a day with jackleg drills (Wasserman, et al., 1991). Long-term occupational exposure to whole-body vibration is associated with low-back pain, early degeneration of the lumbar spine and herniated lumbar discs (Bovenzi & Hulshof, 1999). Cronin et al.(2004) reported an itching sensation in the lower limb, jaw pain, neck pain and lower limb pain following vibration in subjects using WBV (26 Hz, 6 mm, 5 min total exposure) (Cronin, Oliver, & McNair, 2004). Additionally, Crewther et al. (2004) reported hot feet, itching in the lower limbs, vertigo and severe hip discomfort (Crewther,
Cronin, & Keogh, 2004). Therefore, during the experiments of study 2 and 3, the adverse effects of WBV will be observed and recorded. Diabetic patients who may have suffered complications were of particular interest.

The overall aim of this research was to examine the effects of WBV training on performance and health. Research to date appears equivocal, so as a consequence meta-analysis will be completed to clearly establish the performance effects. Following this, two independent studies will be completed with a clinical and athletic population to examine possible benefits of WBV training. In summary, the essence of this thesis is to uncover the health and performance effects of WBV which may be useful in both the sport science and medicine fields.
1.1 Literature review

Introduction

Whole body vibration (WBV) is a new tool used by some practitioners to improve health. It is now widely used in physiotherapy, rehabilitation and sport science. These machines transfer oscillatory motion to the subject who normally stands on a platform. It has been shown that whole body vibration has positive health effects, including improved balance, bone mass, vascular blood flow and nerve conduction velocity (Prisby, et al., 2008).

Whole body vibration is also promoted as a means of improving muscle strength, but the evidence of performance gain is equivocal with some reporting improvements while others finding no performance benefit (Luo, et al., 2005; Nordlund & Thorstensson, 2007). To date, there has been no previous meta-analytical review to combine the effects muscle strength following adaptation to WBV training of individual studies. Results from a meta-analysis may indicate a clearer picture of the beneficial effects of WBV on muscular systems, and will be used to guide the subsequent research trials in this thesis as to appropriate vibration parameters such as amplitude and frequency of oscillation.

One of the chronic diseases placing considerable global burden on most industrialised countries is diabetes. Previous research suggested WBV stimulates muscle contraction (Cardinale & Bosco, 2003), and this may increase muscle glucose uptake leading to improved diabetic control (Baum, et al., 2007; Di Loreto, et al., 2004). If this is the case WBV may be a useful tool at combating the rise of diabetes. However, the positive effect of WBV on diabetic control remains unclear because although Baum et al. (2007) found an improvement in HbA1c levels, they were not consistent for all subjects and were not found to be significant overall. In addition, some studies showed WBV increases tissue blood flow (Kerschan-Schindl, et al., 2001; Lohman, et al., 2007), thereby possibly reducing diabetic complications such as peripheral vascular disease and peripheral neuropathy. However, the effect of WBV on peripheral vascular and nervous system parameters in type II diabetics has never been investigated. Therefore, a randomized controlled trial study will be conducted to evaluate the effects of WBV on glucose metabolism, peripheral vascular and nervous function in type II diabetics.

Some research has suggested WBV increases tissue blood flow (Kerschan-Schindl, et al., 2001; Lohman, et al., 2007), increases flexibility and reduces muscle soreness (Cronin, Nash,
& Whatman, 2007; Rhea, et al., 2009), which may promote performance recovery after
exercise (Edge, et al., 2009). However, a previous study did not find any beneficial effects of
WBV in promoting performance recovery 1 day after intensive exercise (Edge, et al., 2009),
but short term effects (up to 1 hour post exercise) of WBV in promoting performance
recovery has not been investigated. This thesis will therefore investigate the short term effects
(up to 1 hour) of a WBV recovery program on blood lactate, muscle power, muscle strength,
flexibility, muscle oxygenation, rate of perceived exertion and muscle soreness compared to a
traditional recovery program.

This research will be conducted in 3 parts: Part 1, the effect of Whole Body Vibration
Training on Jump Height: Meta-analysis, Part 2, the health effect of whole body vibration in
diabetic patients (Type II): a randomized controlled trial (which is separated into two studies),
Part 3, the effect of whole body vibration training on performance recovery.

My original hypothesis was to investigate the health and performance (muscle strength)
effects of WBV in a compromised population (type II diabetes). Therefore initially I needed
to find out best practice in terms of vibration load, this was one outcome goal of study 1 the
meta-analysis. Because of the huge variety of studies and parameters investigated in research
in this field, I decided to concentrate solely on a non-subjective easily measured health
indicator (muscle strength via a jump test). Using the information gained from this initial
investigation I proceeded to investigate the effect of best practice WBV training on type II
diabetics in a randomised control trial. The results of this investigation are incorporated into
study 2 and 3. The optimal WBV training protocol may effectively stimulate reflex muscle
contraction leading to effective diabetic control, and peripheral vascular blood flow
improvement thereby reducing diabetic complications in study 2. Originally, in study 3, I was
to investigate the longer term effects of WBV on type II diabetes patients, however, because
of funding issues I had to alter this study to look at the effects of WBV during recovery.
Additionally, as most of vascular parameter findings in study 2 were unclear, I wanted to
explore the mechanism behind the effects of WBV on peripheral vascular blood flow. Thus, I
had to alter study 3 to look at the effects of WBV on blood perfusion by monitoring muscle
blood flow and muscle oxygenation during acute training that may be useful for exercise
recovery of athletes. This last study may seem disjointed from the previous studies, however
the main aim was to look at acute effects which might indicate physiological reasons behind
the results found in my previous studies. In addition, since WBV has been suggested to be a
useful recovery tool this last study was also developed to help answer this question.
Background information

Whole body vibration (WBV) is an exercise training technique widely promoted in new exercise programs. The development of vibration machines used on humans has been published in several websites (O’Sullivan, 2007; VibraTrim, 2010; Wikipedia, 2011). The first recognition of vibration training is purported to be ancient Greece, where doctors used saws wrapped in cotton to transmit vibrations to human body. In 1857, Swedish physician, Dr. Gustav Zander invented therapeutic exercise machines including vibration machines. Later, Dr. John Harvey Kellogg (American physician) invented a WBV machine in 1895. He created a vibration chair, standing platform and bars to alleviate constipation, headaches and back pain. By 1960, Dr. Biemann in East Germany had invented a technique called rhythmic neuromuscular stimulation on the human back. In the 1970s, Russian sport scientist, Dr. Vladimir Nazarov, introduced WBV training to prevent demineralisation of bone and muscle loss in astronauts during spaceflight in a weightless environment. Russian researchers also found WBV improved muscle strength, flexibility and sport injury healing. Russians kept the technology of WBV a secret until the fall of Communism. Consequently, WBV technology became more obtainable and extended to Europe in the early 1990’s. A number of countries in Europe, America and Asia have conducted widespread research on WBV since 1990. The European Space Agency and NASA are currently studying WBV technology for the maintenance of bone and muscle strength in astronauts. Simultaneously, WBV is being used in modern gyms, physiotherapy clinics and rehabilitation facilities all over the world.

Vibration is an oscillatory movement or a movement in one direction and back in opposite direction. In the modern environment, vibration can occur in several circumstances such as motorized vehicles or industrial machines that produce different wave forms (Figure 1.1). The commercial WBV machine generates deterministic sinusoidal wave forms (Jordan, et al., 2005), the intensity of which, can be determined by frequency, amplitude and acceleration (Figure 1.2). Frequency is the number of cycles per unit time (sec.) expressed in Hertz (Hz). Amplitude is the distance the vibration displaces from its negative peak to its positive peak expressed in mm. Acceleration is the rate of change of velocity over time. The units of acceleration are metres per second squared (m/s²) or gravity unit (1g = 9.81 m/s²). The frequency and amplitude are the factors that determine acceleration. Acceleration is directly proportion to net force affecting human body (From Newton’s law, force equals mass multiplied by acceleration).
Whole body vibration machines are categorized into 3 types according to type of platform movement (Pel, et al., 2009) (Figure 1.3). The most popular type is vertical vibration, in which the platform moves up and down. This type also includes the machines that move in tri-dimension (X, Y and Z axis). Commercial machines in this category include, Power Plate®, Nemes®, Vibra Pro®, Vibrafit®, FitVibe®, Pneu-Vibe®, Vibrogym®, Soloflex®, Body-Pulse®, Juvent 1000® (Cochrane, 2011b). The second type is oscillating vibration, tilting a
platform on mid-axis similar to a seesaw movement (e.g. Galileo® machine) (Cochrane, 2011b). The last type is called elliptical, in which the platform moves in an oval motion along the horizontal plane such as the Power Maxx® machine (Pel, et al., 2009). Madou & Cronin (2008) suggested the type of platform movement may be a factor when considering the effect of such training on the human body (Madou & Cronin, 2008).

Figure 1.3 Types of platform movement

**Vibration parameters**

**Frequency**

Application of WBV to muscle or tendon can stimulate a tonic vibration reflex (Cardinale & Bosco, 2003) (Figure 1.4). The frequency of vibration is positively correlated with the tonic vibration reflex which acts to enhance motor unit synchronization (Jordan et al., 2005; Martin and Park, 1997). However, very high frequency of WBV (>150 Hz) can reduce motor unit synchronization (Martin & Park, 1997). Cardinale & Lim (2003) found WBV at frequency 30,
40 and 50 Hz produced electromyography responses of vastus lateralis muscle higher than control (no vibration), and frequency at 30 Hz generated the greatest response (Cardinale & Lim, 2003b) suggesting that this frequency caused the greatest muscle synchronisation. Da silva et al. (2006) found that acute vibration training at 6 sets of 1 min exposure, frequency of 30 Hz, 4 mm amplitude increased countermovement jump height and leg power (4.56% and 4.57%) compared to 20 Hz (0.78% and 1.47%) and 40 Hz (-2.70% and 1.23%) (Da Silva, et al., 2006). A number of studies revealed the improvement of muscle power and muscle strength after WBV application at frequencies between 15 Hz to 50 Hz (Luo, et al., 2005). Issurin (2005) suggested the optimal frequency to stimulate muscle contraction was 30 Hz to 50 Hz because this range of frequency produced muscle spindle firing rates which corresponded to discharge rates of motor units during muscle contraction (Issurin, 2005). However, Cardinale and Lim (2003) showed greater effect of low frequency vibration at 20 Hz, 4 mm, 5 bouts of one min training in untrained participants increased squat jump and countermovement jump height (4.17% and 2.03%) compared to 40 Hz (-0.04% and -3.85%) (Cardinale & Lim, 2003a). While, Turner et al. (2011) revealed high frequency vibration at 40 Hz, 8-mm, 30 sec in trained men significantly increased countermovement jump height (6%) compared to 0, 30, 35 Hz (Turner, Sanderson, & Attwood, 2011). Vibration frequency may be individualised to gain maximum beneficial effect on muscle stimulation (Di Giminiani, Tihanyi, Safar, & Scrimaglio, 2009). The untrained participants may have more benefit in low frequency training while trained participants may be suitable for high frequency vibration.
Amplitude

Whole body vibration training with higher amplitude produces a greater workload for the body. Rittweger et al. (2002) showed WBV (oscillating vibration) at 26 Hz with three amplitudes (2.5, 5 and 7.5 mm) increased oxygen uptake (17.8%, 44.9% and 100.6%) compared to baseline, and the levels of oxygen uptake correlated to the levels of vibration amplitude (Rittweger, et al., 2002). Marin et al. (2009) showed WBV at 30 Hz induced more electromyographic activity of lower limbs muscles with an amplitude of 4 mm (62.7% for vastus lateralis muscle and 130% for gastrocnemius medialis muscle) compared to 2 mm (27.2% and 74.8%) (Marin, et al., 2009). Adams et al. (2009) studied acute effect of vertical WBV for 45 sec on countermovement jump peak power, and revealed the effect of amplitude is associated with frequency to produce the greatest effect. Vibration training should be applied with a high amplitude (4-6 mm) with a high frequency (50 Hz), or a low amplitude (2-4 mm) with a low frequency (30 Hz) (Adams, et al., 2009). Petit et al. (2010) found the vertical WBV training (10 min per session, 6 weeks duration) with high frequency (50 Hz) and high amplitude (4 mm) was the most effective to significantly increase knee extensor eccentric voluntary torque (16.3%), knee flexor isometric voluntary torque (13.2%) and countermovement jump performance (4.8%), compared to low frequency (30 Hz) and low amplitude (2 mm) (Petit, et al., 2010). From the previous studies, it seems that vertical WBV training with high frequency and high amplitude should be recommended for effective muscle strength and performance improvement in both acute and regular training scenarios (Petit, et al., 2010).

Acceleration

Acceleration is proportional to the applied force that is related to changing of vibration frequency and amplitude. The effect of different accelerations of WBV has mostly been reported on the effect of different frequencies and amplitudes. Bazett-Jones et al. (2008) compared five accelerations 1 g (0 Hz, 0 mm), 2.16 g (30 Hz, 2-4 mm), 2.80 g (40 Hz, 2-4 mm), 4.87 g (35 Hz, 4-6 mm), and 5.83g (50 Hz, 4-6 mm) measured by an accelerometer at the vibration platform) of 45 sec vertical WBV and found that the women performed higher counter movement jumps following the 2.80 g (9.0%) and 5.83 g (8.3%) compared to the control at 1 g (-6.7%) (Bazett-Jones, Finch, & Dugan, 2008). Acceleration of WBV may depend on body weight, type of machine, and distance from platform. Pel et al. (2009) found the highest vertical acceleration measured was from the oscillating movement machine (Galileo®,) followed by vertical movement machine (Power Plate®) and horizontal movement machine (Power Maxx®) (Pel, et al., 2009). Pollock et al. (2010) revealed the acceleration
progressively decreased with increased distance from the vibration platform (Pollock, Woledge, Mills, Martin, & Newham, 2010). Therefore it is important to standardise foot placement during WBV training.

Duration
Different durations or vibration exposure times may produce different effects on human body. A common use vibration exposure time suggested by Bosco’s was 10 repeats of 1 min interspersed with 1 min rest (Bosco, et al., 2000). Adams et al. (2009) found vibration time exposure at 30, 45, and 60 seconds had no different impact on acute effect of WBV (30,40,50 Hz and 2-4, 4-6 mm amplitude) on vertical jump peak power (Adams, et al., 2009). Luo et al. (2005) suggested that in acute studies, short duration vibration enhanced neuromuscular function, whereas long duration exposure produced muscle fatigue and decreased neuromuscular performance (Luo, et al., 2005). Stewart et al. (2009) found acute WBV (26 Hz, 4 mm amplitude) 2 min exposure increased isometric knee extensor strength (3.8%), while 4 and 6 min exposure decreased isometric knee extensor strength measured after the next day (Stewart, Cochrane, & Morton, 2009). Cochrane (2001) suggested intermittent WBV protocol was more beneficial than continuous training. WBV for more than 1 min vibration exposure is expected to improve muscle strength and power, and may have greater risk of injury if combined with high acceleration (Cochrane, 2011b).

Posture
Different postures of training or squat positions may have various effects on muscle stimulation. Roelants et al.(2006) found that during WBV training (35 Hz, 2.5 mm), the electromyographic activity of lower limb muscles during a high squat (knee angle 125°, hip angle 140°) increased 115.1% for rectus femoris,102.0% for vastus medialis and 92.5% for vastus lateralis and 301.3% for gastrocnemius muscles greater than during a low squat (knee angle 90°, hip angle 90°), 49.1% for rectus femoris, 59.0% for vastus medialis and 51.7% , for vastus lateralis and 134.1% for gastrocnemius muscles (Roelants, Verschueren, Delecluse, Levin, & Stijnen, 2006). Abercromby et al. (2007) reported electromyographic activity of leg muscles during vertical vibration during a static squat (knee flexion18.5°) increased 77% for vastus lateralis, 9% for biceps femoris, 151% for gastrocnemius and 223% for tibialis anterior muscles greater than during dynamic squatting (knee flexion 10-35°), 0% for vastus lateralis, 0% for biceps femoris, 34% for gastrocnemius and 145% for tibialis anterior muscles. These authors also found increased electromyographic activity of vastus lateralis, gastrocnemius and tibialis anterior was greater during small knee flexion angles (10-15°) and smaller in large
knee flexion angles (31-35°) in dynamic squat (Abercromby, et al., 2007a). It seems that the ideal position of WBV for the most effective muscle contraction stimulation is a static squat with a small knee flexion angle. However, too small knee angle flexion may produce larger vibration transmission to trunk and head causing vertigo and discomfort. A knee flexion angle between 26°-30° reduced head acceleration by about 50 % compared to a knee flexion angle 10°-15° (Abercromby, et al., 2007b).

Contraindications
Whole body vibration training is not recommended for pregnancy, epilepsy, headache, blurred vision or serious ocular disease, acute hernia, discopathy, hip and knee implants and individuals with pacemakers. Pregnancy is considered as a contraindication because it has been studied that vibration exposure may cause the reduction of uterine blood flow, menstrual disturbances, and abnormal pregnancy such as abortions or stillbirths (Penkov, 2007). Epilepsy is also considered as contraindication for WBV training. The potential serious injury from falling may happen if a WBV trainee has a seizure during standing on the platform, however, there is no research in this case (T-ZoneVibration, 2012a). The hip and knee implants and individuals with pacemaker have been concerned that the vibration may cause migration of the implants and pacemaker (T-ZoneVibration, 2012b). Vibration exposure may cause vertebral discopathy by increasing internal pressure, increasing anteroposterior shear flexibility, and decreasing resistance to buckling instability (Wilder, 1993). Vibration in individuals with vertebral disc disorder should be prohibited. Severe headache and blurred vision or serious ocular diseases should be careful that the trainee probably fall down during WBV training and has subsequent serious injury (Moseley & Griffin, 1986; Vibrogym, 2012). Recent fracture and wound should be considered for developing non-union fracture and non-healing wound after WBV training (Vibrogym, 2012). Other contraindication such as intraocular lens implantation, a symptomatic renal stone should be considered. There is report of 2 cases of intraocular lens (IOL) dislocation after WBV training (Vela, Andreu, Diaz-Cascajosa, & Buil, 2010). Also, there is a report of case with significant morbidity in an asymptomatic nephrolithiasis patients after one session of WBV training (Monteleone, De Lorenzo, Sgroi, De Angelis, & Di Renzo, 2007).

Whole body vibration and conventional exercise
The beneficial effect of whole body vibration to improve muscle strength and performance compared to conventional exercise has been studied. Delecluse et al. (2003) suggested WBV and resistive exercise improved both isometric and dynamic knee extensor strength but only
WBV improved countermovement jump height by 7.6% compared to control group (Delecluse, et al., 2003). Roelant et al. (2004) and Bogaerts et al. (2007) showed WBV and resistive exercise improved both isometric, dynamic knee extensor strength and countermovement jump height but there was no statistical significant different between two groups (Bogaerts, et al., 2007; Roelants, Delecluse, & Verschueren, 2004). Raimundo et al. (2009) revealed WBV significantly improved vertical jump height effectively more than aerobic exercise (walking) by 7% while walking improved time of 4-m walking and chair rise test more than WBV (Raimundo, Gusi, & Tomas-Carus, 2009). It is possible that WBV may generate muscular adaptation similar to resistive exercise (Delecluse, et al., 2003; Roelants, Delecluse, & Verschueren, 2004). WBV may stimulate stretch reflex and Ia afferent input during a stretch-shortening contraction that which may produce greater effect on countermovement jump (Delecluse, et al., 2003; Roelants, Delecluse, & Verschueren, 2004).

**Health effect of whole body vibration**

Whole body vibration generates high acceleration or increases gravity-related load impacting on musculoskeletal system, which causes greater musculoskeletal adaptation (Cardinale & Bosco, 2003; Wilcock, Whatman, Harris, & Keogh, 2009). Application of vibration on muscle or tendon machinery enhances the tonic vibration reflex which stimulates reflex muscle contraction (Cardinale & Bosco, 2003). Vibration stimulates the primary endings of the muscle spindles (Ia afferents) leading to activation of alpha motor neurons (Cardinale & Bosco, 2003; Jordan, et al., 2005). Vibration activates this reflex response by monosynaptic and polysynaptic pathways (Burke & Schiller, 1976; Jordan, et al., 2005). The application of vibration is likely to enhance electromyographic activity of the muscle which usually indicates synchronization improvement of motor units (Bosco, et al., 1999; Delecluse, et al., 2003), and increased motor unit firing frequency (Cochrane, 2011a; Griffin, Garland, Ivanova, & Gossen, 2001) leading to an increase in muscle strength and power. Vibration also stimulates gamma nerves to enhance the sensitivity of primary nerve ending to vibration (Anastasijevic & Vuco, 1972; Cardinale & Bosco, 2003) which may recruit previous inactive muscle fibres into active contraction (Cochrane, 2011a). The long term effect WBV training is similar to resistance exercise producing neurological adaptation that enhances motor unit firing, motor unit synchronization, synergist muscle contraction, antagonist muscle inhibition and adaptation of the reflex response (Bosco, et al., 2000; Torvinen, Kannus, Sievanen, et al., 2002). Increasing muscle mass or muscle hypertrophy after vibration has been reported from experiments in mice (Xie, Rubin, & Judex, 2008). However, there is currently no comparative study on changes in human muscle characteristics (Rittweger, 2010).
A number of studies have been conducted with a variety of methods, vibration protocols and measurements with the aim to improve muscle power and strength. For example, WBV (44 Hz, 30 m.s\(^{-2}\) in acceleration) increased maximal isometric force by 4.9-8.3% (Liebermann & Issurin, 1997) and maximal power during elbow flexion improved 7.9-10.4% (Issurin & Tenenbaum, 1999). WBV (15-30Hz, 4 mm) increased isometric extension strength of lower limbs by 3.2 % and countermovement jump height by 2.5% (Torvinen, Kannus, Sievanen, et al., 2002) (Torvinen, Kannus, SievaÈnen, et al., 2002). Chronic or regular training (WBV, 35-40Hz, 2.5-5.0 mm) for 24 weeks induced increases in isometric and isokinetic of knee extension strength (from 5.9 to 24.4%) (Roelants, Delecluse, Goris, & Verschueren, 2004). Regular WBV training (25-40 Hz, 2.0 mm) for 16 weeks increased countermovement jump height 8.5% (Torvinen, Kannus, Sievanen, et al., 2002). However, a number of studies have also reported no benefit of WBV on muscle performance both acutely (Bongiovanni, Hagbarth, & Stjernberg, 1990; Jackson & Turner, 2003) and chronically (Cochrane, Legg, & Hooker, 2004; Delecluse, Roelants, Diels, Koninckx, & Verschueren, 2005; Ruiter, Raak, Schilperoort, Hollander, & Haan, 2003).

Whole body vibration stimulates muscle contraction to also increase force loading on bone, and can lead to increased bone density. Verschueren et al. (2004) found ground reaction force that is related to skeletal bone strain increased from two times body weight at start WBV (35-40 Hz, 1.7-2.5 mm in amplitude, for 6 months) to 5 times body weight from week 3 onward (Verschueren, et al., 2004). Increasing the magnitude of strain on skeletal bone prevents bone resorption and increases bone formation (Rubin & Lanyon, 1984, 1985). Vibration training has been proposed as a means of increasing bone mass by stimulating osteoblast activity to enhance bone formation (Garman, Rubin, & Judex, 2007). Verschueren et al. (2004) showed WBV (35-40 Hz, 1.7-2.5 mm in amplitude) significantly increased bone mineral density of hip by 0.93% in postmenopausal women after 24 weeks of training (Verschueren, et al., 2004). Another study in a similar group of women reported WBV (12.6 Hz, 3 cm) improved bone mineral density of femoral neck by 4.3% after 8 months therapy (Gusi, Raimundo, & Leal, 2006).

Whole body vibration activates reflex muscle contraction, thereby stimulating muscle activity and muscle metabolic demand resulting in increased blood flow (Cardinale & Wakeling, 2005). Vibration may also increase the shearing force at the vascular endothelium, which may release endothelium- derived vasodilators such as nitric oxide and prostaglandins as a response to increased shear forces (Lythgo, et al., 2009). Both of these changes may result in
higher blood flow which can be reduced in some diseases like type II diabetes. Nakamura et al. (1995) found WBV increased tissue blood flow by vasodilatation processes via a reduction in release of vasoconstrictor substance (endothelin) (Nakamura, et al., 1995). Kerschan-Schindl et al. (2001) revealed that the mean blood flow velocity in the popliteal artery increased from 6.5 to 13.0 cm.s\(^{-1}\) after 9-min of WBV training (26 Hz, 3 mm) (Kerschan-Schindl, et al., 2001). Lythgo et al. (2009) also reported that the mean blood velocity in the common femoral artery increased five-fold after 45 second of WBV training (20-30 Hz, 4.5 mm) (Lythgo, et al., 2009). Additionally, Lohman et al. (2007) showed that 3 minutes of WBV (30 Hz, 5-6 mm) increased skin blood flow by 147% (Lohman, et al., 2007). While these acute changes may be significant, vascular adaptation after chronic use of WBV has not been investigated, particularly in people suffering from type II diabetes who regularly suffer from vascularisation problems.

Whole body vibration stimulates reflex muscle contraction leading to increased muscle blood flow and probably endoneurium blood flow. Previous studies showed vibration may have some effects on nerve conduction velocity. In a rhesus monkey animal model, one hour of 1 g WBV produced conflicting results with vibration of (a) 12 Hz causing an increase in conduction velocity of approximately 4.35% (b) 6 and 8 Hz causing a decrease of conduction velocity of approximately 5.51 and 2.45% (Floyd, et al., 1973). Another experiment in rats showed prolonged vibration (4 hour a day, 7 days vibration exposed at 43.5 Hz, 1.5 mm) produced myelin and axonal damage to peripheral nerves (Matloub, et al., 2005). The effect of WBV training on nerve conduction velocity in humans has not been studied, but if WBV increases peripheral tissue perfusion via vasodilatation process, nerve conduction velocity might also be improved or maintained.

Vibration also increases the excitatory state of neuromuscular system, and probably stimulates the endocrine system (Cardinale & Bosco, 2003). Bosco et al. (2000) proposed that the effect of WBV on hormonal response may be similar to physical exercise by increasing testosterone and growth hormone (Bosco, et al., 2000). Exercise stimulates testosterone via increasing testosterone blood concentration, adrenergic stimulation, lactate-stimulated secretion, increasing synthesis and secretion by the testes and decreasing hepatic clearance (Kraemer & Ratamess, 2005; Sutton, Coleman, Casey, & Lazarus, 1973). Exercise stimulates growth hormone secretion via neural-hormonal regulation, stimulating the hypothalamic-anterior pituitary axis from higher brain or cerebral motor cortex (Kraemer & Ratamess, 2005). Exercise induced blood acidosis or lactate is also suggested as one of mechanisms that
stimulates growth hormone release (Kraemer & Ratamess, 2005). Acute hormonal changes have been observed after WBV application whereby serum growth hormone and testosterone levels were increased by 360% and 7% respectively, while cortisol levels were decreased by 32% immediately after 10 minutes of WBV (26 Hz, 4 mm) in young adults (Bosco, et al., 2000). Another study on an elderly group (66-85 years) showed that after an acute bout of 5 minutes of WBV exercise (30 Hz, 4 mm), IGF-1 levels increased by 30% and remained for up to 2 hours after the vibration whereas the cortisol levels decreased below pre-exercise levels by 40% after 2 hours (Cardinale, Soiza, Leiper, Gibson, & Primrose, 2008). Such hormonal changes may produce positive health effects to improve muscle performance and well being.

Apart from beneficial effects of WBV, prolonged vibration exposure may cause harmful health effects. For example, hand arm vibration syndrome (Raynaud's phenomenon, numbness, tingling and pain in the hands) has been commonly found in miners who are exposed to jackleg drills for up to 3 hours a day (Wasserman, et al., 1991). Long-term occupational exposure to vibration is associated with low-back pain, early degeneration of the lumbar spine and herniated lumbar discs (Bovenzi & Hulshof, 1999). On the other hand, vibration exposure to WBV via exercise machine is quite low compared to vibration in workplaces. However, Cronin et al. (2004) reported an itching sensation in the lower limb, jaw pain, neck pain and lower limb pain following vibration (26 Hz, 6 mm, 5 min total exposure) (Cronin, et al., 2004). Additionally, Crewther et al. (2004) reported hot feet, itching in the lower limbs, vertigo and severe hip discomfort in untrained participants (Crewther, et al., 2004). Vibration enhances skin shearing forces and causes vasodilatation and erythema itching, which may be mediated by histamine release from mast cells (Rittweger, 2010). A small angle knee flex may produce higher force transmission to hip and head producing vertigo and discomfort (Abercromby, et al., 2007a; Pel, et al., 2009). Therefore the deleterious effects of WBV training need to be documented so that in our pursuit for new information, we do not put subjects at increased harm.

Study 1
Numerous studies about WBV effect on muscle performances have been conducted. However, these effects remain unclear because some studies have found positive effects whereas some studies have shown negative effects. Luo et al. (2005) reviewed 14 randomized controlled studies, and concluded that WBV may have a beneficial acute (during vibration), acute residual (immediately after WBV) and chronic (after regular WBV exercise) effect on strength and power (Luo, et al., 2005). In contrast, Nordlund and Thorstensson
(2007) reviewed 12 studies and reported that WBV had little or no effect on jump performance (Nordlund & Thorstensson, 2007). Since results are contradictory, I would like to use a meta-analysis technique to provide stronger information on the effect of WBV training and muscle jump performance. As a result of the large variations in study design and effect measurements, this study will confine the study criteria to those studies using countermovement jump (CMJ) and squat jump (SJ) as their outcome measures criteria that are important proper functioning of the human body. Additionally, study 1 will provide a stronger basis for setting vibration parameters including frequency, amplitude and duration exposure for improvement in jump height. Vibration training with proper parameters may effectively stimulate muscle contraction that may increase glucose uptake which would be beneficial for diabetic control (study 2) and increase muscle blood flow and oxygenation which would be useful for exercise recovery in athletes (study 3).

**Study 2**

Diabetes mellitus is one of the major health concerns affecting people around the world. Type II diabetes (sometimes referred to as non-insulin-dependent diabetes, or adult-onset diabetes) is the most common type (Alberti & Zimmet, 1998). Chronic complications of diabetes mellitus results in impairment and malfunction of various organs and tissues such as cardiovascular disease, diabetic retinopathy, diabetic nephropathy, and diabetic neuropathy (Alberti & Zimmet, 1998). Currently, management of diabetes consists of medication, diet control, exercise and lifestyle modification.

Whole body vibration is an innovative treatment introduced to help diabetic patients by reducing fasting blood sugar levels (FBS), glycosylated hemoglobin (HbA1c) and fasting insulin, and increasing insulin sensitivity. WBV exercise may stimulate muscle contraction and increase the ability to transport glucose into muscle cells (Baum, et al., 2007) thereby decreasing the toxic effect of high glucose loads. In healthy male subjects, plasma glucose level was reduced by 1% after 10 series of 1 min duration vibrations (30 Hz, 4 mm) (Di Loreto, et al., 2004). In type II diabetic patients fasting blood glucose was reduced by 6.3% and HbA1c decreased by approximately 3% after 12 weeks of training (30-35 Hz, 2 mm) (Baum, et al., 2007). However, the beneficial effect of WBV training on type II diabetics remains unclear as the control group also showed decreased fasting blood glucose and HbA1c. From study 1, I will have the ideal WBV training parameters from results of meta-analysis study which may provide a greater beneficial effect of WBV on HbA1c and FBS. The underlying mechanism such as changes in fasting insulin and insulin sensitivity which
have not been investigated will be evaluated in this study. In addition, WBV may increase peripheral blood flow during training (Kerschan-Schindl, et al., 2001; Lohman, et al., 2007; Lythgo, et al., 2009) leading to enhanced vasodilatation adaptation that probably improves peripheral tissue perfusion including peripheral nerve function. Adaptation of peripheral vasculature and peripheral nerves after regular WBV training that may be useful for diabetic complications has not been investigated to date. In study 2, I would like to investigate the effect of regular WBV training on on HbA1c, FBS, fasting insulin, insulin sensitivity, peripheral nerve conduction velocity and peripheral blood flow in diabetic patients.

**Study 3**

Promoting recovery after exercise is essential for athletes to improve subsequent sports performance. Several techniques to maximize the recovery process have been studied including active recovery, stretching, massage, and contrast water immersion therapy (Barnett, 2006). Vibration machine transfers vibration force from a moving platform to the human body and evidence suggests it may affect tissue blood flow which may promote performance recovery after exercise.

Whole body vibration has been proposed to increased local blood flow (Kerschan-Schindl, et al., 2001; Lohman, et al., 2007; Lythgo, et al., 2009) that may useful for promoting exercise recovery. Vibration training may enhance lactic acid and waste products elimination leading to an increased ability of the athlete to perform in subsequent exercise bouts and reduce the potential for Delayed Onset of Muscle Soreness (DOMS). Rhea et al. (2009) found the stretching group on an iTonic WBV machine (35 Hz, 2 mm) who trained twice a day for 3 days after a strenuous resistance exercise had significantly lowered perceived pain scores compared to the control group (Rhea, et al., 2009). Also, vibration training may improve flexibility that is useful for enhancing performance. Cronin et al. (2007) found that segmental vibration training improved dynamic knee joint motion by 2.1% (Cronin, et al., 2007). Issurin et al. (1994) found that vibration during stretching exercise significantly increased leg and trunk flexibility compared to conventional stretching (by 7.5% and 37.8%, respectively) (Issurin, Liebermann, & Tenenbaum, 1994). It seems that WBV training may reduce lactic acid and waste products, reduce muscle soreness and increase flexibility that may be beneficial to athletes by improving muscle and performance recovery.

There are many studies investigating the effect of WBV training on strength and power development, however, the beneficial effect of WBV at improving muscle recovery is unclear.
Edge et al. (2009) found no statistical difference in metabolic (oxygen consumption, respiratory exchange ratio, blood lactate concentration), muscle damage (creatine kinase) or performance levels (3 km time trial) after 1 day recovery from high intensity exercise training between WBV (12Hz, 6 mm, 2 sets of 15 min exposure) and a control group (Edge, et al., 2009). The WBV protocol of low frequency may not be adequate to increase muscle blood flow for enhancing muscle recovery. The results from study 1 will provide the WBV training with ideal parameters that are supposed to stimulate the greatest muscle contraction. The greater muscle stimulation may enhance greater muscle blood flow to generate a greater benefit on muscle recovery. In addition, the short term effect of WBV (1 hour after strenuous exercise) on metabolic and performance recovery has not been investigated. In study 3, I would like to investigate the short term effect of WBV during exercise recovery on lactate, muscle power, muscle strength, flexibility, rate of perceived exertion and muscle soreness. I also would like to explore possible mechanisms behind any changes in performance by monitoring muscle blood flow and muscle oxygenation during exercise recovery.
Research objectives

1. To analyse the current evidence for the effectiveness of WBV on jump height by meta-analysis method.

2. To evaluate the effect of WBV on FBS, HbA1c, insulin levels, insulin sensitivity, peripheral vascular blood flow, peripheral nerve conduction velocity in type II diabetic patients.

3. To evaluate the effect of a WBV program on recovery of lactate, muscle power, muscle strength, flexibility, rate of perceived exertion, muscle soreness and muscle oxygenation compared to a traditional active recovery program.
Originality of the thesis

1. Study 1 is the first study to complete a meta-analysis on the effects of WBV on jump height compared to no exercise and cardiovascular-type exercise controls.
2. No study to date has provided meta-analysis data that is useful for adjusting the vibration protocols for muscle strength and power training enhancement.
3. Study 2 is the first study to compare the effects of regular WBV on fasting blood sugar, HbA1c, insulin level and insulin sensitivity in type II diabetics in a randomized controlled trial.
4. No other study has investigated the effect of regular WBV training on peripheral vascular adaptation in type II diabetics.
5. No other study has investigated the effect of regular WBV training on nerve conduction velocity in type II diabetics.
6. Study 3 is the first study to compare the recovery effect of WBV to a traditional active recovery program on blood lactate, power, strength, fatigue and pain.
7. No study to date has monitored muscle oxygenation using near-infrared spectroscopy (NIRS) levels on active tissue to uncover potential mechanism behind WBV recovery program.
Conferences

Chapter 2 was presented at the American College of Sport Medicine 57th annual meeting at Baltimore Maryland USA during 1-5 June 2010 and a Postgraduate conference 2010 at Lincoln University New Zealand 2-3 September 2010.
Chapter 2

Effect of whole body vibration training on jump height:
meta-analysis

2.1 Abstract

Whole body vibration (WBV) is a new tool widely promoted by some as a means of improving muscle strength, but the evidence of a performance benefit is unclear with some reporting improvements and others finding none. The objective of this study is to analyse the current evidence for the effectiveness of WBV on jump height. MEDLINE, Web of Knowledge, Sciedirect, Proquest, Scopus, Google Scholar and SPORTDiscus databases were searched for studies to be included in the analysis. To be included, the studies had to have been randomized controlled trials or matched design studies comparing the effect of WBV training on countermovement and squat jump height. The standardised mean difference (SMD) was calculated and combined with a random effects model using the RevMan5 statistical program. The overall effect of WBV training (from the 14 studies included) compared to having no additional exercise on countermovement jump height yielded a positive standardised mean difference of 0.82 (95% confidence interval 0.56-1.09). The effect of WBV training on squat jump height was 0.68 (0.08-1.11). Vibration exercise consisting of a higher frequency (>30 Hz, 0.97, 0.66-1.28), higher amplitude (> 3 mm, 0.84, 0.48-1.19), longer exposure duration (> 10 min/session, 0.92, 0.48-1.36), longer training period (>12 weeks, 1.05, 0.64-1.46) and among non athletes (1.12, 0.74-1.50) had greater benefit for jump height improvement than a lower frequency (≤ 30 Hz, 0.56, 0.13-0.99), lower amplitude (≤ 3 mm, 0.79, 0.34-1.24), shorter exposure duration (≤ 10 min/session, 0.75, 0.42-1.08), intermediate training period (4-12 weeks, 0.70, 0.29-1.11), shorter training period (< 4 weeks, 0.58,-0.08-1.23) and in athletes (0.56, 0.26-0.86). The effect of WBV training compared to a standard cardiovascular-type exercise group from 4 studies was 0.63 (0.10-1.15). In conclusion, WBV training produces a moderate to large effect on jump height. Vibration training protocols with higher frequencies, higher amplitudes, longer exposures per session and longer training periods are more likely to enhance lower limb muscle power.

Keywords
Whole body vibration, meta-analysis, muscle strength, jump height
2.2 Introduction

Whole body vibration (WBV) is an oscillatory training protocol widely promoted in commercial gyms as a means of improving strength and losing weight. Over 47 years ago such training was first introduced by a Russian sport scientist, Dr Vladimir Nazarov, who used it to prevent bone and muscle loss in astronauts during spaceflight (O’Sullivan, 2007). Recent research suggests WBV training not only affects muscle and bone but also the endocrine, vascular and neural systems (Prisby, et al., 2008).

The effects of WBV training on muscle power and strength are unclear with contradictory results to date. Luo et al. (2005) reviewed 14 randomized controlled studies and concluded that WBV may have a respective: (a) acute (during vibration) (b) acute residual (immediately after WBV), and (c) chronic (after regular vibration exercise up to 3 weeks later) beneficial effect on strength and power (Luo, et al., 2005). Similarly, Rehn et al. (2007) found moderate to strong evidence for performance improvement after long-term WBV training (up to 9 days later) but no clear evidence after short-term vibration exercise (immediately after WBV) (Rehn, Lidstrom, Skoglund, & Lindstrom, 2007). Nordlund and Thorstensson (2007) reviewed 12 studies and reported that WBV had greater improvement on strength and/or jump performance compared to a passive control group (no extra exercise), and had little or no effect on strength and/or jump performance compared to control group performing the same exercise (Nordlund & Thorstensson, 2007). Wilcock et al. (2009) analysed the effect size of WBV on countermovement jump height compared to control group (no additional exercise), and reported a small beneficial effect on explosive power in trained athletes (effect size = 0.24-0.39) in studies of 5-8 weeks training (Wilcock, et al., 2009).

The muscle strength and countermovement jump height were improved after WBV training with various vibration parameters. The proper frequency was proposed by comparison studies of difference frequencies with the same amplitude and duration, however, the optimal frequency for WBV training was not found. At a frequency of 20 Hz, 4 mm amplitude, participants increased squat jump and countermovement jump height (4.17% and 2.03%) compared to 40 Hz (-0.04% and -3.85%) (Cardinale & Lim, 2003a). In another study WBV with frequency of 30 Hz, 4 mm amplitude produced higher countermovement jump height and leg power (4.56% and 4.57%) compared to 20 Hz (0.78% and 1.47%) and 40 Hz ( -2.70% and 1.23% ) (Da Silva, et al., 2006). A frequency of 40 Hz, 8-mm, 30 sec in trained men
significantly increased countermovement jump height (6%) compared to 0, 30, 35 Hz (Turner, et al., 2011).

In addition to different frequencies different amplitudes of WBV may cause different effects on muscle strength and power. WBV with an amplitude of 4 mm (30 Hz) induced more electromyographic activity of vastus lateralis muscle and gastrocnemius medialis muscle (62.7% and 130%) compared to 2 mm with the same frequency (27.2% and 74.8%) (Marin, et al., 2009). There may also be an interaction effect between vibration frequency and amplitude. Adams et al. (2009) suggested WBV should be applied with a high amplitude with a high frequency (4-6 mm and 50 Hz), or a low amplitude with a low frequency (2-4 mm and 30 Hz) (Adams, et al., 2009). Acceleration which is proportional to the applied force and is related to changes in vibration frequency and amplitude is also important. Petit et al. (2010) found vertical WBV training with high acceleration (high frequency and high amplitude) was the most effective at increasing muscle strength and jump height, compared to low acceleration (low frequency and low amplitude) (Petit, et al., 2010). Bazett-Jones et al. (2008) compared five accelerations of 45 sec vertical WBV (1 g, 2.16 g, 2.80 g, 4.87 g, and 5.83 g) and found that the women participants performed higher counter movement jumps following the 2.80 g (9.0%) and 5.83 g (8.3%) compared to the control at 1 g (-6.7%) (Bazett-Jones, et al., 2008).

For biological adaptation to improve muscle strength and power, the duration of vibration is important. WBV training with 10 sets of 1 min interspersed with 1 min rest is a common protocol suggested by Bosco (Bosco, et al., 2000). Cochrane (2001) suggested intermittent WBV protocol was more favourable than continuous training. WBV for more than 1 min vibration exposure is expected to improve muscle strength and power, but may have greater risk of injury if combined with high acceleration (Cochrane, 2011b). Previous studies showed the duration of WBV training for effective muscular strength and power improvement ranged from 3- 30 min per session and 3 to 32 week for training duration (Luo, et al., 2005; Rehn, et al., 2007). However, there has been no research which has investigated the effect of different training durations (while keeping vibration frequency and amplitudes the same) to uncover what the most ideal training duration should be.

To date, there has been no meta-analytical study completed which provides an overall statistical assessment of the effects of WBV on muscle strength and power. The lack of such a study is possibly due to the large variations in study design and measures of effects and/or
outcomes. To overcome such limitations, the current study has limited the study criteria to those studies using countermovement jump (CMJ) and squat jump (SJ) as their performance measure. Such measures have high test-retest reliability (0.98 and 0.97 for CMJ and SJ, respectively) (Markovic, Dizdar, Jukic, & Cardinale, 2004) and high validity with explosive power factor measured via principal component factor analysis of various jump tests (r = 0.87 and 0.81) (Markovic, et al., 2004). The aim of this study therefore, was to analyse the current evidence for a beneficial effect of WBV training on jump height (either via CMJ or SJ) by meta-analysing all appropriate studies to date. It also aims to identify the vibration parameters that are more effective at increasing jump height.

2.3 Methods

Identification of studies
Whole body vibration articles were searched from MEDLINE, Web of Knowledge, Sciencedirect, Proquest, Scopus, Google Scholar and SPORTDiscus databases using the keywords: whole body vibration, vibration platform, randomized controlled trials, muscle strength, muscle performance and jump height.

Inclusion criteria
All randomized controlled trials or matched design studies in humans were included in this study. The participants in the studies were between 17-80 years of age. The study design had to be long-term WBV training (regular training) compared with having no additional exercise (the control) or additional exercise (cardiovascular or cardiovascular with resistance exercise). The outcomes of interest were CMJ height or SJ height. We excluded studies on the acute effect of WBV training (effects immediately after WBV) and the effect of WBV training combined with extra exercises.

Studies found but not included in the meta-analysis were for the following reasons: non English article (Bosco, et al., 2001), non typical vertical jump test (Wyon, Guinan, & Hawkey, 2010), and vibration combined with exercise (Fernandez-Rio, Terrados, Fernandez-Garcia, & Suman, 2010; Kvorning, Bagger, Caserotti, & Madsen, 2006; Lamont, et al., 2008, 2009; Osawa & Oguma, 2011; Roelants, Delecluse, & Verschueren, 2004).
Quality assessment

The methodological quality of assessment was evaluated using the Jadad scale (Jadad, et al., 1996). The score ranges from 1 to 5 (very poor, poor, fair, good and excellent), and is based on the use of randomization and blinding and the dropout rates. The Jadad score of the included studies ranged from 1-3 points (very poor to fair). The characteristics of each study are described in Table 2.1.

Data extraction and analysis

Since jump height is a continuous variable, the standardised mean difference (SMD) was used to estimate the effect size of each study. To calculate the SMD, the mean difference and standard deviation (SD) of difference were extracted from the intervention and the control groups of the included articles. In the event of any missing data, the original authors were contacted and the data requested. If there was no response from the authors, the Cochrane Handbook for systematic review interventions was used as the guideline for analysis (Higgins & Green, 2009). If the SD was missing, the SD was calculated from the standard error, confidence interval or p-value, whichever was available. If the statistical values were not provided, the SD was calculated from the difference of the SD of the raw pre and post baseline data. If the mean and SD difference were presented by line or bar graphs, the mean and SD were estimated by measuring values from the graphs directly. The SMD was then calculated from the formula: the mean difference of WBV group - the mean difference of control group) / pooled SD of the difference of the WBV and control groups. The SMD of all studies were combined with a random effects model (inverse variance method) considered both within-study and between-study variance, more conservative than fixed effects (Laird & Mosteller, 1990). The SMD was calculated by using the RevMan5 statistical program known as Hedge's adjusted $g$ (Higgins & Green, 2009). According to Cohen’s effect size, a SMD value of less than 0.25 is considered trivial, 0.25-0.5 small effect, 0.5-0.8 moderate effect and greater than 0.8 large effect (Cohen, 1992). The possible publication bias was evaluated by funnel plots and the trim and fill procedure to assess the potential missing studies. A factor analysis was conducted on the effect of WBV compared with no exercise group on CMJ height. Factor analyses of WBV compared with no exercise group on SJ height and WBV compared with normal exercise were not performed because of the insufficient number of studies.
2.4 Results

The included studies were subdivided into studies that compared WBV with control groups that did or did not allow additional exercise.

Whole body vibration vs. Control (no exercise)
A total of 14 studies were used in the analysis of the effects of WBV on CMJ height (Annino, et al., 2007; Bogaerts, et al., 2007; Bosco, et al., 1998; Cochrane, et al., 2004; Colson, Pensini, Espinosa, Garrandes, & Legros, 2010; de Ruiter, Van Raak, Schilperoort, Hollander, & de Haan, 2003; Delecluse, et al., 2005; Delecluse, et al., 2003; Di Giminiani, et al., 2009; Fagnani, Giombini, Di Cesare, Pigozzi, & Di Salvo, 2006; Paradisis & Zacharogiannis, 2007; Roelants, Delecluse, & Verschueren, 2004; Torvinen, Kannus, Sievanen, et al., 2002; Torvinen, et al., 2003). A full description of the study characteristics is shown in Table 2.1 and 2.2. Apart from Delecluse et al. (2003), who had control subjects train on a stationary (placebo) vibration machine, all control groups were asked to maintain their conventional lifestyle (Delecluse, et al., 2003). The WBV training protocol for most studies was multi-positional (e.g., subjects were asked to move to different positions on the vibration platform during WBV) progressively-loaded (i.e., duration of WBV increased during the study). Only one study asked subjects to train on the platform in a stationary position for the duration of the study (Di Giminiani, et al., 2009). The overall effect of WBV training without any additional exercise on CMJ height was a positive SMD of 0.82 (95% confident interval 0.56-1.09, p value < 0.001) compared to controls (Table 2.3). There was no heterogeneity between studies ($\tau^2 = 0.10$, $\chi^2 = 21.24$, df $=13$ (p=0.07); $I^2 = 39\%$). The forest plot of CMJ height in WBV and non-exercise controls is presented in Figure 2.1. Examination of the funnel plot of SMD and standard error showed that no publication bias was detected (Figure 2.4). The trim and fill analysis showed no evidence of any potential missing studies.

Factors effecting CMJ performance are shown in Table 2.4. WBV produced greater results in non-athletes (1.12, 0.74-1.50; SMD, 95% CI) compared to athletes (0.56, 0.26-0.86). In addition, longer WBV training periods produced greater effect sizes (>12 weeks, 1.05, 0.64-1.46) compared to intermediate (4-12 weeks, 0.70, 0.29-1.11) or shorter training periods (<4 weeks, 0.58, 0.08-1.23). Whole body vibration training, consisting of higher frequency (>30 Hz, 0.97, 0.66-1.28), higher amplitude (>3mm, 0.84, 0.48-1.19) and longer durations (>10 min per session, 0.92, 0.48-1.36), had a greater benefit for CMJ height than lower frequency (≤30 Hz, 0.56, 0.13-0.99), lower amplitude (≤3mm, 0.79, 0.34-1.24), or shorter...
durations (≤ 10 min per sessions 0.75, 0.42- 1.08) (Table 2.4). There was no statistically significant heterogeneity in the analysis of each contributing factor (p > 0.05).

As with CMJ performance, the overall effect of WBV training on SJ performance compared to controls without any additional exercise was a positive SMD of 0.68 (0.08-1.11, p=0.02) (Table 2.5). There was no significant heterogeneity in this analysis (\(\tau^2 = 0.00; \chi^2 = 0.45, df = 2 (p = 0.80); I^2 = 0\%\)). The forest plot of SJ height in WBV and non-exercise controls is presented in Figure 2.2.

**Whole body vibration vs. Exercise**

A total of 4 studies compared WBV training with normal exercise on CMJ performance (Table 2.6). Three of the four studies, from the 13 previously analysed (on whole body vibration vs. non exercise), had 3 comparison groups; that is, whole body vibration, exercise, and controls (no exercise) (Bogaerts, et al., 2007; Delecluse, et al., 2003; Roelants, Delecluse, & Verschueren, 2004). The fourth study had 2 groups: whole body vibration and exercise (Raimundo, et al., 2009). Exercise protocols comprised of cardiovascular and resistive training in 3 studies (Bogaerts, et al., 2007; Delecluse, et al., 2003; Roelants, Delecluse, & Verschueren, 2004) and a walking program in another (Raimundo, et al., 2009). Using WBV training compared to a normal exercise program produced a moderate beneficial effect (SMD = 0.63, 0.10-1.15, p = 0.02). There was no significant heterogeneity detected in the analysis (\(\tau^2 = 0.17; \chi^2 = 7.58 df = 3 (P = 0.06); I^2 = 60\%\)). The forest plot of CMJ height in WBV and exercise controls is presented in Figure 2.3.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Sex/Age</th>
<th>Design</th>
<th>Parameter</th>
<th>Device</th>
<th>Characteristic</th>
<th>Assessment</th>
<th>Jadad score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV =11</td>
<td>WBV=21.0 yr</td>
<td>8 weeks</td>
<td>A=5 cm</td>
<td>(Bosco system)</td>
<td>CON=Continue training ballet</td>
<td>2. Knee extensor performance leg press exercise (force, power and average velocity)</td>
<td>Blind = 0</td>
</tr>
<tr>
<td></td>
<td>CON= 11</td>
<td>CON=21.2 yr</td>
<td>3 times/week</td>
<td>Ac=5g</td>
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<td>Withdraw = 1</td>
<td>Total =2</td>
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<td></td>
<td>Drop out =0</td>
<td></td>
<td>Vibration exposure</td>
<td>D= 40 sec/position</td>
<td>Vertical sinusoid</td>
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<td>Total =2</td>
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<td>3.5 min/session</td>
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<td></td>
<td>WBV= 25</td>
<td>WBV = 66.9 yr</td>
<td>47 weeks</td>
<td>A=2.5-5 mm</td>
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<td>CON= No lifestyle change</td>
<td>2. Isometric knee extensor strength</td>
<td>Blind = 0</td>
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<tr>
<td></td>
<td>EX = 25</td>
<td>EX = 67.6 yr</td>
<td>3 times/wk</td>
<td>D=30-60 sec/ position</td>
<td>Progressive training</td>
<td>EX= 1.5 hour cardiovascular (walking, running, cycling or stepping at 70-80% of maximum heart rate reserve), resistance (leg press and leg extension 1-2 sets with 8-15 RM), balance and stretching exercise, 3 times a week</td>
<td>3. Muscle mass</td>
<td>Withdraw = 1</td>
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<tr>
<td></td>
<td>CON = 32</td>
<td>CON = 68.6 yr</td>
<td>Vibration exposure</td>
<td></td>
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<td>Total =2</td>
<td>Total =2</td>
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<td></td>
<td>Drop out= 13</td>
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<td>2-15 min/session</td>
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<td></td>
<td>WBV=7</td>
<td>WBV=20.4 yr</td>
<td>10 days everyday</td>
<td>A=10 mm</td>
<td></td>
<td>CON= Maintain physical activities</td>
<td>2. Continuous jumping for 5 seconds</td>
<td>Blind = 0</td>
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<tr>
<td></td>
<td>CON = 7</td>
<td>CON=19.9 yr</td>
<td>Vibration exposure</td>
<td>Ac= 54 m/s² (5.59g)</td>
<td>Vertical Sinusoidal</td>
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<td>Withdraw = 1</td>
<td>Total =2</td>
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<td></td>
<td>Drop out = 0</td>
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<td>7.5 -10 min/session</td>
<td>D= 90-120 sec/position</td>
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<td>Total =2</td>
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<tr>
<td>Cochrane (2004)</td>
<td>Sport science students</td>
<td>Male =16</td>
<td>RCT</td>
<td>F=26 Hz</td>
<td>Galileo 2000</td>
<td>WBV= Standing upright, 2 squats, one leg standing (both) exercises</td>
<td>1. Countermovement jump height</td>
<td>Random =1</td>
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<tr>
<td></td>
<td>WBV=12</td>
<td>Female =8</td>
<td>9 days</td>
<td>A=11 mm</td>
<td></td>
<td>CON= Standing on floor, performing the same position</td>
<td>2. Squat jump</td>
<td>Blind = 0</td>
</tr>
<tr>
<td></td>
<td>Control =12</td>
<td>Age both group=23.9 yr</td>
<td>Vibration exposure</td>
<td>D= 2 min/position</td>
<td>Vertical vibration</td>
<td></td>
<td>3. Sprint test 5, 10, 20 m</td>
<td>Withdraw = 1</td>
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<td></td>
<td>Drop out =0</td>
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<td>10 min/session</td>
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<td>4. Agility test (505, up and back)</td>
<td>Total =2</td>
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<tr>
<td>Colson (2010)</td>
<td>Basketball players</td>
<td>Male =13</td>
<td>RCT</td>
<td>F=40 Hz</td>
<td>Silverplate</td>
<td>WBV= High squat and high squat with standing on toes exercises</td>
<td>1. Countermovement jump height</td>
<td>Random =1</td>
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<tr>
<td></td>
<td>WBV=10</td>
<td>Female =5</td>
<td>4 weeks</td>
<td>A=4 mm</td>
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<td>CON= Maintain basketball training</td>
<td>2. Squat jump</td>
<td>Blind = 0</td>
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<tr>
<td></td>
<td>CON=8</td>
<td>WBV=20.4 yr</td>
<td>3 times/week</td>
<td>D= 30 sec/position</td>
<td>Vertical vibration</td>
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<td>3. Drop jump</td>
<td>Withdraw = 1</td>
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<td></td>
<td>Drop out =0</td>
<td>WBV=19.3 yr</td>
<td>Vibration exposure</td>
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<td>4. 30-second rebound jump</td>
<td>Total =2</td>
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<td>10 min/session</td>
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<td>5. 10-m sprint test</td>
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<td>6. Maximal isometric strength of knee extensor</td>
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<td>Study (Year)</td>
<td>Participants</td>
<td>Treatment Details</td>
<td>Outcome Measures</td>
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<tr>
<td>Delecluse (2003)</td>
<td>Untrained female WBV=18</td>
<td>RCT 12 weeks, 3 times/wk</td>
<td>Power Plate WBV= 4 squat and lunge exercises</td>
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<td>PL =19</td>
<td>Vibration exposure 3-20 min/session</td>
<td>1. Counter movement jump height</td>
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<td></td>
<td>EX = 18</td>
<td>Progressive training Vertical sinusoidal</td>
<td>2. Isometric knee extensor strength</td>
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<td></td>
<td>CON = 12</td>
<td>Drop out =7</td>
<td>3. Dynamic knee extensor strength</td>
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<td>Only female WBV= 21.5 yr</td>
<td>4. Ballistic strength test</td>
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<td>WBV= 21.5 yr</td>
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<tr>
<td>Delecluse (2005)</td>
<td>Sprint trained athletes WBV= 10</td>
<td>RCT 5 weeks, 3 times/wk</td>
<td>Power Plate WBV= 5 squat and lunge exercises</td>
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<td></td>
<td>CON= 10</td>
<td>Vibration exposure 9-18 min/session</td>
<td>1. Counter movement jump height</td>
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<td></td>
<td>Drop out =5</td>
<td>Progressive training</td>
<td>2. Isometric knee flexor/extensor strength</td>
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<td>Male =13 Female =7 Age 17-30 yr</td>
<td>3. Dynamic knee flexor/extensor strength</td>
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<td>WBV= 19.9 yr CON = 20.7 yr</td>
<td>4. Start action</td>
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<td>Matched for MVC of knee extensor</td>
<td>5. Sprint running velocity</td>
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<tr>
<td>De Ruiter (2003)</td>
<td>Physically active students WBV =9</td>
<td>RCT 11 weeks, 3 times/wk</td>
<td>Galileo 2000 WBV = squat exercise</td>
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<td></td>
<td>Control = 10</td>
<td>Vibration exposure 5-8 min/session</td>
<td>CON = Conventional exercise</td>
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<td>Progressive training</td>
<td>1. Counter movement jump height</td>
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<td>Male = 12 Female = 7 WBV = 19.9 yr</td>
<td>2. Maximal voluntary contraction force</td>
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<td>CON = 20.7 yr</td>
<td>3. Maximal force generating capacity</td>
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<td>4. Stimulated maximal rates of electrically</td>
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<td>Control =23.63 yr</td>
<td>RCT 8 week, 3 times/wk</td>
<td>5. Voluntary maximal rate of force rise</td>
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<td>Vibration exposure 1.5-6 min/session</td>
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<td>Vibration exposure 1.5-6 min/session</td>
<td>Progressive training Vertical sinusoidal</td>
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<td></td>
<td>Only female WBV= 24 yr</td>
<td>Nemes-LCB-040 WBV= 2 squat exercises</td>
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<td></td>
<td></td>
<td>RCT 8 week, 3 times/wk</td>
<td>CON= Continue sport training</td>
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<td></td>
<td>Vibration exposure 10 min/session</td>
<td>1. Countermovement jump</td>
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<td></td>
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<td>2. Isokinetic leg press (force and work)</td>
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<td></td>
<td>RCT 8 week, 3 times/wk</td>
<td>3. Flexibility test (sit to reach test)</td>
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<td>Vibration exposure 10 min/session</td>
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<td></td>
<td>RCT 8 week, 3 times/wk</td>
<td>F=30 Hz (fix) A=2 mm Ac=0.1-5.5 g</td>
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<td>Vibration exposure 10 min/session</td>
<td>Progressive training Vertical sinusoidal</td>
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<td></td>
<td>Only female WBV= 24 yr</td>
<td>Nemes-Lsb Bosco-system WBV= Stand on knee angle 90 degree</td>
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<td>Individual= Frequency was set individually for each person</td>
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<td>Only female WBV= 24 yr</td>
<td>CON= Stand on platform (no vibration)</td>
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<td>F=20-45 Hz (individual ) A=2 mm</td>
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<td>Vibration exposure 10 min/session</td>
<td>Individual= Frequency was set individually for each person</td>
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<td>Only female WBV= 24 yr</td>
<td>CON= Stand on platform (no vibration)</td>
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<td>Vibration exposure 1.5-6 min/session</td>
<td>Progressive training Vertical sinusoidal</td>
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<td></td>
<td></td>
<td>RCT 8 week, 3 times/wk</td>
<td>CON= Continue sport training</td>
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<td></td>
<td></td>
<td>Vibration exposure 10 min/session</td>
<td>1. Countermovement jump</td>
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<td>Only female WBV= 24 yr</td>
<td>2. Isokinetic leg press (force and work)</td>
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<td>RCT 8 week, 3 times/wk</td>
<td>3. Flexibility test (sit to reach test)</td>
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<td>F=30 Hz (fix) A=2 mm Ac=0.1-5.5 g</td>
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<td>Nemes-Lsb Bosco-system WBV= Stand on knee angle 90 degree</td>
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<td>Individual= Frequency was set individually for each person</td>
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<td></td>
<td>Only female WBV= 24 yr</td>
<td>CON= Stand on platform (no vibration)</td>
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<td>RCT 8 week, 3 times/wk</td>
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<td>Vibration exposure 10 min/session</td>
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<td>Only female WBV= 24 yr</td>
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<td>Study Group</td>
<td>Gender</td>
<td>Age</td>
<td>Frequency</td>
<td>Amplitude</td>
<td>Acceleration</td>
<td>Duration</td>
<td>Equipment</td>
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<tr>
<td>Paradisis (2007)</td>
<td>Active athletes in the past</td>
<td>Male =12</td>
<td>21.3 yr</td>
<td>F=30 Hz</td>
<td>A=2.5 mm</td>
<td>Ac= 2.28 g</td>
<td>D= 40-60 sec/position</td>
<td>Power Plate</td>
</tr>
<tr>
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<td>Male =12 Female =12</td>
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<tr>
<td></td>
<td>Age both group = 21.3 yr</td>
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<td>Raimundo (2009)</td>
<td>Postmenopausal women</td>
<td>Only female</td>
<td>66 yr</td>
<td>F=12.6 Hz</td>
<td>A=3 mm-6 mm</td>
<td>D= 1 min/position</td>
<td>Vertical vibration</td>
<td>Galileo 2000</td>
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<tr>
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<td>Male =12 Female =12</td>
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<tr>
<td></td>
<td>Age both group = 66 yr</td>
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<td>Roelants (2004)</td>
<td>Postmenopausal women</td>
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<td>64.9 yr</td>
<td>F=35-40 Hz</td>
<td>A=2.5-5 mm</td>
<td>Ac= 2.28-5.09 g</td>
<td>D=30-60 sec/position</td>
<td>Progressive training</td>
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<td>Male =21 Female= 35</td>
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<td>Age both group = 25.5 yr</td>
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<td>Male= 35</td>
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<td>Age both group = 25.5 yr</td>
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<td>Female= 35</td>
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<td>Age both group = 25.5 yr</td>
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</table>

**WBV=** Whole body vibration, **EX=** Exercise, **CON=** Control, **PL=** Placebo, **RCT=** randomized control trial, **F=** Frequency, **A=** Amplitude, **Ac =** Acceleration, **D=** duration, **NA=** not applicable
Table 2.2  Summary of 14 randomized controlled trial studies in WBV and non-exercise controls

<table>
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<tr>
<th>Sample size (number of subjects)</th>
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<tr>
<td>Whole body vibration</td>
<td>213</td>
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<tr>
<td>Control</td>
<td>213</td>
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<table>
<thead>
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<th>Population (number of studies)</th>
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<tbody>
<tr>
<td>Athletes</td>
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<tr>
<td>Non-athletes</td>
<td>5</td>
</tr>
<tr>
<td>Healthy adults</td>
<td>3</td>
</tr>
<tr>
<td>Postmenopausal</td>
<td>1</td>
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<tr>
<td>Elderly</td>
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<table>
<thead>
<tr>
<th>Sex (number of studies)</th>
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<tbody>
<tr>
<td>Only male</td>
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<tr>
<td>Only female</td>
<td>4</td>
</tr>
<tr>
<td>Both sexes</td>
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</tr>
<tr>
<td>Unspecified</td>
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<table>
<thead>
<tr>
<th>Age (number of studies)</th>
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<td>&lt; 30 years</td>
<td>12</td>
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<tr>
<td>&gt;60 years</td>
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</tbody>
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<th>Publication date (number of studies)</th>
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<td>&lt;2000</td>
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<td>2000-2005</td>
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<td>2006-2010</td>
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<th>Devices (number of studies)</th>
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<td>Power Plate</td>
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<td>Kuntotary</td>
<td>2</td>
</tr>
<tr>
<td>Galileo</td>
<td>4</td>
</tr>
<tr>
<td>Nemes-Lsb Bosco-system</td>
<td>2</td>
</tr>
<tr>
<td>Silverplate</td>
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</tbody>
</table>

| Duration of study                  | 9 days to 47 weeks |

Table 2.3 Meta-analysis of CMJ height in WBV and non-exercise controls

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<thead>
<tr>
<th>Studies</th>
<th>WBV Mean</th>
<th>WBV SD</th>
<th>WBV No. of subjects</th>
<th>Control Mean</th>
<th>Control SD</th>
<th>Control No. of subjects</th>
<th>SMD (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annino 2007</td>
<td>6.3</td>
<td>3.8</td>
<td>11</td>
<td>-1.1</td>
<td>4.7</td>
<td>11</td>
<td>1.67 (0.67, 2.67)</td>
</tr>
<tr>
<td>Bogaert 2007</td>
<td>10.9</td>
<td>15.3</td>
<td>25</td>
<td>1.8</td>
<td>15.6</td>
<td>32</td>
<td>0.58 (0.05, 1.11)</td>
</tr>
<tr>
<td>Bosco 1998</td>
<td>1.6</td>
<td>4.9</td>
<td>7</td>
<td>-0.3</td>
<td>3.7</td>
<td>7</td>
<td>0.41 (-0.65, 1.48)</td>
</tr>
<tr>
<td>Cochrane 2004</td>
<td>3.9</td>
<td>10.9</td>
<td>12</td>
<td>-3.3</td>
<td>9.5</td>
<td>12</td>
<td>0.68 (-0.15, 1.50)</td>
</tr>
<tr>
<td>Colson 2010</td>
<td>-1.9</td>
<td>6.3</td>
<td>10</td>
<td>-3.5</td>
<td>7.7</td>
<td>8</td>
<td>0.23 (-0.70, 1.16)</td>
</tr>
<tr>
<td>Delecluse 2003</td>
<td>7.6</td>
<td>4.3</td>
<td>18</td>
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<td>1.57 (0.73, 2.42)</td>
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<td>10.0</td>
<td>10</td>
<td>-3.6</td>
<td>9.1</td>
<td>10</td>
<td>0.68 (-0.23, 1.58)</td>
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<td>De Ruiter 2002</td>
<td>3.7</td>
<td>3.0</td>
<td>3</td>
<td>3.0</td>
<td>4.8</td>
<td>10</td>
<td>0.16 (-0.74, 1.07)</td>
</tr>
<tr>
<td>Fagnani 2006</td>
<td>9.6</td>
<td>5.7</td>
<td>13</td>
<td>3.3</td>
<td>10.0</td>
<td>11</td>
<td>0.77 (-0.07, 1.61)</td>
</tr>
<tr>
<td>Giminiani 2009</td>
<td>2.5</td>
<td>6.3</td>
<td>9</td>
<td>1.7</td>
<td>3.7</td>
<td>11</td>
<td>0.14 (-0.74, 1.02)</td>
</tr>
<tr>
<td>Paradiasis 2007</td>
<td>3.3</td>
<td>5.8</td>
<td>12</td>
<td>0.3</td>
<td>7.2</td>
<td>12</td>
<td>0.44 (-0.37, 1.25)</td>
</tr>
<tr>
<td>Roelant 2004</td>
<td>19.4</td>
<td>13.7</td>
<td>24</td>
<td>-1.1</td>
<td>15.7</td>
<td>25</td>
<td>1.36 (0.74, 1.99)</td>
</tr>
<tr>
<td>Torvinen 2002</td>
<td>10.1</td>
<td>9.7</td>
<td>26</td>
<td>1.3</td>
<td>9.9</td>
<td>26</td>
<td>0.88 (0.31, 1.46)</td>
</tr>
<tr>
<td>Torvinen 2003</td>
<td>7.3</td>
<td>4.6</td>
<td>27</td>
<td>-0.5</td>
<td>5.9</td>
<td>26</td>
<td>1.46 (0.85, 2.07)</td>
</tr>
</tbody>
</table>

Total 213 213 0.82 (0.56, 1.09)

WBV, whole body vibration; SMD, standardised mean difference; CI, confidence interval
Table 2.4 The effect of selected factors on CMJ height in WBV and non-exercise controls

<table>
<thead>
<tr>
<th>Factors</th>
<th>No of Studies</th>
<th>WBV subjects</th>
<th>Control subjects</th>
<th>SMD (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency &gt; 30 Hz</td>
<td>8</td>
<td>153</td>
<td>150</td>
<td>0.97 (0.66-1.28)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Frequency ≤ 30 Hz</td>
<td>6</td>
<td>60</td>
<td>63</td>
<td>0.56 (0.13-0.99)</td>
<td>0.010</td>
</tr>
<tr>
<td>Amplitude &gt; 3 mm</td>
<td>9</td>
<td>129</td>
<td>128</td>
<td>0.84 (0.48-1.19)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Amplitude ≤ 3 mm</td>
<td>5</td>
<td>84</td>
<td>85</td>
<td>0.79 (0.34-1.24)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Exposure &gt; 10 min/session</td>
<td>5</td>
<td>89</td>
<td>91</td>
<td>0.92 (0.48-1.36)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Exposure ≤ 10 min/session</td>
<td>9</td>
<td>142</td>
<td>147</td>
<td>0.75 (0.42-1.08)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Training &lt; 4 weeks</td>
<td>2</td>
<td>19</td>
<td>19</td>
<td>0.58 (-0.08-1.23)</td>
<td>0.080</td>
</tr>
<tr>
<td>Training 4 – 12 weeks</td>
<td>8</td>
<td>92</td>
<td>85</td>
<td>0.70 (0.29-1.11)</td>
<td>0.001</td>
</tr>
<tr>
<td>Training &gt; 12 weeks</td>
<td>4</td>
<td>102</td>
<td>109</td>
<td>1.05 (0.64-1.46)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Athletes</td>
<td>9</td>
<td>93</td>
<td>92</td>
<td>0.56 (0.26-0.86)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Non-athletes</td>
<td>5</td>
<td>120</td>
<td>121</td>
<td>1.12 (0.74-1.50)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

WBV, whole body vibration; CMJ, counter movement jump; SMD, standardised mean difference; CI, confidence interval
## Table 2.5 Meta-analysis of SJ height in WBV and non-exercise controls

<table>
<thead>
<tr>
<th>Studies</th>
<th>WBV</th>
<th>Control</th>
<th>SMD (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>No. of subjects</td>
</tr>
<tr>
<td>Cochrane 2004</td>
<td>4.4</td>
<td>12.4</td>
<td>12</td>
</tr>
<tr>
<td>Colson 2010</td>
<td>6.7</td>
<td>9.6</td>
<td>10</td>
</tr>
<tr>
<td>Giminiani 2009</td>
<td>3.0</td>
<td>3.2</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>31</td>
</tr>
</tbody>
</table>

WBV, whole body vibration; SJ, squat jump; SMD, standardised mean difference; CI, confidence interval
<table>
<thead>
<tr>
<th>Studies</th>
<th>WBV</th>
<th>Control</th>
<th>SMD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>No. of subjects</td>
</tr>
<tr>
<td>Bogaert 2007</td>
<td>10.9</td>
<td>15.3</td>
<td>25</td>
</tr>
<tr>
<td>Delecluse 2003</td>
<td>7.6</td>
<td>4.3</td>
<td>18</td>
</tr>
<tr>
<td>Raimundo 2009</td>
<td>13.2</td>
<td>22.9</td>
<td>14</td>
</tr>
<tr>
<td>Roelant 2004</td>
<td>19.4</td>
<td>13.7</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>81</td>
</tr>
</tbody>
</table>

WBV, whole body vibration; CMJ, counter movement jump; SMD, standardised mean difference; CI, confidence interval
Figure 2.1 Forrest plot of CMJ height in WBV and non-exercise controls (WBV, whole body vibration; CMJ, counter movement jump)
Figure 2.2 Forrest plot of SJ height in WBV and non-exercise controls (WBV, whole body vibration; SJ, squat jump)
Figure 2.3 Forrest plot of CMJ height in WBV and exercise controls (WBV, whole body vibration; CMJ, counter movement jump)
Figure 2.4 Funnel plot of CMJ height in WBV and non-exercise controls
2.5 Discussion

This study has found that WBV training compared to non-exercise controls produced a large positive effect on CMJ (effect size 0.82) and a moderate effect on SJ height performance (effect size 0.68). Similarly, vibration training compared to a normal exercise program of similar duration had a moderate effect on CMJ height (effect size 0.63). In the same way, both the review study of Issurin (2005) and the systematic review study of Rehn et al. (2007) suggested a beneficial effect of WBV on jump height (Issurin, 2005; Rehn, et al., 2007). However, others have found little or no effect, probably due to insensitive subjects (i.e., having a high levels of fitness) or inadequate study design (e.g., poor compliance of WBV training or high variation of routine exercise during the intervention period) (Nordlund & Thorstensson, 2007; Wilcock, et al., 2009).

The mechanisms behind the improvements found in muscle power (CMJ and SJ) are likely to be based on neural adaptations (Issurin, 2005). Vibration activates muscle spindles, thereby stimulating alpha motor neurons and enhancing stretch reflexes (Cardinale & Bosco, 2003). An increase in stretch-reflex activation should increase muscle contraction thereby producing greater muscle tone during acute WBV. However, it has been proposed that over the long term, neural adaptation following WBV training is similar to resistance exercise training producing enhancement of motor unit firing, motor unit synchronization, synergist muscle contraction, antagonist muscle inhibition and adaptation of the reflex response (Bosco, et al., 2000; Torvinen, Kannus, Sievanen, et al., 2002). Previous research has revealed that an increase in electromyographic activity following acute vibration exercise provides indirect evidence of increased recruitment or better synchronization of motor units (Bosco, et al., 1999; Cardinale & Lim, 2003b; Delecluse, et al., 2003; Roelants, et al., 2006), especially the high-threshold motor units that affect the fast-twitch fibres (Issurin, 2005; Rittweger, Beller, & Felsenberg, 2000; Samuelson, Jorfeldt, & Ahlborg, 1989). Increasing motor unit firing frequency also has been found during vibration application during isometric contraction of the triceps muscle (Griffin, et al., 2001). Enhanced synchronization of motor units and increased ability of motor units firing together produce a more effective muscle contraction and greater force production. In addition, muscular adaptation or muscle hypertrophy after vibration has been reported from experimental studies in mice. This research indicated an increase in both cross section area and total number of muscle fibers (type I and type II) after 6 weeks vibration training (Xie, et al., 2008). However, such information on the effect of WBV training on human muscle fibers remains unresearched (Rittweger, 2010).
The mechanism behind the improvement of muscle strength is not only neural adaptation but also hormonal stimulation. The acute hormonal response to WBV training may be similar to exercise training that produces changes in growth hormone, IGF-1 and testosterone (Rittweger, 2010). WBV may stimulate hormonal secretion via neural-hormonal regulation (higher brain or cerebral motor cortex stimulates the hypothalamic-anterior pituitary axis), or other pathways such as stimulating the target gland directly (i.e. testes), adrenergic stimulation, lactate-stimulated secretion and decreasing hepatic clearance (Bosco, et al., 2000; Kraemer & Ratamess, 2005). Serum growth hormone and testosterone levels were increased by 360% and 7% respectively, immediately after 10 minutes of WBV (26 Hz, 4 mm) in young adults (Bosco, et al., 2000), and IGF-1 levels increased by 30% and remained for up to 2 hours after an acute bout of 5 minutes of WBV exercise (30 Hz, 4 mm) (Cardinale, et al., 2008). Such hormonal changes may induce muscle hypertrophy, leading to improved muscle strength and power (Herbst & Bhasin, 2004; Widdowson, Healy, Sonksen, & Gibney, 2009). However, the effect of regular WBV training on hormonal changes has not been investigated and requires additional research.

Whole body vibration training seems to improve both static and dynamic muscle strength similar to traditional exercise, however, WBV training seems to improve muscle explosive power to a greater extent than conventional exercise. Previous studies suggested WBV training and resistance training improved countermovement jump height, isometric and dynamic knee extensor strength (Bogaerts, et al., 2007; Roelants, Delecluse, & Verschueren, 2004). Muscle mass also increased in both WBV and resistive exercise group (Bogaerts, et al., 2007). However, there was no significant difference in muscle strength and muscle mass between WBV training and resistance exercise (Bogaerts, et al., 2007; Roelants, Delecluse, & Verschueren, 2004). In contrast, Delecluse et al.(2003) found WBV and resistive exercise improved both isometric and dynamic knee extensor strength but only WBV significantly improved countermovement jump height by 7.6% compared to control group (Delecluse, et al., 2003). Our meta-analysis study also supported the beneficial effect of WBV training on CMJ height over and above a normal exercise program. WBV training may elicit biological adaptations similar to resistive exercise (Delecluse, et al., 2003; Roelants, Delecluse, & Verschueren, 2004). Whole body vibration stimulates the sensory receptors and Ia afferent input leading to a more enhancement of stretch reflex, that generates the greater force production during a stretch-shortening contraction in countermovement jump (Delecluse, et al., 2003). The neurological adaptation of resistance training (performance of voluntary
contractions) has been found at supraspinal center, descending corticospinal tracts and spinal circuitry (Carroll, Riek, & Carson, 2001). However, resistance training has a little effect on Ia afferent stimulation, and this may not improve countermovement jump (Delecluse, et al., 2003). In addition, Raimundo et al. (2009) also found that WBV training improved power produced during a countermovement jump compared to walking training. However walking training improved time to complete the 4-m walk compared to WBV. Taking this data together it seems that WBV training is better at improving explosive power than traditional resistance or aerobic exercise but not as good as traditional exercise when it comes to improving strength or aerobic endurance (Raimundo, et al., 2009).

Vibration parameters
The results of this study suggested a higher frequency vibration is more beneficial than lower frequency. Da Silva et al. (2006) showed that a frequency of 30 Hz produced an increased CMJ height (4.6%) compared to 20 Hz (0.8%) and 40 Hz (-2.7%) (Da Silva, et al., 2006). Similarly, Ronnestad (2009) showed that a frequency of 50 Hz increased peak average power for CMJ (4.4%) of untrained subjects, while there was no significant change at 20 or 35 Hz (Ronnestad, 2009). It has been found that the frequency of vibration is positively correlated with the tonic vibration reflex which acts to enhance motor unit synchronization (Jordan, et al., 2005; Martin & Park, 1997). However, a frequency that is very high (> 150 Hz) has been found to reduce motor unit synchronization (Martin & Park, 1997). Our results are in accord with previous research (Issurin, 2005) which suggests that the optimal WBV frequency is between 30-50 Hz. It is assumed that this frequency produces muscle spindle firing rates that correspond to discharge rates of motor units during maximal muscle contraction. Regular vibration training with a high amplitude (>3 mm) had a greater effect on jump height compared to low amplitude (≤ 3 mm). Likewise, Luo et al. (2005) suggested a higher amplitude (4 mm) induced larger effects than lower amplitudes. It is known that vibrations of a higher amplitude (4 mm) induce greater electromyographic activity than lower amplitudes (2 mm) ( Marin, et al., 2009). Increased EMG activity is correlated with enhanced muscle activation and therefore a greater training stimulus (David, et al., 2000). In contrast, Gerodimos et al. (2010) found that there was no significant effect of amplitudes of 4, 6 and 8 mm on SJ during acute WBV training (Gerodimos, et al., 2010). The inconsistency in findings is probably due to the difference in training methods, loading parameters, body positions and types of platforms (Gerodimos, et al., 2010). Adams et al. (2009) suggested the effect of amplitude may be related to frequency; that is, in order to generate the greatest effect, a high
amplitude (4-6 mm) should be applied with a high frequency (50 Hz), while a low amplitude (2-4 mm) should be applied with a low frequency (30 Hz) (Adams, et al., 2009). Further research is needed to elucidate this relationship.

This study revealed that longer duration exposure (> 10 minutes per session) in regular vibration training produced greater benefits than short duration exposure (≤ 10 minutes). Alternatively, it has been found that in acute studies, short duration vibration facilitated neuromuscular function, while long duration exposure caused muscle fatigue and decreased neuromuscular function (Luo, et al., 2005). The beneficial effect of long duration exposure found in this study may, however, be explained by the overload training principle. Most of the studies reviewed (10 of 14 studies in Table 2.1) used progressive loading of vibration training programs that gradually increased vibration stress on muscles. Overload training improves both neural adaptation and muscle hypertrophy (Kraemer, et al., 2002) and WBV training over a longer period probably provides sufficient stimulus/overload for such adaptations to be manifested.

We found an almost linear increase in the effect of the intensity of vibration (frequency, amplitude and exposure duration) with the duration of the training period; training over 12 weeks was almost twice as effective as a training period of less than 4 weeks. Presumably, regular WBV training requires a certain amount of stimulation time for adaptation and physiological changes including possible hormonal and biochemical changes (Issurin, 2005) to occur. The time required, particularly for hormonal and biochemical changes, with vibration training may be similar to resistance training which tends to be more profound after 4 weeks of training (Staron, et al., 1994).

Factor analysis in the current study showed the non-athlete group had a size effect greater than the athlete group as found by Rehn et al. (2007). It is likely that WBV enhances muscle strength adaptation proportionally to the baseline level; so that athletes who regularly exercise, keeping the muscle trained to some degree, improved less whereas non-athletes, who are less active and therefore less adapted, improved more.

**Bias**

The vulnerability of this study lies in the quality of the separate studies used in the analysis. Most of studies had Jadad scores of about 1- 3 points indicating poor to fair methods. Notwithstanding this, we found no significant heterogeneity among the included studies.
which suggests that the effect sizes of the individual studies had similar treatment effects. Importantly, the trim and fill analysis and the symmetrical funnel shape graph indicated there was no identification and selection bias detected (Walker, Hernandez, & Kattan, 2008). Other factors such as the type of vibration machine, technique and position of training should be analysed in the future for possible variances in effects.

2.6 Conclusion

Whole body vibration training produces a moderate to high positive effect on jump performance. Vibration protocols with higher frequencies, higher amplitudes and of longer durations per session are suggested for enhancement of lower limb muscle power. Vibration training may be more effective for non-athletes than for athletes.

2.7 Acknowledgements

The authors acknowledge the Lincoln University for financial and facility support.
2.8 References


Reflections on study 1 (chapter 2)

This meta-analysis provides evidence that WBV training improves jump performance. The mechanisms behind this performance change are probably related to stimulation of reflex muscle contraction. This increased muscle contraction may result in improved muscle glucose uptake and previous research has already indicated a beneficial effect of WBV training on peripheral vascular blood flow. Therefore the effect of WBV may be useful for diabetic patients on glycemic control and possibly for the prevention of diabetic complications via improved blood flow which is normally detrimentally affected in these patients. Therefore in study 2 or chapter 3 I set out to investigate the effect of WBV (using the most appropriate vibration protocols found in the meta-analysis) on the physiology of diabetic sufferers.
Chapter 3

Effect of whole body vibration on glycemic indices, blood flow and nerve conduction velocity of lower limbs in type II diabetic patients

3.1 Abstract

Whole body vibration (WBV) is a relatively new training tool commonly used in commercial gyms. Vibration training may induce metabolic changes which help to control diabetes and its complications making it a potentially useful therapeutic device. We conducted a randomized, controlled trial at Srinagarind Hospital in Khon Kaen, Northeast Thailand. The effect of WBV on fasting blood sugar (FBS), glycosylated hemoglobin (HbA1c), fasting insulin levels and insulin sensitivity was evaluated in 36 type II diabetic patients (13 males, 23 females, 63.2 ± 7.7 years, FBS 142.8 ± 43.9 mg.dl⁻¹, mean ± SD). The patients were randomized into two groups (WBV and control). The WBV group was given two sets of six one-minute vibration squats, three times per week for twelve weeks. Training load increased progressively from an initial vibration frequency of 30 Hz and a platform amplitude shift of 2 mm to 40 Hz and 4 mm in week 5 and thereafter. The control group maintained their normal physical activity levels. Regular WBV training had little overall effect between groups for FBS, HbA1c, fasting insulin level and insulin sensitivity (p > 0.05). However, after dichotomizing participants into well controlled (HbA1c < 8) and poorly controlled (HbA1c ≥ 8) patients, we found that in the poorly controlled patients, WBV produced a substantial reduction in FBS (-20.80 ± 18.99%; mean ± 95% CI, p = 0.012), an improvement in insulin sensitivity (4.67 ± 5.19%; p = 0.043) along with a positive, albeit non-significant increase in HbA1c and fasting insulin levels. By contrast, WBV had little effect on glycemic indices in the well-controlled diabetic group. In addition, regular WBV training caused a substantial reduction in resting diastolic blood pressure (-11.66 ± 8.92%, mean ± 95% CI, p < 0.001) but made very little difference to resting heart rate or resting systolic blood pressure. We also found possible beneficial decreases in peak systolic velocity (-3.13 ± 12.7%, p = 0.143) but changes in end diastolic velocity, systolic/diastolic ratio, resistive index and vascular diameter were unclear. Additionally, WBV training effects on nerve conduction velocity of peroneal, tibial and sural nerves were unclear. In conclusion, WBV may be a useful exercise intervention for reducing FBS and increasing control of HbA1c and fasting insulin levels, and increasing insulin sensitivity for poorly controlled diabetic patients. Vibration training also may reduce
diastolic blood pressure and peak systolic velocity, which may afford better control of vascular complications. However, the positive effect of WBV on the peripheral nervous system remains unclear.

**Keywords:** Whole body vibration, Diabetes, Glycemic control, Peripheral vessels, Peripheral nerves
3.2 Introduction

Type II diabetes or adult-onset diabetes is the most common type of diabetes and leads to complications including retinopathy, nephropathy, neuropathy and cardiovascular disease (Alberti & Zimmet, 1998). Currently, management of diabetes consists of medication, diet control, exercise and lifestyle modification.

Whole body vibration (WBV) is an innovative strategy that may be a useful alternative or supplement to current exercise prescriptions for diabetic patients (Baum, et al., 2007). Vibration training produces a positive health effect by stimulating muscle contraction, increasing peripheral blood flow, and energy consumption (Prisby, et al., 2008; Rittweger, Schiessl, & Felsenberg, 2001). These effects may help with diabetes and its complications.

Whole body vibration stimulates muscle contraction by activating muscle spindles, thereby enhancing stretch-reflex activation (Cardinale & Bosco, 2003). Some authors suggest normal regular WBV training generates muscle adaptation similar to normal resistance exercise training (Bosco, et al., 2000; Torvinen, Kannus, Sievanen, et al., 2002). It is well accepted that regular physical exercise increases glucose uptake in exercising muscle resulting in enhanced insulin sensitivity in diabetics (Goodyear & Kahn, 1998). For that reason, regular WBV training may help diabetic patients to control glucose metabolism by reducing fasting blood sugar (FBS), glycosylated hemoglobin (HbA1c; a marker for evaluating average blood sugar levels over the previous 3 months), fasting insulin and increasing insulin sensitivity. In addition, WBV may produce positive effects by increasing peripheral blood flow and peripheral nerve function (Prisby, et al., 2008; Rittweger, et al., 2001) and this may assist in controlling diabetes-dependent vascular disease.

Previous research indicates WBV has a positive effect on glucose metabolism. The plasma glucose levels in healthy male subjects were reduced by 1% after a series of 10 x 1 min bouts of vibration therapy interspersed with 1 min rest periods (30 Hz, 4 mm in amplitude, 17 g in acceleration) (Di Loreto, et al., 2004). In type II diabetics, FBS and HbA1c levels were reduced by approximately 4.2% and 3% respectively after 12 weeks of WBV using a horizontal swinging platform (30-35 Hz, 2 mm amplitude, 8 bouts of 30 seconds, 3 days a week), compared to a diabetic control group (stretching and resistance training) (Baum, et al., 2007). However, a fully controlled randomized control trial has not been undertaken to
elucidate the effects of vibration training compared to a normal lifestyle without WBV training.

Mean blood flow velocity in the popliteal artery of healthy adults increased by 200% after 9 minutes of vibration training (at 26 Hz, 3 mm in amplitude, 8 g in peak acceleration) (Kerschan-Schindl, et al., 2001). In a similar study, skin blood flow of the lower leg was increased by approximately 250% after 3 bouts of 60 seconds of vibration training (at 30 Hz, 5-6 mm in amplitude, 7 g in peak acceleration) (Lohman, et al., 2007). Also, Maloney-Hinds et al. (2008) revealed that arm massage vibration (dominant forearm and hand placed on the machine for 10 minutes) at 30 and 50 Hz, 5-6 mm amplitude, significantly increased skin blood flow in the arms (Maloney-Hinds, Petrofsky, & Zimmerman, 2008). The effect is thought to be caused by increasing endothelium-derived vasodilators such as nitric oxide (Lohman, et al., 2007; Lythgo, et al., 2009), and reduction in vasoconstrictor substance release from the smooth muscle (Kerschan-Schindl, et al., 2001; Nakamura, et al., 1995). These vibration effects may therefore be protective of the ischemic processes, which are the result of diabetic complications. Currently, however, there is a lack of research into whether such changes actually occur in diabetic patients when using WBV training.

In addition to the potential beneficial changes found with vibration training to blood glucose levels and blood vessel dynamics, vibration may also have a positive effect on nerve conduction velocity. In a rhesus monkey animal model, one hour of 1 g WBV with vibration of 12 Hz caused an increase of approximately 4.35%, however vibration of 6 and 8 Hz caused a decrease of approximately 5.51 and 2.45%, (respectively) in nerve latency time (Floyd, et al., 1973). The effect of such training on nerve conduction velocity in humans is not known, but we hypothesize that if WBV increases blood perfusion via changes in vasodilatation, nerve function might also be improved or maintained. Therefore, this study aims to evaluate the effect of regular WBV training on FBS, HbA1c, fasting insulin levels, insulin sensitivity, peripheral vascular blood flow and peripheral nerve conduction on a cohort of Type II diabetic patients. We hypothesized that WBV training would improve glycemic control, peripheral blood perfusion and peripheral nerve conduction in Type II diabetic patients.
3.3 Methods

Participants and experimental design
This randomized controlled trial was conducted at Srinagarind Hospital, Khon Kaen University, Thailand in 2010. The participants were type II diabetic patients who were diagnosed by a registered medical physician at a primary care unit. Forty patients who met the following criteria were tested pre- (baseline) and 12 weeks after (post) intervention. Inclusion criteria for type II diabetics included, patients receiving diet control programs or oral medication for diabetes over the last year. Exclusion criteria included (i) having any serious medical diseases (e.g. diabetic retinopathy, myocardial infarction, uncontrolled hypertension or renal failure), (ii) having previous hip, knee or shoulder operations or, (iii) any uncontrolled back, ankle, knee and hip pain. The participants were randomized into the WBV or the control group. Three people in the WBV group and one in the control group withdrew because of time constraints. Of the 17 included in the WBV group, 16 completed 100% of the vibration training and one 70% of the training. All participants were instructed to maintain their normal diet, normal level of physical activity and prescribed medications throughout the experiment. Before commencing the study, the research procedures were approved by the Human Ethic Committees of both Khon Kaen University, Thailand and Lincoln University, New Zealand.

Whole body vibration program
The WBV group was trained on a vertical vibration machine (Fitvibe Excel; Belkin, Belgium) for two sets of 6 one-minute vibration squats interspersed with 20 second rest periods, 3 times per week for 12 weeks (total exercise time of 36 minutes per week). We used WBV training with different postures to stimulate different lower extremity muscles (Roelants, et al., 2006) and used hand hold accessories for stimulation of the upper body extremities (Marín, et al., 2012), thereby increasing the overall muscle mass used. In addition, we were guided by the manufacturer’s instructions when constructing this training protocol. The six static positions consisted of, (a) a deep squat position (knee angle 90°), (b) high squat position (knee angle 125°), (c) high squat position (with raised heels), (d) slight knee flexion 1 (holding hand straps with shoulder flexion), (e) slight knee flexion 2 (holding hand straps with shoulder abduction) and (f) slight knee flexion 3 (holding hand straps with elbow flexion) (Figure 3.1). The training load increased progressively from an initial vibration frequency of 30 Hz and a platform amplitude shift of 2 mm (1.43 g in peak acceleration) in week 1, to 40 Hz, and 4 mm (7.34 g in peak acceleration) in week 5, which was maintained until the end of the study.
(week 12). Adverse effects were recorded throughout the training program. The control group was told to maintain their normal physical activity levels for 12 weeks.
a. Deep squat position (knee angle 90°)

b. High squat position (knee angle 125°)

c. High squat position (with raised heels)

d. Slight knee flexion (holding hand straps with shoulder abduction)

e. Slight knee flexion (holding hand straps with shoulder flexion)

f. Slight knee flexion (holding hand straps with elbow flexion)

Figure 3.1 Positions of WBV training in type II diabetic patients
Physical activity and resting physiological measures
Participant physical activity levels were evaluated using the Thai version of the International Physical Activity Questionnaire Long Form (IPAQ) (Dedkhard, 2006). All physiological measures were taken at the clinic at the same time of day with participants wearing light clothing and no shoes. Weight and height were measured using a beam balance scale with an attached stadiometer (Detecto scales, New York, USA). Weight was measured by taking two measurements to the nearest 0.1 kg. If the measures differed by more than 0.5 kg, a third measurement was taken and the mean of the two closest measurements recorded. Height (to the nearest 0.1 cm) was similarly determined. Blood pressure of the upper right arm was measured in sitting position using an automatic blood pressure monitor (Terumo ES H55, Terumo Co., Japan) after 15 minutes of rest.

Resting physiological measures
Resting physiological variables were measured on each participant at the diabetic clinic at the same time of day to reduce diurnal variation. The participants dressed in light clothing and wore no shoes during tests. Weight and height were measured to the nearest 0.1 kg and 0.1 cm by using a beam balance scale with an attached stadiometer (Detecto scales, New York, USA). Weight and height was measured by taking two measurements. A third measurement was taken if the first 2 measurements differed by weight > 0.5 kg or height > 0.1 cm. The average of the two closest measurements was recorded. Blood pressure measurements of the upper right arm were obtained with the participant in a sitting position using a digital blood pressure monitor (Terumo ES H55, Terumo Co., Japan) after 15 minutes of rest by a registered nurse.

Blood samples & insulin sensitivity
All blood samples were taken by nurses at Srinagarind Hospital by venipuncture of the antecubital vein in the morning after an overnight fast. The samples were analyzed by experienced, laboratory technicians at Srinagarind Hospital using an automated machine (Cobas® 6000 analyser; Roche Diagnostics Corp., Indianapolis, IN, USA) for FBS, HbA1c, and an Automatic Gamma Counter (Wallac 1470 Wizard, Perkin Elmer Inc., Boston, MA, USA) for fasting insulin level. In this study, the quantitative insulin sensitivity check index (QUICKI) was calculated from the inverse of the sum of the logarithm of fasting insulin and fasting glucose \(1 / (\log (\text{fasting insulin} \text{ } \mu \text{IU/ml}) + \log (\text{fasting glucose} \text{ } \text{mg/dl}))\) (Katz, et al., 2000).
Ultrasound Doppler

Duplex ultrasound (US) scanning of the right popliteal artery at the mid popliteal fossa with the patient in a prone position was performed after a 15 minute rest, by an experienced radiologist masked to all the patient data. Each artery segment was examined with a 10 MHz linear array transducer with a Toshiba Xario XG scanner (Toshiba Medical Systems, Tokyo, Japan) at a room temperature of 25°C. The color-flow mode was used to identify the vessel and to position the sample volume. The diameter of the arteries was obtained by longitudinal imaging, placing the tracker ball-guided calipers across the intimal-luminal interphases of the near and far walls. Measurements were repeated three times, then averaged. A computer spectral analysis of the Doppler signals was completed to obtain profiles of the velocity waveforms (peak systolic velocity (PSV), end diastolic velocity (EDV), systolic/diastolic ratio (S/D), and resistive index (RI)). This is possible by allowing the sample volume gate to be adjusted to encompass the entire lumen of the artery and the angle of insonation being maintained at 60°. Doppler spectral waveforms containing aliasing, (noise due to venous flow or wall motion,) were discarded. The mean of three different sets of flow estimations was obtained per patient both pre and post intervention.

Nerve conduction study

Rehabilitation doctors (blinded to patient groups) performed the nerve conduction study using an electrodiagnosis machine (Nicolet Viking Select; Nicolet Biomedical, Madison, Wisconsin, USA) at a room temperature of 25°C. Measurement of motor nerve conduction velocity was completed on both sides of body in the peroneal nerves and tibial nerves (filter setting at 2 Hz to 10 kHz, sensitivity at 1 to 5 mV, sweep speed at 2 to 5 ms). The peroneal nerve was stimulated distally (on the anterior ankle) and proximally (at the fibular head) and the resultant compound muscle action potential (CMAP) recorded from the extensor digitorum brevis muscle. The tibial nerve was stimulated distally (at the ankle above the flexor retinaculum) and proximally (at the popliteal fossa) and the CMAP taken from the abductor hallucis muscle. Assessment of sensory nerve conduction was performed on both sides of the body in the sural nerves (setting filter at 20 Hz to 2 kHz, sensitivity at 5 to 10 µV, sweep speed at 1 to 2 ms). A recording surface electrode was placed posterior to the neck of the lateral malleolus of the fibular. The electrical stimulator was applied slightly lateral to the midline in the lower one-third of the posterior aspect of the leg 10 cm from the surface electrode. Supramaximal electrical stimulation was given by a bipolar electrode (single pulse, 0.2 ms duration).
Subjective effects
Patients’ subjective feelings were observed and recorded throughout the training program. Subjective feelings of vibration training including lower extremity pain and numbness were separately assessed using a visual analogue scale questionnaire (VAS), which ranged from 0 (no pain or numbness) to 10 (unbearable pain or worst possible numbness).

Statistical Analysis
We used an Excel spreadsheet developed by Hopkins (Hopkins, 2001), based on the unequal-variances unpaired t test for evaluating the magnitude of the effect and estimating the chance that true effects were substantial. We chose 0.20 standardized units (change in mean divided by the pooled standard deviation) as the smallest worthwhile change (Cohen, 1988) to make an inference about the true values of the effect of WBV. Uncertainties in the estimate of change were presented as 95% confidence intervals and likelihoods that the true value of the effect was a substantial enhancement or impairment. P-values were also obtained from the spreadsheet and inserted for those unfamiliar with magnitude-based effect statistical procedures. Independent variables including the severity of type II diabetes (HbA1c ≥ 8 = severe, HbA1c < 8 = less severe) (Karter, et al., 2005), age, gender, body composition and duration of diabetes also were analysed.

3.4 Results
Thirty-six participants (13 males and 23 females, age 63.2 ± 7.7 years, BMI 26.1 ± 3.6 kg.m⁻², FBS 142.8 ± 43.9 mg.dl⁻¹, mean ± SD) completed the two testing protocols (baseline, post intervention). There was no substantial difference between the WBV and control groups in age, duration of diabetes diagnosis, or physical activity levels, (Table 3.1). No adverse effects of WBV were reported throughout the study. After 12-weeks training, we found very little difference in body weight (-0.25 ± 2.36%, mean ± 95% CI, p = 0.897), BMI (0.28 ± 2.62%, p = 0.788) or physical activity (0.22 ± 25.13%, p = 0.851) between groups (Table 3.2). We found very little difference in resting heart rate or resting systolic blood pressure, however compared to the control group, the WBV group had a lower resting diastolic blood pressure as a result of training by -11.66 ± 8.92% (mean ± 95%CI, p < 0.001) after the training intervention (Table 3.3).
**Blood tests**
Relative to the control group, participants who underwent vibration training had a drop in FBS by -7.57 ± 13.28% (p = 0.05). Changes to the other blood markers were trivial or unclear (Table 3.4). When the participants were categorized according to the severity of type II diabetes (HbA1c ≥ 8, or HbA1c < 8), we found vibration training decreased FBS by -20.80 ± 18.99% (p < 0.01) and increased insulin sensitivity by 4.67 ± 5.19% (p < 0.04) in the poorly controlled diabetic group (Table 3.5).

Age, gender and body composition of participants had little effect on changes in blood parameters after WBV training (Table 3.6-3.8) apart from more obese subjects having a greater drop in FBS. However, participants who suffered type II diabetes for 5 years or less tended to respond better to WBV training than participants who had been diagnosed with diabetes for more than 5 years. Relative to control participants, those diagnosed with diabetes for 5 years or less were likely to show reduced FBS (-14.17 ± 21.27 %) and HbA1c (-10.24 ± 17.95 %) levels as a result of the WBV training (Table 3.9). Such a change did not occur in the patients who suffered diabetes for 5 years or longer.

**Ultrasound Doppler**
Compared to the control group, the WBV group showed a possible decrease in peak systolic velocity (-3.13 ± 12.7%, p = 0.143); however, changes in end diastolic velocity, S/D ratio, RI and diameter of right popliteal artery were unclear (Table 3.10). When the participants were categorized into well controlled (HbA1c < 8) and poorly controlled diabetic groups (HbA1c ≥ 8), we did not find any substantial difference in peak systolic velocity, end diastolic velocity, S/D ratio, RI or diameter of right popliteal artery between the groups. In addition, age, gender, body composition and diabetic duration of patients had little effect on changes in all Doppler ultrasound parameters.

**Nerve conduction velocity**
WBV training for 12 weeks had no clear effects on motor (peroneal and tibial) or sensory (sural) nerve function (Table 3.11). Related factors including the severity of type II diabetes (well controlled and poorly controlled group), age, gender, body composition and duration of diabetes had little effect on changes in all tested nerves.
Subjective Effects of Vibration Training

Whole body vibration training did not substantially change the subjective feeling of pain or numbness compared to the control group (Table 3.12). In addition, no participant reported any unpleasant or harmful effects as a consequence of the WBV.
Table 3.1 Characteristics of the WBV and control groups (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>WBV</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Age (year)</td>
<td>60.94±11.23</td>
<td>63.95±4.85</td>
</tr>
<tr>
<td>Sex</td>
<td>M 7 / F 10</td>
<td>M 6 / F 13</td>
</tr>
<tr>
<td>Duration (year)</td>
<td>6.94±5.40</td>
<td>8.47±5.92</td>
</tr>
<tr>
<td>of diabetes diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical activity</td>
<td>4209±1591</td>
<td>3939±2926</td>
</tr>
<tr>
<td>(MET-minutes/ week)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting heart rate</td>
<td>77.75±14.17</td>
<td>75.12±9.80</td>
</tr>
<tr>
<td>(beat.min⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>133.65±11.45</td>
<td>133.88±16.70</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>74.65±15.60</td>
<td>71.58±12.21</td>
</tr>
</tbody>
</table>

SBP, resting systolic blood pressure; DBP, resting diastolic blood pressure; WBV, whole body vibration; CON, control
Table 3.2 Baseline and mean changes in body weight, BMI and physical activity levels in the WBV and control groups and the chances that the true differences between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>% Change</th>
<th>% Difference</th>
<th>±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>Qualitative</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>61.41</td>
<td>63.58</td>
<td>0.43</td>
<td>0.68</td>
<td>-0.25±2.36</td>
<td>1</td>
<td>Trivial</td>
</tr>
<tr>
<td>BMI (kg.m⁻²)</td>
<td>25.67</td>
<td>26.73</td>
<td>0.69</td>
<td>0.41</td>
<td>0.28±2.62</td>
<td>59</td>
<td>Unclear</td>
</tr>
<tr>
<td>Physical activity</td>
<td>4209</td>
<td>3939</td>
<td>-0.98</td>
<td>-1.20</td>
<td>0.22±25.13</td>
<td>21</td>
<td>Unclear</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (BMI, body mass index; WBV, Whole body vibration; CON, control)
Table 3.3 Baseline and mean changes in resting cardiovascular parameters in the WBV and control groups and the chances that true difference between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>% Change</th>
<th>% Difference ±95%CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td>HR (beat.min⁻¹)</td>
<td>77.75</td>
<td>75.11</td>
<td>0.24</td>
<td>-0.70</td>
<td>0.94±6.46</td>
</tr>
<tr>
<td></td>
<td>(unclear)</td>
<td>0.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>133.65</td>
<td>133.88</td>
<td>-2.90</td>
<td>-2.89</td>
<td>-0.01±6.55</td>
</tr>
<tr>
<td></td>
<td>(unclear)</td>
<td>0.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>74.65</td>
<td>71.58</td>
<td>-11.51</td>
<td>0.15</td>
<td>-11.66±8.92</td>
</tr>
<tr>
<td></td>
<td>(almost certainly lower)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (WBV, whole body vibration; CON, control; BMI, body mass index; HR, resting heart rate; SBP, resting systolic blood pressure; DBP, resting diastolic blood pressure)
Table 3.4 Baseline and mean changes in blood parameters of the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>% Change</th>
<th>% Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>Qualitative</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>WBV 148.65 CON 130.05</td>
<td>-19.39</td>
<td>-11.82</td>
<td>-7.57±13.28</td>
<td>73</td>
<td>Possibly</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>WBV 8.49 CON 7.75</td>
<td>-1.11</td>
<td>4.96</td>
<td>-6.07±9.86</td>
<td>32</td>
<td>Trivial</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>WBV 20.76 CON 22.58</td>
<td>-14.33</td>
<td>-18.98</td>
<td>4.65±25.48</td>
<td>19</td>
<td>Unclear</td>
</tr>
<tr>
<td>QUICKI</td>
<td>WBV 0.29 CON 0.29</td>
<td>5.23</td>
<td>5.14</td>
<td>0.09±4.48</td>
<td>25</td>
<td>Unclear</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (FBS, fasting blood sugar; HbA1c, glycosylated hemoglobin; QUICKI, the quantitative insulin sensitivity check index; WBV, whole body vibration; CON, control)
Table 3.5 Baseline and mean changes in HbA1c subgroup of the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>% Change</th>
<th>Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td>HbA1c ≥ 8 (WBV n = 9, CON n = 8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>167.78</td>
<td>145.75</td>
<td>-22.52</td>
<td>-1.72</td>
<td>-20.80±18.99</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>9.81</td>
<td>9.18</td>
<td>-5.10</td>
<td>2.45</td>
<td>-7.55±15.80</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>21.30</td>
<td>25.55</td>
<td>-17.72</td>
<td>-11.16</td>
<td>-6.56±38.54</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.28</td>
<td>0.29</td>
<td>6.57</td>
<td>1.90</td>
<td>4.67±5.19</td>
</tr>
<tr>
<td>HbA1c &lt; 8 (WBV n = 8, CON n = 11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>127.13</td>
<td>118.64</td>
<td>-13.11</td>
<td>-20.84</td>
<td>7.73±15.39</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>7.00</td>
<td>6.72</td>
<td>4.60</td>
<td>7.44</td>
<td>-2.84±6.17</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>20.16</td>
<td>20.42</td>
<td>-10.30</td>
<td>-26.10</td>
<td>15.80±31.99</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.30</td>
<td>3.37</td>
<td>7.38</td>
<td>-4.01±6.45</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI; add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (FBS, fasting blood sugar; HbA1c, glycosylated hemoglobin; QUICKI, the quantitative insulin sensitivity check index; WBV, whole body vibration; CON, control)
Table 3.6 Baseline and mean changes in age subgroup of the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th>Age ≤ 60 (WBV n = 6, CON n = 4)</th>
<th>Baseline</th>
<th>% Change</th>
<th>Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>161.17</td>
<td>110.75</td>
<td>WBV 11.79±24.91</td>
<td>32</td>
<td>Unclear</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>9.17</td>
<td>7.58</td>
<td>WBV 18.83±23.17</td>
<td>76</td>
<td>Unclear</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>17.62</td>
<td>18.52</td>
<td>WBV 14.7±60.99</td>
<td>36</td>
<td>Unclear</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.30</td>
<td>WBV 3.83±13.38</td>
<td>72</td>
<td>Unclear</td>
</tr>
<tr>
<td>Age &gt; 60 (WBV n = 11, CON n=15)</td>
<td>Baseline</td>
<td>% Change</td>
<td>Difference ±95% CI</td>
<td>Chances that true differences are substantial*</td>
<td>P value</td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>141</td>
<td>135.2</td>
<td>WBV 5.26±13.69</td>
<td>64</td>
<td>Unclear</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>8.12</td>
<td>7.8</td>
<td>WBV 0.74±5.72</td>
<td>7</td>
<td>Unclear</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>22.47</td>
<td>23.66</td>
<td>WBV 1.22±30.49</td>
<td>27</td>
<td>Unclear</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.29</td>
<td>WBV 1.47±5.44</td>
<td>23</td>
<td>Unclear</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI; add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (FBS, fasting blood sugar; HbA1c, glycosylated hemoglobin; QUICKI, the quantitative insulin sensitivity check index; WBV, whole body vibration; CON, control)
Table 3.7 Baseline and mean changes in gender subgroup of the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>% Change</th>
<th>Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td>Male (WBV n = 7, CON n = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>158.14</td>
<td>149.67</td>
<td>-25.75</td>
<td>-9.47</td>
<td>-16.28±26.56</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>9.71</td>
<td>8.15</td>
<td>-7.65</td>
<td>5.93</td>
<td>-13.58±19.40</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>18.58</td>
<td>23.75</td>
<td>-7.64</td>
<td>-12.81</td>
<td>5.17±45.59</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.29</td>
<td>3.35</td>
<td>3.84</td>
<td>2.51±7.67</td>
</tr>
<tr>
<td>Female (WBV n = 9, CON n = 13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>142.11</td>
<td>121</td>
<td>-11.73</td>
<td>-13.16</td>
<td>1.43±13.06</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>7.71</td>
<td>7.57</td>
<td>5.48</td>
<td>4.47</td>
<td>1.01±6.99</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>22.99</td>
<td>22.04</td>
<td>-16.09</td>
<td>-22.05</td>
<td>5.96±32.48</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.30</td>
<td>3.02</td>
<td>5.72</td>
<td>-2.7±5.91</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ±95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (FBS, fasting blood sugar; HbA1c, glycosylated hemoglobin; QUICKI, the quantitative insulin sensitivity check index; WBV, whole body vibration; CON, control)
Table 3.8 Baseline and mean changes in BMI subgroup of the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th>Baseline, % Change</th>
<th>Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
</tr>
<tr>
<td><strong>BMI ≤ 25 kg.m⁻²</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>149.67</td>
<td>122.17</td>
<td>-12.69</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>7.67</td>
<td>7.42</td>
<td>6.96</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>23.65</td>
<td>18.78</td>
<td>-32.22</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.28</td>
<td>0.30</td>
<td>8.15</td>
</tr>
<tr>
<td><strong>BMI &gt; 25 kg.m⁻²</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>149.5</td>
<td>133.69</td>
<td>-22.47</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>8.93</td>
<td>7.91</td>
<td>-6.27</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>19.37</td>
<td>24.34</td>
<td>-10.37</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.29</td>
<td>4.42</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (BMI, body mass index; FBS, fasting blood sugar; HbA1c, glycosylated hemoglobin; QUICKI, the quantitative insulin sensitivity check index; WBV, whole body vibration; CON, control)
Table 3.9  Baseline and mean changes in diabetes duration subgroup of the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>% Change</th>
<th>Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
</tr>
<tr>
<td>≤ 5 years (WBV n = 9, CON n = 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>142.33</td>
<td>138.71</td>
<td>-23.03</td>
<td>-8.86</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>8.39</td>
<td>8.17</td>
<td>-5.69</td>
<td>4.55</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>20.20</td>
<td>19.40</td>
<td>-19.71</td>
<td>-17.12</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.30</td>
<td>6.66</td>
<td>3.03</td>
</tr>
<tr>
<td>&gt; 5 years (WBV n =8, CON n =12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBS (mg.dl⁻¹)</td>
<td>158.86</td>
<td>125</td>
<td>-13.94</td>
<td>-13.73</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>8.54</td>
<td>7.51</td>
<td>3.18</td>
<td>5.22</td>
</tr>
<tr>
<td>Insulin (µIU.ml⁻¹)</td>
<td>21.96</td>
<td>24.44</td>
<td>-19.50</td>
<td>-19.85</td>
</tr>
<tr>
<td>QUICKI</td>
<td>0.29</td>
<td>0.29</td>
<td>4.64</td>
<td>6.38</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (FBS, fasting blood sugar; HbA1c, glycosylated hemoglobin; QUICKI, the quantitative insulin sensitivity check index; WBV, whole body vibration; CON, control)
Table 3.10 Baseline and mean changes in blood velocity parameters of right popliteal artery in the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>% Change</th>
<th>% Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV (cm/sec)</td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55.6</td>
<td>63.0</td>
<td>-6.4</td>
<td>-3.3</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDV (cm/sec)</td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.4</td>
<td>4.7</td>
<td>-110.3</td>
<td>-47</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/D ratio</td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.8</td>
<td>5.5</td>
<td>128.1</td>
<td>-43.9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI</td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>0.9</td>
<td>9.4</td>
<td>6.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.1</td>
<td>6.1</td>
<td>0.9</td>
<td>1.0</td>
<td>14</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (WBV, whole body vibration; CON, control; PSV, peak systolic velocity; EDV, end diastolic velocity; S/D ratio, systolic/diastolic ratio; RI, resistive index)
Table 3.11 Baseline and mean changes in nerve conduction study in the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>% Change</th>
<th>% Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td><strong>Right peroneal nerve</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal latency (ms)</td>
<td>4.96</td>
<td>4.55</td>
<td>-2.64</td>
<td>0.65</td>
<td>-3.29±12.87</td>
</tr>
<tr>
<td>Distal amplitude (mV)</td>
<td>2.56</td>
<td>3.15</td>
<td>37.07</td>
<td>5.41</td>
<td>31.66±38.82</td>
</tr>
<tr>
<td>Velocity (m.sec⁻¹)</td>
<td>45.68</td>
<td>48.00</td>
<td>-1.09</td>
<td>-1.71</td>
<td>0.62±9.62</td>
</tr>
<tr>
<td><strong>Left peroneal nerve</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal latency (ms)</td>
<td>5.23</td>
<td>4.78</td>
<td>-4.78</td>
<td>-0.37</td>
<td>-4.41±12.38</td>
</tr>
<tr>
<td>Distal amplitude (mV)</td>
<td>2.86</td>
<td>2.32</td>
<td>8.08</td>
<td>23.54</td>
<td>-15.46±44.69</td>
</tr>
<tr>
<td>Velocity (m.sec⁻¹)</td>
<td>45.19</td>
<td>45.59</td>
<td>-2.07</td>
<td>-0.77</td>
<td>-1.30±8.99</td>
</tr>
<tr>
<td><strong>Right tibial nerve</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal latency (ms)</td>
<td>4.92</td>
<td>4.81</td>
<td>2.16</td>
<td>0.24</td>
<td>1.92±15.53</td>
</tr>
<tr>
<td>Distal amplitude (mV)</td>
<td>7.28</td>
<td>7.29</td>
<td>11.77</td>
<td>1.86</td>
<td>9.91±40.63</td>
</tr>
<tr>
<td>Velocity (m.sec⁻¹)</td>
<td>42.38</td>
<td>42.88</td>
<td>-3.99</td>
<td>-1.92</td>
<td>-2.07±8.68</td>
</tr>
<tr>
<td><strong>Left tibial nerve</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal latency (ms)</td>
<td>4.85</td>
<td>4.62</td>
<td>8.51</td>
<td>6.62</td>
<td>1.89±11.89</td>
</tr>
<tr>
<td>Distal amplitude (mV)</td>
<td>8.09</td>
<td>6.98</td>
<td>-10.58</td>
<td>9.77</td>
<td>-20.35±36.53</td>
</tr>
<tr>
<td>Velocity (m.sec⁻¹)</td>
<td>41.88</td>
<td>43.12</td>
<td>6.87</td>
<td>3.96</td>
<td>2.91±9.58</td>
</tr>
<tr>
<td><strong>Right sural nerve</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency (ms)</td>
<td>2.23</td>
<td>0.84</td>
<td>0.56</td>
<td>14.08</td>
<td>-13.52±92.04</td>
</tr>
<tr>
<td>Amplitude (μV)</td>
<td>5.38</td>
<td>3.94</td>
<td>0.00</td>
<td>-42.86</td>
<td>42.86±70.80</td>
</tr>
<tr>
<td><strong>Left sural nerve</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency (ms)</td>
<td>1.75</td>
<td>1.06</td>
<td>-12.14</td>
<td>3.84</td>
<td>-15.98±114.09</td>
</tr>
<tr>
<td>Amplitude (μV)</td>
<td>5.44</td>
<td>3.00</td>
<td>-47.13</td>
<td>-29.41</td>
<td>-17.72±113.33</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI; add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (WBV, whole body vibration; CON, control)
Table 3.12  Baseline and mean changes in subjective feeling of pain and numbness in the WBV and control groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>%Change</th>
<th>% Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>CON</td>
<td>WBV</td>
<td>CON</td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>4.85</td>
<td>5.20</td>
<td>-59.51</td>
<td>-59.07</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>-0.44±44.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numbness</td>
<td>2.61</td>
<td>3.40</td>
<td>-22.50</td>
<td>-57.88</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>35.38±63.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change of 0.20 standardized units for all measures ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (WBV, whole body vibration; CON, control)
3.5 Discussion

The main novel findings of this study are that 12 weeks of WBV training substantially improved fasting blood sugar levels and insulin sensitivity in patients with poorly controlled diabetes. We also found indications that WBV training may improve glycemic control in relatively new diabetic patients (diagnosed 5 years or less) and those who are more overweight. In addition, WBV training substantially reduced diastolic blood pressure and had a clinically beneficial effect on peak systolic velocity of the right popliteal artery. However, the beneficial effects of WBV on peripheral nerves remain unclear.

Our study found that there was no substantial change in body weight after WBV training similar to previous research (Fjeldstad, Palmer, Bemben, & Bemben, 2009; Roelants, Delecuse, Goris, et al., 2004; Yoo, et al., 2009). It seems that WBV may not increase caloric expenditure enough to reduce body weight. However, total body fat reduction has been observed after (long-term) WBV training in postmenopausal women. Verschueren et al. (2004) found that total fat mass decreased 2.3 ± 5.1% after 6 months WBV training (35-40 Hz, 1.7-2.5 mm amplitude) (Verschueren, et al., 2004). Fjeldstad et al. (2009) also found that 8 months WBV training (40 Hz, 3 mm amplitude) with resistive exercise significantly reduced total body fat by 1.8% compared to resistive exercise group (Fjeldstad, et al., 2009). Short-term (6-weeks) WBV training in conjunction with endurance training has also resulted in small but worthwhile reductions in percentage fat mass (-0.4%) compared to endurance training alone (Wilms, et al., 2012). WBV may reduce body fat perhaps via increased oxygen uptake and energy expenditure (Rittweger, et al., 2001), however, vibration training over a shorter period (for example 12 weeks in our study) did not alter total body weight in the participants of this study and probably did not alter body fat measures, however further studies are needed to support this conclusion, since body compartmental analysis was not conducted in this study.

Glycemic indices

It is thought that WBV stimulates the stretch reflex by activating muscle spindles to enhance muscle contraction (Cardinale & Bosco, 2003) and generates vasodilatation (Kerschan-Schindl, et al., 2001; Lythgo, et al., 2009; Nakamura, et al., 1995) leading to increase glucose utilization. The physiological mechanisms of WBV on glucose uptake of muscle cells probably are similar to physical exercise. These mechanisms include enhanced glucose transporter protein GLUT4 via activation of post-receptor insulin signalling and AMPK
AMP-activated protein kinase), increased cytoplasmic calcium, enhanced autocrine or paracrine (nitric oxide) response, and increased glycogen synthase and phosphorylase activities (Pereira & Lancha, 2004). Exercise also increases muscle glucose delivery and utilization by increasing muscle blood flow, muscle capillary density and muscle mass (Andersen & Henriksson, 1977; Ebeling, et al., 1993; Eriksson, et al., 1997). In addition, in diabetic patients, WBV may help diabetic control by improving beta cell function and insulin resistance or enhanced responsiveness of muscle glucose uptake, similar to physical exercise (Bloem & Chang, 2008; Goodyear & Kahn, 1998; Krook, et al., 2000).

However, we found that 12 weeks of WBV training did not have significant effects on FBS, HbA1c, fasting insulin and insulin sensitivity in the overall group of type II diabetic patients. Our results corroborate work by Baum et al. (Baum, et al., 2007) who found that FBS and HbA1c were not significantly improved in the WBV group compared to the control group. Perhaps the workload of traditional WBV training is not sufficient to provide substantial changes. Typical resistance exercise protocols recommended for diabetic control involve progressive resistance training up to 3 sets of 8-10 repetitions for 8-10 major muscles three times a week at a weight 8-10 RM (Gordon, Benson, Bird, & Fraser, 2009; Sigal, Kenny, Wasserman, Castaneda-Sceppa, & White, 2006). Effective aerobic exercise protocols recommended a cumulative energy expenditure of at least 1,000 kcal/week, or at least 150 min exercise per week at moderate intensity exercise or at least 90 min of exercise per week for high intensity exercise (Albright, et al., 2000; Gordon, et al., 2009; Sigal, et al., 2006). The WBV training protocol used in this study would be classified as moderate intensity exercise (Bogaerts, et al., 2009) but only consisted of 36 min/week well short of the recommended 150 min/week, which may have influenced the results of this study.

However, heterogeneity of diabetic type II patients may play an important role in the results of this study. For example, type II diabetes has various degrees of insulin resistance, insulin deficiency and complications. We performed an analysis of the related factors including age, gender, BMI, baseline HbA1c levels and duration of diabetes. We found a beneficial effect on FBS and insulin sensitivity in poorly controlled diabetic patients (or high baseline HbA1c patients who have a high blood glucose level over the last three months). Our findings indicate the effect of WBV on glycemic control depends on the underlying levels of blood glucose. Vibration may act in a similar way to anti-diabetic drugs such as sulfonylureas (Bohannon, 2002) which improves the release of insulin from the damaged beta cells. The mechanisms of WBV for enhanced beta cell function probably are similar to physical exercise
(Slentz, et al., 2009). Regular exercise may reduce the elevation of fatty acids and blood glucose (Gordon, et al., 2009; Shojae-Moradie, et al., 2007; Sigal, et al., 2006) that induce a glucolipotoxic effect on beta cells (Poitout, et al., 2010; Prentki & Nolan, 2006). The reduction of hyperglycemia, free fatty acids and triglycerides has been shown to generate the recovery of insulin secretion of beta cells (Lim, et al., 2011; Slentz, et al., 2009).

It seems that for poorly controlled diabetic patients, WBV training over a 12 week period resulted in an increased insulin sensitivity. This is supported by the higher QUICKI score (indicating improved sensitivity or reduced insulin resistance), and lower (albeit non-significant) resting insulin concentration. Such changes over time would result in the lower FBS and HbA1c levels found in these participants (Table 3.4). The WBV training created a greater exercise stress and subsequent adaptation on those individuals compared to the well-controlled patients. It is known that increased adipose tissue levels can increase the release of substances such as leptin and tumour necrosis-α which effects muscle and liver glucose metabolism, thereby increasing insulin resistance (Frayn, 2001). We speculate that the WBV training may have caused a greater reduction in adipose tissue in the poorly controlled patients as witnessed by the change in BMI values which decreased by 3.2% in the poorly controlled compared to well controlled group. Such a change has been shown to increase insulin sensitivity (Hordern, et al., 2008). We also found the greater reduction of FBS levels in the WBV training group who had high BMI (> 25 kg.m⁻²) which is similar to Tessier et al. (2000) who showed that diabetic patients with high BMI have greater response to physical exercise (Tessier, et al., 2000). We hypothesize that WBV training reduces adipose tissue and increases lean body mass (Fjeldstad, et al., 2009; Verschueren, et al., 2004), particularly in poorly controlled diabetic subjects leading to improved insulin sensitivity similar to physical exercise. However, we did not directly measure adipose tissue in our subjects, therefore this remains speculate until future research is carried out.

In addition, we found WBV training in relatively new diabetics (diagnosed 5 years or less) had a greater reduction in both FBS and HbA1c than patients with longer duration of diabetes (more than 5 years). Likewise, previous studies found newly diagnosed diabetic patients have greater responsiveness of muscle glucose uptake to physical exercise (Hu, et al., 2011; Stettler, et al., 2006) compared to patients with a longer history of diabetes. The diabetic patients with a longer history are associated with an increasing degree of beta cell dysfunction (Bagust & Beale, 2003), insulin resistance (Verma, Paneri, Badi, & Raman, 2006) and vascular complications (Donnelly, Emslie-Smith, Gardner, & Morris, 2000) that
may have resulted in poor glycemic response to physical exercise which is probably also the case for WBV. On the other hand, WBV training in newly diagnosed diabetic patients may produce effective diabetic control, thereby leading to successful prevention of potential diabetic complications.

Traditional WBV training in our study had substantial beneficial effects in some specific diabetic groups. However, we did not observe substantial beneficial effects overall. Our WBV training protocol may have been insufficient to produce adaptation in all subjects. The degree of exercise intensity is related to insulin sensitivity change (that is, more intensity, greater improvement in insulin sensitivity) while exercise volume (intensity and duration) is related to HbA1c levels change (Segerstrom, et al., 2010). An increasing in duration of training (per session), regularity of training (per week) and intensity of WBV such as adding loads on the body or dynamic exercise training while completing WBV may provide better results than we have found. In addition, subgroup analysis reduced the number of patients in each group that may have lead to inadequate sample sizes.

We did not observe any adverse effects of WBV on type II diabetic patients such as pain, abnormal sensation, injury or hypoglycaemia. However, adverse effects related to diabetic complications such as retinopathy and nephropathy can occur with exercise. Vigorous exercise may trigger vitreous haemorrhage or retinal detachment in severe diabetic retinopathy, and may increase urinary protein excretion (Sigal, et al., 2006). Therefore, WBV with high loads and prolonged exposure times may put such patients at risk of these complications. This study did not perform retinal examination or monitor renal function, however, we suggest future research into the area of WBV and diabetes should consider such monitoring.

**Peripheral vessel**

After 12 weeks of WBV training both systolic and diastolic resting blood pressure in our subjects (substantial decrease in diastolic only) decreased compared to controls. It is suggested that WBV may dilate small blood vessels in muscles and thereby decrease peripheral vascular resistance (Kerschan-Schindl, et al., 2001). If true, diastolic blood pressure, which is mainly determined by peripheral vascular resistance, would tend to decrease also. Since systolic blood pressure is mainly determined by cardiac output, changes in peripheral resistance would not be as obvious. The blood pressure changes found in our subjects would therefore tend to follow this hypothesis. Similar to previous research, we
found that WBV has little effect on resting heart rate (Hazell, Thomas, Deguire, & Lemon, 2008). The absence of any change in heart rate was not unexpected since heart rate and stroke volume can be used to modify cardiac output to maintain blood pressure.

An interesting finding from the current study was that regular WBV training substantially reduced peak systolic velocity of right popliteal artery. The reduction of blood velocity is correlated to blood pressure and reduced vascular stenosis or resistance (Alexandrov, et al., 1997; Hunink, Polak, Barlan, & O'Leary, 1993; Kroger, Massalha, & Rudofsky, 1998; Moneta, et al., 1995), and this finding is correlated to our results that WBV significantly reduced diastolic blood pressure. Chronic hyperglycemia impairs endothelium dependent (nitric oxide mediated) vasodilatation, increases endothelium-derived vasoconstrictors, increases inflammation, alters vascular smooth muscle and platelet function, which contributes to atherosclerosis (Beckman, Creager, & Libby, 2002; Creager, Luscher, Cosentino, & Beckman, 2003). Vibration exposure may reduce peripheral vascular resistance by increasing endothelium-derived vasodilators such as nitric oxide (Lohman, et al., 2007; Lythgo, et al., 2009), and inhibiting vasoconstrictor substance release (endothelin) from smooth muscles (Nakamura, et al., 1995). As with the adaptation process in exercise training, regular WBV training may alter peripheral blood vessels by increasing arteriole vasodilatation by releasing endothelial nitric oxide and prostaglandins (Koller, Huang, Sun, & Kaley, 1995), or by increasing the size of the capillary bed of the skeletal muscle (Blomqvist & Saltin, 1983). In addition, WBV may improve vascular function by reducing atherosclerosis process in diabetic patients. Oki et al. (1989) revealed after applied longitudinal vibration at a frequency of 30 or 60 Hz for 12 weeks in rabbits, the aortic wall was thinner and the area of plaque formation in the intima was smaller than control (Oki, Ishitake, Ohkubo, & Matoba, 1989).

**Peripheral nerve**

It is well understood that type II diabetes causes considerable damage to nerve tissue from vascular and metabolic defects (Stevens, Feldman, & Greene, 1995). Physical exercise improves nerve blood flow by enhanced the release of nitric oxide and vascular endothelial growth factor (Gustafsson, Puntschart, Kaijsjer, Jansson, & Sundberg, 1999; Maiorana, O'Driscoll, Taylor, & Green, 2003). Physical exercise activates nitric oxide thereby inhibiting aldose reductase (Judzewitsch, et al., 1983; Ramana, Chandra, Srivastava, Bhatnagar, & Srivastava, 2003), and stimulates Na/K ATPase activity to improve nerve conduction velocity (Hohman, Cotter, & Cameron, 2000; Kjeldsen, Richter, Galbo, Lortie, & Clausen, 1986).
Regular WBV training has been suggested to increase blood perfusion (Kerschan-Schindl, et al., 2001; Lohman, et al., 2007) probably similar to exercise, but the effect of WBV on metabolic change to enhance peripheral nerve function requires additional research.

Previous studies have examined the effects of exercise on nerve conduction velocity in diabetics. Tesfaye et al. (1992) found acute exercise (before and after) at 80% predicted maximum heart rate did not improve sensory sural nerve conduction velocity in diabetic neuropathy while exercise can improve nerve conduction velocity in healthy nerves (Tesfaye, Harris, Wilson, & Ward, 1992). It was explained that the poor response of diabetic nerves to exercise may be from the poor blood perfusion in diabetic vascular complications. Balbucci et al. (2006) found the long term exercise (walking, 50%-85% of heart rate reserve, 4 hours a week for 4 years) increased nerve conduction velocity of the peroneal (0.8%) and sural nerves (3.8%) in diabetic patients (average duration of diabetes 8.4 years) (Balducci, et al., 2006).

Hung et al. (2009) showed Tai Chi Chuan exercise (44-77% of maximal heart rate, 60 min per session, 3 sessions a week) for 12 weeks in type II diabetics (average duration of diabetes 3.1 years) improved both the tibial (4.8% for right, 2.7% for left) and median nerve’s conduction velocity (2.3% for right, 2% for left) but found no significant changes in the peroneal and ulnar nerves (Hung, et al., 2009). Therefore, it seems that exercise can in some cases improve nerve health however the effect of WBV exercise over 12 weeks was not beneficial to nerve health in our subjects.

The workload of WBV training was considered as a factor related to the improvement of blood perfusion (Lythgo, et al., 2009), thereby increasing peripheral nerve function. Previous studies have showed both moderate to high and low to moderate exercise intensity can improve nerve conduction velocity (Balducci, et al., 2006; Hung, et al., 2009). Our WBV protocol was categorized as moderate intensity exercise (Bogaerts, et al., 2009) similar to Hung’s study. Therefore we are confident the participants were working hard enough. However, duration per session of our study was less than Hung’s study. It has been suggested that the duration of exercise is related to endothelium-derived vasodilators secretion (Green, Maiorana, O'Driscoll, & Taylor, 2004) which is related to the amount of blood perfusion. The exercise volume of WBV training we used was probably insufficient to cause adaptation to the nerve witnessed by Balducci’s and Hung’s studies.

Training duration or training type may also play a role. Balbucci’s research had subjects train (walk for 4 hours per week for 4 years). With a longer duration perhaps the WBV training
protocol in this protocol used in this study may be effective at improving nerve health. Alternatively, beneficial nerve change may also be reliant on the type of exercise used during training. Whole body movement as in the Balbucci’s study may improve blood flow to a greater extent. Tai Chi (as reported in Hung et al. 2009) may also be better at stimulating the necessary changes for nerve conduction velocity to improve.

We found substantial change in glycemic control related to severity of diabetes and duration of diabetes, while we did not find substantial change in peripheral vessel adaptation and nerve conduction velocity related to those factors. The degree of glycemic control after WBV training depends on multiple factors such as severity of beta cell dysfunction and insulin resistance, while the degree of vascular adaptation and nerve conduction velocity after WBV training may not be related to severity of diabetes. The degree of vascular adaptation is probably more correlated to the intensity and duration of exercise (Kojda & Hambrecht, 2005; Saltin, Radegran, Koskolou, & Roach, 1998). Similarly, the degree of nerve conduction velocity improvement is probably correlated to peripheral nerve blood perfusion (Cameron, Cotter, & Low, 1991; Nagamatsu, et al., 1995). The workload and duration of WBV training may be an important factor to enhance vascular remodelling, increase peripheral perfusion and improve nerve conduction velocity and requires more investigation.

Our study found that the effect of WBV in reducing the subjective feeling of pain in diabetic patients was unclear (Table 4.4). However, Hong (2011) reported application of 8 weeks of WBV (30 Hz, 5 mm amplitude, 3 sets of 3 min exposure, 5 days a week) reduced the pain score from a diabetic neuropathy patients by 66-75 % (Hong, 2011). The mechanism of WBV in reducing pain has not been fully explained but it may be similar to vibration massage. From the gate-control theory, reception of vibration is conducted by large sensory fibers (Type A-Beta), which can inhibit the input of pain from small sensory fibers (Type C-fiber) (Melzack & Wall, 1965). The contradictory results between Hong and our study may be due to the difference in the nature and severity of pain. We measured moderate non-specific lower limb pain (pain score 4-5) while Hong (2011) focused on severe neuropathic lower limb pain (pain score 6-8). WBV may have profound positive effects on mitigating severe neuropathic pain. However, Hong’s report presented only one case (no control) and is not ideal research to support any change of pain with WBV.


3.6 Conclusion

In summary, our study revealed that WBV training in type II diabetic patients had beneficial effects on the control of FBS, HbA1c, insulin levels and insulin sensitivity, among poorly controlled diabetics. It seems that WBV training may benefit those patients that have been diagnosed with type II diabetes more recently (≤ 5 years) compared to patients suffering from the disease for a longer period (> 5 years), and those with higher BMI. In addition, WBV training in type II diabetics reduced diastolic blood pressure and peak systolic velocity in the popliteal artery. The vascular findings suggest that the vasodilatation changes are likely to be protective for diabetics with vascular complications. The effects of WBV on peripheral nerves remain unclear and require further study.

3.7 Acknowledgements

Special thanks to all the patients for their contribution and participation, Ms Pornsawan Wongkarnchanakul and Lee Wattanan Trading Company for supporting the Fitvibe® whole body vibration machine. Thanks also to Dr. Sujin Bureerat, Faculty of engineering, KhonKaen University.
3.8 References


Reflections on study 2 (chapter 3)

Chapter 3 provided support for the beneficial effect of WBV training on glycemic control, diastolic blood pressure and peak systolic velocity in the popliteal artery in type II diabetic patients. However, most of the ultrasound Doppler parameters were unclear and I also did not find any significant changes in nerve conduction velocity after WBV training that might suggest improvement in peripheral nerve blood perfusion. Therefore the use of WBV training to induce enhanced tissue blood perfusion was not clear cut and remains speculative. In Chapter 4 I wanted to investigate more directly whether WBV has any beneficial effect on muscle blood flow perfusion since the results of Chapter 3 would suggest otherwise and yet others have found such a link. Since blood perfusion is important in performance and recovery of blood perfusion is likely to result in accelerated performance recovery in Chapter 4 I explored the effect of WBV on muscle perfusion by monitoring muscle blood flow and muscle oxygenation in athletes during recovery.
Chapter 4
Effect of whole body vibration training on performance recovery

4.1 Abstract

Whole body vibration (oscillatory movements usually performed on specialized pieces of equipment) has been proposed as a means of performance recovery after exercise. Its benefits and mechanisms, however, are unclear and further investigation is needed. The aim of this study is to evaluate the effect of a whole body vibration (WBV) program on recovery of lactate levels, muscle power, muscle strength, flexibility, rate of perceived exertion, muscle soreness and muscle oxygenation compared to a traditional active recovery program. A crossover study in which 16 male athletes performed 6 sets of 30 sec Wingate tests, then were randomized into two groups: Group 1, active recovery program (10 minutes of cycling and stretching) and Group 2 WBV in which athletes completed 1 set of stretching hamstrings and both side hip & quadriceps muscles on a WBV machine (stretch WBV) at 30 Hz, 1-2 mm amplitude, 30 sec and 2 sets of lateral thigh muscles, hamstrings, quadriceps and calves massage (passive WBV) at 40 Hz, 4-5 mm amplitude, for 60 sec. After one week, the groups were reversed and the procedure replicated. There was no statistically significant difference in blood lactate concentration, anaerobic capacity, anaerobic power, fatigue index, 3-sec maximum voluntary contraction force, jump height, flexibility, rate of perceived exertion, or muscle soreness between the two groups. The WBV substantially increased muscle oxygenation compared to the active and non-recovery groups and substantially increased muscle blood flow compared to the non-recovery program. In conclusion, WBV had little effect at improving performance compared to a normal active recovery however the WBV recovery program increased muscle oxygenation and muscle blood flow.

Keywords: whole body vibration, recovery program, lactate, strength, flexibility, muscle soreness, near-infrared spectroscopy
4.2 Introduction

Promoting recovery after exercise is essential for athletes in order to improve subsequent sport performance. Several techniques to maximize the recovery process have been studied including, active recovery, stretching, massage, contrast water immersion therapy, hyperbaric oxygen therapy, non steroidal anti-inflammatory drugs, electro-myo-stimulation, compression garments and combined modalities (Barnett, 2006). Whole body vibration (WBV) is a relatively new technique that uses oscillatory movement created by specific machines attached to a platform and is widely promoted in commercial gyms as a new technique for recovery. Vibration machines transfer vibration force from a moving platform to the human body and evidence suggests it may affect tissue blood flow which may promote recovery after exercise.

Blood flow is an important factor in the recovery of muscle performance after high-intensity exercise. Changes in blood flow can affect phosphocreatine (PCr) metabolism, lactate removal and acid-base balance. In a recent study arterial occlusion (which subsequently decreased blood flow to the muscles distal to the occlusion) after exercise prevented PCr resynthesis and recovery of lactate and the acid-base balance (Kemps, et al., 2010; Quistorff, Johansen, & Sahlin, 1993; Yoshida & Watari, 1997). Adequate blood flow is essential at maintaining oxygen supply to the recovering muscle and helps to increase PCr resynthesis, lactate elimination and recovery of muscle strength (Sahlin, Harris, & Hultman, 1979; Tesch & Wright, 1983). Significantly higher blood flow to the muscle has been found during active recovery (Bangsbo, Johansen, Graham, & Saltin, 1993), and enhanced power output, exercise performance and lactate elimination, compared to passive recovery (Ahmaidi, et al., 1996; Bangsbo, et al., 1993; Bogdanis, Nevill, Lakomy, Graham, & Louis, 1996; Corder, Potteiger, Nau, Figoni, & Hershberger, 2000).

Previous research indicates that WBV may increase tissue blood flow by the vasodilatation process through increasing endothelium-derived vasodilators such as nitric oxide and prostaglandins (Lohman, et al., 2007; Lythgo, et al., 2009) and a reduction in the release of the vasoconstrictor substance, endothelin, from smooth muscle (Nakamura, et al., 1995). Kerschan-Schindl et al. (2001) reported that the mean blood flow velocity from the popliteal artery increased from 6.5 to 13.0 cm.s\(^{-1}\) after 9-min of standing on a vibration machine set at 26 Hz and 3 mm amplitude. Lythgo et al. (2009) found that the mean blood velocity in the common femoral artery increased five-fold during WBV training in a squatting position.
(recorded during 45 sec of 1-min vibration bouts) at 20-30 Hz, 4.5 mm amplitude compared to a standing position without vibration (Lythgo, et al., 2009). Additionally, Lohman et al. (2007) found that skin blood flow increased approximately 147% after 3 minutes (and remained at 92% at 10 minutes) of passive vibration (30 Hz, 5-6 mm amplitude) compared to very little change in an exercise only or vibration and exercise group (Lohman, et al., 2007). Maloney-Hinds et al. (2008) also showed that 5 minutes of arm massage vibration (resting arm on the machine) at 30 and 50 Hz at 5-6 mm amplitude significantly increased skin blood flow in the arms (Maloney-Hinds, et al., 2008). Such changes in vascular perfusion resulting from vibration alone or vibration during exercise may result in more effective removal of waste products and perhaps an increased uptake of oxygen and PCr resynthesis after exercise.

Whole body vibration may also help the recovery of muscle after exercise in other ways. For example, Rhea et al. (2009) reported that stretching on an iTonic vibration machine (set at 35 Hz with 2 mm amplitude for 6 min total exposure) twice daily for 3 days after strenuous exercise significantly reduced perceived pain at 12, 24, 48, 72 hr after resistance training and repeated sprint exercise (Rhea, et al., 2009). Issurin et al. (1994) further proposed that stretching with WBV increased flexibility more than a conventional stretching exercise (Issurin, et al., 1994), which may help those sportspeople who require high flexibility. By contrast, Edge et al. (2009) found no statistical difference in metabolic parameters (oxygen consumption, respiratory exchange ratio, blood lactate concentration), indicators of muscle damage (creatine kinase) or performance levels (3-km time trial) after 24 hours recovery from high intensity exercise training between the WBV and control groups. Their vibration protocol included standing and sitting on a vibration platform (12 Hz, 6 mm amplitude) for 2 sets of 15 min after the initial training bout (Edge, et al., 2009). There is considerable uncertainty in the literature on the beneficial effects of vibration training as a recovery tool and therefore further investigation is warranted, in particular, little is known about muscle oxygenation during WBV training and subsequent performance after high-intensity repeated sprint work, similar to what team athletes might endure during a match.

The aim of this project was therefore to investigate the effect of a WBV recovery program (passive vibration and stretching on a vibration machine) on blood lactate, muscle power, muscle strength, flexibility, muscle oxygenation, rate of perceived exertion and muscle soreness compared to a traditional recovery program. We hypothesized that a WBV recovery program may improve muscle recovery similar to that of an active recovery program without the need for a significant elevation in metabolism.
4.3 Methods

Participants
Participants in this crossover study were 16 rugby players from a local premier division 1 team (age 19.1 ± 1.4 years, body weight 86.8 ± 11.4 kg, height 182.8 ± 6.2 cm and BMI 25.9 ± 2.9 kg.m$^{-2}$, mean ± SD). Any participants with serious or uncontrolled health problems such as diabetes, hypertension, or back, hip, knee and ankle pain, including those with previous back, hip, knee or ankle surgery were excluded from the study. All participants gave informed consent and all procedures were approved by the Lincoln University Human Research Ethics Committee.

Interventions
The participants performed a series of highly intensive exercises to simulate in a controlled manner, what might be expected of the participants during a typical training session or game. The exercises consisted of six 30-sec Wingate tests on a Velotron cycle ergometer (Velotron Wingate software, version 1.0; Racermate Inc.). Each bout was interspersed with 30 sec of active recovery (cycling at 40W). Each subject’s weight was entered into the software, and the computer applied the workload for each male athlete at 9.8% of body weight. During the test the athletes were given verbal encouragement to keep cycling as fast as possible. Before the Wingate test, participants completed a 5-minute warm up comprising of cycling and also stretching of the hamstring, calf and quadriceps muscles. The athletes were familiarized with the equipment and all of the testing procedures by performing a trial one week prior to the main trial.

The athletes were randomized into 2 groups, group 1 (active recovery) and group 2 (WBV). After the high intensive interval training (HIIT) session, group 1 undertook an active recovery of 5 minutes of cycling at 50% of maximum heart rate (Belcastro & Bonen, 1975) and 5 minutes of stretching exercises (quadriceps, hip flexors, hamstrings, calf and adductors, 3 sets of 10 sec holding for each muscle), and group 2 completed their recovery program on a three-dimensional Powerplate vibration machine (PowerPlate Pro5™; PowerPlate North America Inc., Northbrook, IL). The WBV recovery protocol followed the manufacturer instructions and consisted of a series of stretching exercises and resting positions on the platform. These exercises were expected to improve flexibility, performance, muscle blood flow and reduce muscle soreness comparable to active recovery protocol (P.J. Marin, et al., 2012). The WBV recovery protocol followed the manufacturer’s instructions and included hamstring and...
quadriceps stretches (30 Hz, 1-2 mm, 30 sec, for the vibration frequency, amplitude and duration, respectively) followed by 2 sets of lateral thigh muscle, hamstrings, quadriceps and calf massage exercises on the vibration platform (40 Hz, 4-5 mm, 60 sec), interspersed with 5 sec rest for the changing from one position to another (Figure 5.1). The total recovery duration was about 10 min for both groups. After a 1-week wash out period the groups were reversed and participants repeated the protocol.

Measurement
Outcome variables including blood lactate levels, anaerobic power, countermovement jump height, flexibility, fatigue, soreness and muscle oxygenation were evaluated prior to exercising, immediately afterward and then 30 min, 60 min, and 1, 2, 3 days post exercise (Figure 5.2).
a. Hamstring stretching  
b. Hip flexor and quadriceps stretching  
c. Lateral thigh muscles massage  
d. Hamstrings massage  
e. Quadriceps massage  
f. Calves massage  

Figure 4.1 Positions of WBV training for recovery program
Figure 4.2 Summary of testing schedule and measurements taken in this study (WBV, whole body vibration; RPE, rate of perceived exertion; MVC, maximum voluntary contraction; NIRS, near-infrared spectroscopy)
Blood lactate
A drop of capillary blood was taken from the fingertip (using standard aseptic technique) at baseline and immediately after each bout of Wingate test, and immediately analyzed using a portable lactate analyzer (Lactate Pro™ Test Meter, Lactate Pro; Arkray Inc., Kyoto, Japan). The lactate analyzer was calibrated as per the manufacturer’s guidelines prior to each testing.

Power, strength and flexibility
The Wingate variables recorded for each test included, anaerobic power (peak power divided by body weight), anaerobic capacity (mean power divided by body weight) and fatigue index (peak power minus minimum power divided by testing duration). The explosive power was determined by the maximum effort countermovement jump test using standard procedures (Yardstick, Swift Performance Equipment, New South Wales). The best of three attempts was recorded. Quadriceps strength was evaluated by measuring the 3-sec maximum isometric voluntary contraction force of the knee extensor muscles. In a sitting position (with the knee flexed at 80 degrees), athletes were verbally encouraged to exert a maximal force lasting 3 sec. A load cell (Tension/S-beam load cell, AST 500, PT instruments, UK, recording rate 10 Hz) attached to the ankle with a Velcro strap 3 cm above the medial malleolus was used to measure the force. Lower back and hamstring flexibility was evaluated using the traditional Sit and Reach test, for which the best of 3 attempts was recorded.

Exertion and muscle soreness
Subject’s ratings of perceived exertion were evaluated using the 15 point Borg’s scale (range, 6 to 20: 6 = no exertion; 20 = maximal exertion) (Borg, 1990). Muscle soreness was determined using a visual analogue scale (range, 0 to 10: 0 = no pain; 10 = the worst pain). The scale was previously validated as a reliable instrument for measuring pain intensity (Summers, 2001). Both scales were rated at baseline, immediately after HITT, and at 30 min and 60 min post exercise (before Wingate test). Only the muscle soreness score was rated during rest at 1, 2 and 3 days post exercise.

Muscle oxygenation
Muscle oxygenation was assessed by near-infrared spectroscopy (NIRS) (on a NIRS-200; Hamamatsu Photonics K.K; Hamamatsu, Japan) at three wavelengths (775, 810 and 850 nm). The NIRS probe consists of the emission and detection probes, and was securely attached to the middle portion of right vastus lateralis muscle at the mid-thigh level and parallel with the long axis of the muscle. Skin was shaved and marked with a permanent marker to ensure
repeated testing at the same location. The NIRS-200 provides changes in oxygenated hemoglobin (O$_2$Hb), deoxygenated hemoglobin (HHb) and derived changes in total hemoglobin (tHb = O$_2$Hb + HHb). NIRS-200 also provides tissue oxygen saturation as the tissue oxygenative index (TOI, percentage ratio of oxygenated to total hemoglobin). The probes were attached prior to any exercise and remained attached throughout the exercise and the 60-min recovery period. The NIRS data was analysed by averaging values during the 1 min pre-test, 1 min post-Wingate tests, initial 5 min and last 5 min of the recovery program and 1 min after the recovery program. After sixteen participants finished the WBV and active recovery, one week later a subset of six of the 16 participants repeated the testing without any recovery program to investigate differences in blood oxygenation without any recovery at all (passive recovery).

**Statistical Analysis**
A spreadsheet for the analysis of crossover trials (Hopkins, 2006) was used to estimate worthwhile differences and chances that true effects were substantial. The spreadsheet for within-subject modeling used unequal-variances t statistic to assess for statistically worthwhile differences among repeated measurement analysis (Hopkins, 1997). The smallest worthwhile change was set at 1% for performances and 0.20 standardized units (change in the mean divided by the between-subject SD at baseline) for physiological variables (Cohen, 1988). Uncertainties in the estimate of change are presented as the 95% confidence intervals and likelihoods that the true value of the effect was a substantial enhancement or impairment. P-values were also taken from the spreadsheet for researchers who are not accustomed to magnitude-based inference statistics.

**4.4 Results**

**Blood lactate**
Blood lactate concentration followed a similar pattern of change throughout the recovery period (Figure 5.3). Blood lactate concentration of WBV group and control group was 2.10 ± 0.94 and 2.36 ± 1.28 mmol.l$^{-1}$ at pre exercise, 14.98 ± 1.51 and 15.64 ± 2.58 mmol.l$^{-1}$ at post exercise immediately, 8.31 ± 3.40 and 7.19 ± 2.05 mmol.l$^{-1}$ at 30 min post exercise, and 8.16 ± 2.37 and 8.19 ± 3.26 mmol.l$^{-1}$ at 60 min post exercise. Relative to the control group blood lactate concentration was substantially higher 30 min post-exercise among participants undertaking WBV (Table 5.1).
Power, Strength, and Flexibility

Anaerobic capacity followed a similar pattern of change throughout the series of Wingate tests and during the recovery period (Figure 5.4) for both groups. Anaerobic capacity of the WBV and control group were, 9.48 ± 1.28 and 9.29 ± 1.37 watt.kg\(^{-1}\), 8.39 ± 1.22 and 8.41 ± 0.81 watt.kg\(^{-1}\), 8.04 ± 0.68 and 8.29 ± 1.38 watt.kg\(^{-1}\), 7.71 ± 1.09 and 7.98 ± 1.10 watt.kg\(^{-1}\), 7.51 ± 0.91 and 7.74 ± 0.76 watt.kg\(^{-1}\), 7.33 ± 1.97 and 7.84 ± 1.05 watt.kg\(^{-1}\), 9.28 ± 1.36 and 9.35 ± 1.50 watt.kg\(^{-1}\), 9.61 ± 1.12 and 9.53 ± 1.33 watt.kg\(^{-1}\), at 1\(^{st}\) test, 2\(^{nd}\) test, 3\(^{rd}\) test, 4\(^{th}\) test, 5\(^{th}\) test, 6\(^{th}\) test, 30 min and 60 min post exercise respectively. Anaerobic performance and fatigue index changed little between the WBV and active recovery groups during recovery with all differences being small and unclear (Table 5.1). In addition, relative to the active recovery group, WBV had little effect on recovery of MVC, jump power or flexibility at 30 and 60 min post exercise (Table 5.2).

Rate of Perceived Exertion

After strenuous exercise, RPE dramatically declined at 30 and 60 min post-test in both groups (post exercise immediately, 18.31 ± 1.62 for WBV and 18.19 ± 1.38 for control, 30 min post exercise, 9.62 ± 1.71 for WBV and 10.56 ± 2.10 for control, 60 min post exercise 8.22 ± 1.40 for WBV and 8.75 ± 2.44 for control). Changes between groups were trivial or unclear at 30 and 60 min post-test (Table 5.1).

Muscle soreness

Muscle soreness increased substantially immediately after the series of Wingate tests (at pre exercise, 0.88 ± 1.15 for WBV and 0.75 ± 0.93 for control, at post exercise immediately, 7.94 ± 1.61 for WBV and 8.13 ± 0.81 for control), however, there was little effect of WBV on muscle soreness recovery over the following 3 days (Figure 5.5).

Near-infrared spectroscopy (NIRS)

Figure 5.6 shows a typical tracing of O\(_2\)Hb, HHb, and TOI from the passive, active and WBV groups. The changing patterns of O\(_2\)Hb, HHb, tHb and TOI at the pre-test (rest), start of the recovery program (time point 0 after the 6 bouts of Wingate tests), 5 and 10 min post exercise (during the recovery program) and the post recovery program of all groups are illustrated in Figure 5.7.
Participants who underwent WBV as part of their recovery protocol had substantially higher O$_2$Hb levels (197.69 ± 68.46 µM.cm$^{-1}$, mean ± 95% CI) 10 min post exercise compared to either a traditional active recovery protocol (138.17 ± 35.58 µM.cm$^{-1}$) or passive recovery (119.43 ± 34.94 µM.cm$^{-1}$). The WBV group also had a substantially higher O$_2$Hb post recovery (after the 10 min recovery session) (227.12 ± 69.03 µM.cm$^{-1}$) compared to passive recovery (99.09 ± 36.60 µM.cm$^{-1}$). Participants who completed either the active recovery or passive recovery (control) protocols had similar O$_2$Hb levels throughout the recorded period. The active recovery group had substantially higher HHb levels 10 min post exercise and post recovery (106.49 ± 37.81, 12.49 ± 11.30 µM.cm$^{-1}$) compared to either the passive recovery (control) (-1.58 ± 36.45, -3.81 ± 36.48 µM.cm$^{-1}$) or WBV group (-64.26 ± 36.79, -31.11 ± 37.72 µM.cm$^{-1}$). The passive recovery group had substantially higher HHb levels than the WBV group for the same periods. The active recovery and WBV groups had substantially higher tHb levels 5 and 10 min post exercise and post recovery (223.36 ± 42.79, 244.66 ± 32, 163.28 ± 32.87; 197.54 ± 55.70, 133.42 ± 78.32, 196.00 ± 80.59 µM.cm$^{-1}$) compared to passive recovery (182.54 ± 20.29, 117.86 ± 23.83, 95.28 ± 25.26 µM.cm$^{-1}$). The active group had substantially higher tHb levels than the WBV group 10 min post exercise while the WBV group had substantially higher tHb levels than the active group post recovery. The active group had substantially lower TOI 10 min post exercise and post recovery (63.73 ± 3.75, 69.46 ± 1.81%) compared to the WBV group (74.50 ± 1.43, 72.19 ± 2.25%) and the passive recovery group (72.95 ± 2.89, 71.93 ± 2.39%). The WBV group had substantially higher TOI 10 min post exercise compared to the passive recovery group.
Table 4.1 Pre recovery (data collected immediately after the 6 Wingate tests but before any recovery strategy) and post recovery (30 min and 60 min) changes in blood lactate and anaerobic indices between groups and the chances that the two differences was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Pre recovery</th>
<th>Post recovery</th>
<th>% Change</th>
<th>% Difference ±95%CI</th>
<th>Chances that true differences are substantial*</th>
<th>Qualitative</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WBV</strong></td>
<td><strong>Active</strong></td>
<td><strong>WBV</strong></td>
<td><strong>Active</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lactate (mmol.L⁻¹)</td>
<td>14.98</td>
<td>15.64</td>
<td>-44.82</td>
<td>-53.32</td>
<td>8.51±9.00</td>
<td>96</td>
<td>Very likely</td>
</tr>
<tr>
<td></td>
<td>60 min</td>
<td>-45.20</td>
<td>-46.38</td>
<td>1.18±14.03</td>
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<td>Anaerobic power (watt.kg⁻¹)</td>
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<td>7.83</td>
<td>22.67</td>
<td>20.73</td>
<td>1.94±8.92</td>
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</tr>
<tr>
<td></td>
<td>60 min</td>
<td>27.07</td>
<td>22.81</td>
<td>4.26±11.27</td>
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<td>0.36</td>
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<tr>
<td>Anaerobic capacity (watt.kg⁻¹)</td>
<td>5.09</td>
<td>5.33</td>
<td>41.62</td>
<td>37.67</td>
<td>3.95±7.53</td>
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</tr>
<tr>
<td></td>
<td>60 min</td>
<td>46.51</td>
<td>38.33</td>
<td>8.18±6.88</td>
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<td>Unclear</td>
<td>0.17</td>
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<tr>
<td>Fatigue index (watt.sec⁻¹)</td>
<td>12.68</td>
<td>13.30</td>
<td>-5.63</td>
<td>-10.87</td>
<td>5.24±13.13</td>
<td>64</td>
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<tr>
<td></td>
<td>60 min</td>
<td>-9.42</td>
<td>-7.85</td>
<td>-1.57±18.93</td>
<td>18</td>
<td>Unclear</td>
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<tr>
<td>RPE</td>
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<td>18.19</td>
<td>-47.25</td>
<td>-41.65</td>
<td>-5.60±5.79</td>
<td>89</td>
<td>trivial</td>
</tr>
<tr>
<td></td>
<td>60 min</td>
<td>-55.01</td>
<td>-51.85</td>
<td>-3.16±5.46</td>
<td>70</td>
<td>Unclear</td>
<td>0.31</td>
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</table>

* Based on the smallest substantial set at 1% for performances and 0.20 standardized units for lactate and RPE ±95%CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (WBV, whole body vibration group; Active, active recovery group; RPE, rate of perceived exertion)
Table 4.2 Baseline (pre-test) and mean changes in the MVC, jump height and flexibility in the WBV and active recovery groups and the chances that true differences between groups was substantial.

<table>
<thead>
<tr>
<th></th>
<th>Base line (Pre-test)</th>
<th>% Change</th>
<th>% Difference ±95% CI</th>
<th>Chances that true differences are substantial*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBV</td>
<td>Active</td>
<td>WBV</td>
<td>Active</td>
<td></td>
</tr>
<tr>
<td>MVC (kg)</td>
<td>67.62</td>
<td>68.54</td>
<td>30 min</td>
<td>-8.72</td>
<td>-11.12</td>
</tr>
<tr>
<td></td>
<td>WBV</td>
<td>Active</td>
<td>60 min</td>
<td>-6.23</td>
<td>-6.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30 min</td>
<td>-3.44</td>
<td>-3.73</td>
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<td></td>
<td></td>
<td></td>
<td>60 min</td>
<td>-1.38</td>
<td>-4.46</td>
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<td></td>
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<td>1.46</td>
<td>2.24</td>
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<td></td>
<td></td>
<td></td>
<td>60 min</td>
<td>5.57</td>
<td>6.38</td>
</tr>
</tbody>
</table>

* Based on the smallest substantial change set at 1% for performances ± 95% CI: add and subtract this number to the mean effect to obtain confidence intervals for the true difference. (WBV, whole body vibration group; Active, active recovery group; MVC, 3-second maximal voluntary contraction)
Figure 4.3 Blood lactate concentration at the pre-test, immediately, 30 and 60 min post recovery in the WBV (open circles) and active recovery (closed circles) groups. Values are the mean ± SD.
Figure 4.4 Anaerobic capacity for 6 sets of Wingate tests, 30 and 60 min post recovery in the WBV (open circles) and active recovery (closed circles) groups. * substantial difference from test 1. Values are the mean ± SD.
Figure 4.5  Muscle soreness before and after WBV (open circles) or active (closed circles). Values are the mean ± SD.
Figure 4.6 Typical time course of $O_2$Hb, HHb, tHb and TOI changes for vastus lateralis monitoring from the pre-test to the post recovery program in the control (passive), active and WBV groups.
Figure 4.7 Changes in $\text{O}_2\text{Hb}$, HHb, tHb and TOI at the pre-test (rest), start of the recovery program (0 min after the 6 Wingate tests), 5 and 10 min during post recovery program and post (after the 10 min recovery program) for the control (triangles), active (closed circles) and WBV (open circles) groups. a, substantial difference between the WBV and the control, b, substantial difference between the active and control groups, c, substantial difference between the WBV and the active groups. Values are the mean ± SD.
4.5 Discussion

The novel finding of this study was that the WBV recovery program increased muscle oxygenation and muscle blood flow, and this may lead to more oxygen in the muscle tissue. However, we found WBV overall had similar effects to a traditional active recovery with metabolic and performance variables changing little between recovery types over the first hour after exercise.

Metabolism and performances

We found WBV during recovery was no better at decreasing blood lactate concentration after HITT than a traditional moderate-intensity active recovery. Moreover, at 30 min post exercise, WBV washed out lactate substantially less than the active program. However, the effect of WBV recovery on lactate clearance at 60 min post exercise was similar to the active program. The mechanism for eliminating blood lactate with WBV exercise may be similar to that of the active recovery program; namely by increasing blood perfusion for rapid distribution of lactate to be metabolized by the liver, heart, active and inactive muscles (Ahmaidi, et al., 1996; Bogdanis, et al., 1996; Corder, et al., 2000). It is known that WBV increases vasodilatation effects through an increase in shearing force at the vascular endothelium, which may release endothelium-derived vasodilators such as nitric oxide and prostaglandins (Lohman, et al., 2007; Lythgo, et al., 2009; Sackner, Gummels, & Adams, 2005) or by reducing the release of the vasoconstrictor substance (endothelin) from vascular smooth muscle (Nakamura, et al., 1995). However, this increased muscle blood flow did not seem to wash blood lactate at any faster in our subjects.

Our study demonstrated that WBV had similar effects to traditional protocols in terms of recovery of power and strength performance. Previous studies found active recovery enhanced power output and exercise performances via increasing blood perfusion compared to a passive recovery (Ahmaidi, et al., 1996; Bogdanis, et al., 1996; Corder, et al., 2000). Possible physiological mechanisms of WBV for the enhanced performance after a recovery program may be similar to the active program that would (a) increase delivery of oxygen, protein and other substances for muscle repair (b) remove muscle lactate, H^+, inorganic phosphate and free radical species and buffer blood pH (c) increase phosphocreatine (PCr) re-synthesis and contribution of aerobic metabolism energy supply (d) increase muscle temperature and reduce muscle swelling and stiffness (Allen, Lamb, & Westerblad, 2008; Bogdanis, et al., 1996; Weerapong, Hume, & Kolt, 2005).
Acidosis has been considered an important factor behind muscle fatigue. It is proposed that acidosis induces muscle fatigue by inhibition of energy metabolism enzymes in glycogenolysis and glycolysis, however, the evidence to support these hypotheses is lacking (Bangsbo, Madsen, Kiens, & Richter, 1996). Inorganic phosphate (P\textsubscript{i}) has recently been suggested as the major cause of muscle fatigue (Westerblad, Allen, & Lannergren, 2002). The accumulation of P\textsubscript{i} increases during muscle contraction mainly due to breakdown of phosphocreatine. Increased P\textsubscript{i} may decrease cross-bridge force production and myofibrillar Ca\textsuperscript{2+} sensitivity, stimulate the SR Ca\textsuperscript{2+} release channels in early fatigue, inhibit the ATP-driven SR Ca\textsuperscript{2+} and enter SR to reduce Ca\textsuperscript{2+} available for release in late fatigue (Westerblad, et al., 2002). Yoshida et al. (1996) found active recovery exercise rapidly decreased the appearance of P\textsubscript{i} and suggested that active recovery maintained blood flow, thereby increasing oxygen supply and effecting the elimination of lactate and P\textsubscript{i} (Yoshida, Watari, & Tagawa, 1996). Whole body vibration may eliminate P\textsubscript{i} to and muscle recovery in the same way as active recovery (i.e. by increasing muscle blood flow).

However, Edge et al. (2009) found no substantial effect of WBV on lactate clearance and sport performance (3-km time trial) when undertaken on the consecutive day compared to a control group (Edge, et al., 2009). The authors claimed that their WBV protocol at low frequency (12 Hz, 6 mm amplitude) may not be adequate to increase muscle blood flow and provide subsequent changes to enhance the recovery process. We used WBV protocol at higher frequency (30 Hz, 1-2 mm for stretching and 40 Hz, 4-5 mm for massage) similar to Bakhtiary et al. (2007) who used 50 Hz of local vibration applied to both sides quadriceps, hamstring and calf muscles, and found significant improvement of isometric maximum voluntary force of quadriceps muscles 24 hours post exercise compared to non vibration group (Bakhtiary, Safavi-Farokhi, & Aminian-Far, 2007). While our study used similarly higher frequency we were unable to show any performance benefit.

Similar to the active recovery program, it is thought that WBV training increases blood perfusion, thereby enhancing removal of lactate acid, H\textsuperscript{+} and other pain causing substances (i.e., bradykinin, serotonin and histamine) as well as reducing swelling and inflammation process from the working muscles (Ahmaidi, et al., 1996; Bogdanis, et al., 1996; Corder, et al., 2000; Zainuddin, Newton, Sacco, & Nosaka, 2005). We found WBV and the active recovery program had similar effects on reported muscle soreness after strenuous exercise in athletes. In contrast, Rhea et al. (2009) showed that stretching and massage in conjunction with vibration significantly reduced perceived pain compared to stretching only in untrained
volunteers (Rhea, et al., 2009). The differences between these two findings may be due to the fact that untrained subjects usually suffer more pain than trained athletes such as the rugby players in this study (Evans, et al., 1986). In addition, RPE changes after HITT exercise in the WBV group was similar to the traditional active recovery group. Suggesting exertion changed little between groups over the course of the study.

Our study showed that WBV had a similar effect on flexibility compared to the active recovery group. In contrast, Issurin et al. (1994) found that vibration during stretching exercise significantly increased leg and trunk flexibility compared to conventional stretching (by 7.5% and 37.8%, respectively) (Issurin, et al., 1994). The underlying physiological mechanisms are probably: reduction of the pain threshold, elevation of blood flow resulting in increasing muscle temperature and tissue compliance and excitation of Golgi tendon organs to inhibit contractions and relax muscles (Issurin, et al., 1994). Cronin et al. (2007) also found that segmental vibration training improved flexibility through improvement of dynamic motion of hamstring musculature by 1.6-2.1%, with greater improvement at a higher vibration load (Cronin, et al., 2007). The degree of flexibility improvement of WBV effect may be due to multiple factors including vibration parameters (Cronin, et al., 2007) or different positions of training. Further investigation for the effective vibration recovery protocol to improve flexibility is warranted.

**Muscle oxygenation**

This study found that WBV and the active recovery program increased muscle blood flow during recovery (i.e., an increase tHb levels indicates an increase in muscle blood flow) (Boushel, et al., 2001; De Blasi, et al., 1994), which may signal increased oxygen to the muscle compared to the non-exercise control group. Similarly, previous research found WBV increased the mean blood velocity in the common femoral artery (Lythgo, et al., 2009) and skin blood flow (Lohman, et al., 2007; Maloney-Hinds, et al., 2008). However, at the end of recovery program, the active recovery group had a higher tHb or muscle blood flow compared to the WBV group. During the Wingate test, both groups should be doing similar work, so the muscle blood flow should be about the same. While at the end of the recovery program, muscle blood flow was increased in the active group, probably due to the active recovery which probably requires more workload.

In addition, WBV increased muscle oxygenation (TOI) while the active program decreased muscle oxygenation. The underlying mechanism is probably linked to the vasodilatation
process (*i.e.*, increased $O_2$Hb, decreased HHb). While the active recovery probably increases muscle workload, thereby increasing the need for oxygen and also increasing the amount of HHb, the WBV recovery probably causes vasodilatation without the need for an increase in oxygen uptake at the muscles. In contrast, previous research revealed that WBV training increased oxygen utilization and reduced muscle oxygenation similar to light or moderate exercise (Mileva, Naleem, Biswas, Marwood, & Bowtell, 2006; Yamada, et al., 2005). However, Mileva et al. (2006) used WBV during squatting or knee extension exercises while our study used stretching and massage during WBV which probably produces less muscle workload and perhaps a greater vasodilatation effect. In terms of muscle oxygenation levels, stretch or massage during WBV may be more suitable as a recovery program than static or dynamic exercise during WBV.

Furthermore, we found the vasodilatation effect of WBV persisted until the post-recovery (*i.e.*, increased tHb, increased $O_2$Hb) compared to the active recovery and non-exercise control group. Likewise, previous studies have found a vasodilatation effect after WBV training (Lohman, et al., 2007; Zhang, Ericson, & Styf, 2003). Reduction of vasoconstrictor substance and increasing vasodilators may be preserved after vibration (Lohman, et al., 2007; Nakamura, et al., 1995). The vasodilatation after WBV recovery may well enhance blood flow to the muscle for longer, perhaps benefitting subsequent performances. Future research is required to investigate the post WBV vasodilatation effect on performance recovery, particularly aerobic performance since enhanced oxygenation of the muscle tissue should have its greatest effect on aerobic metabolism.

### 4.6 Conclusion

Overall, the WBV and the active recovery program had similar effects on lactate recovery, power, strength, flexibility, rate of perceived exertion and muscle pain after intensive exercise in rugby players. Monitoring of muscle oxygenation levels revealed that the WBV recovery program improved muscle oxygenation without the subsequent exercise in energy demand required by active recovery and therefore may be useful for recovery of the aerobic energy systems.
4.7 Acknowledgements

Special thank to the athletes for their contribution and participation, and Mr. Edzard Zeinstra and Ms. Karen Beard-Greer of the Powerplate Company for supporting this research.
4.8 References


Chapter 5
General Summary

Since the early 1990’s WBV technology has become more accessible and more popular, and although there are a number of studies on WBV, this technique is still relatively new and requires further investigation to reveal applications for both sport and medicine. My research projects investigated a number of questions regarding the effect of WBV on muscular performance, glucose metabolism, peripheral vascular, peripheral nervous systems, and recovery systems. The results of the three studies in my thesis have attempted to answer questions and add considerable new knowledge to the area of WBV training.

The first focus of my thesis was the effect of WBV on the muscular system. Chapter 2 revealed WBV has a large effect on muscle performance. I found that WBV has a significant and large positive effect on explosive power (jump height) compared to no exercise. WBV training probably stimulates muscle contraction, similar to exercise training, and subsequently improves muscle strength more than no exercise at all. Higher frequencies, higher amplitudes, longer exposures per session and longer training periods have significantly greater effects compared to lower frequencies, lower amplitudes, shorter exposures per session and shorter training periods. I also found the effect size of WBV training was higher for non-athletes compared to athletes. The findings indicated WBV may be more useful for sedentary people, elderly or diabetic patients. In addition, this study showed WBV has a moderate effect on jump height compared to more contemporary cardiovascular or weight lifting exercises. WBV may stimulate the shortening cycle or rapid movement of muscle more than cardiovascular or weight lifting exercises. WBV training may be more valuable for sports such as high jump or long jump. However, this study did not analyse muscle strength (i.e. isotonic and isometric force), muscle endurance and types of sport performance (i.e. sprinting, running, and cycling) because of the heterogeneity of measurements and the lack of reported studies. Also, the study did not perform sub-group analysis of the type or brand of machine used because of a variety of machines and the small number of reported studies in each type of machine. The different brands or types may produce different accelerations or forces which may affect the muscular system. Such analysis should be performed in the future when sufficient studies are available.
The results from the meta-analysis showed WBV increases muscle power from enhanced muscle contraction, thereby increased glucose uptake. Thus, I wanted to investigate the effect of WBV on glucose metabolism and other physiological systems in type II diabetics in chapter 3. The optimal vibration parameters from meta-analysis study (high frequency and high amplitude) were used in this diabetic intervention study. Overall, we found that 12 weeks of WBV training (using the vibration protocol identified as most effective in study 1) did not have significant effects on FBS, HbA1c, fasting insulin and insulin sensitivity in type II diabetic patients. It is probably due to the exercise volume of traditional WBV training which may not be sufficient to provide substantial changes. However, the heterogeneity of diabetic patients has affected our results. We found substantially decreased FBS and increased insulin sensitivity in poorly controlled diabetic patients (HbA1c ≥ 8), and substantially decreased FBS and HbA1c in relatively new diagnosed diabetic patients (≤ 5 years). It is likely that WBV stimulates muscle contraction leading to an increase in glucose uptake into muscle. The changing of insulin sensitivity is correlated to the intensity of training while the changing of HbA1c levels is correlated to the exercise volume (Segerstrom, et al., 2010). High load over a larger period of time may provide better results and requires more investigation.

A number of previous studies have indicated that local blood flow increased during acute WBV training; however, no study exists on peripheral vascular adaptation after regular WBV training. In chapter 3, I describe a novel study of peripheral vascular adaptation evaluated by ultrasound Doppler in diabetics after WBV training. The results showed a possible decrease in peak systolic velocity but no substantial change in end diastolic velocity, the diameter and resistance index of the femoral artery. A possible physiological mechanism underlying the change in peak systolic velocity is a decrease in peripheral vascular resistance due to vasodilatation adaptation of the arterioles. I also found a significant reduction in resting diastolic blood pressure, possibly due to reduced peripheral vascular resistance. These vasodilatory changes after regular WBV training may increase the blood supply or tissue oxygenation to the muscle which may be useful for ameliorating diabetic complications. From my research I can be reasonably assured that WBV enhances blood flow, compared to a non-exercise control group. The next stage would be the investigation of whether WBV is better than cardiovascular or resistive exercise programs.

Whole body vibration has been suggested to improve peripheral nerve function via an increase of blood perfusion. In chapter 3, however, I did not find any positive effect of regular
WBV training on nerve conduction or subjective numbness in the legs of diabetic patients. Previous research on animals showed that 1-hour of 1 g vibration improved nerve conduction time (Floyd, et al., 1973) whereas 5-day of vibration (82 Hz, 0.21 mm, 4 hours a day) produced myelin sheath and axonal damage (Lundborg, Dahlen, Hansson, Kanje, & Necking, 1990; Matloub, et al., 2005). The frequency and duration of vibration parameters may have differential effects on peripheral nerves (Chang, Ho, & Yu, 1994; Okada, 1986). Our WBV protocol may not have increased tissue perfusion enough to improve peripheral nerve function. Because of the unclear effect of most vascular parameters from ultrasound Doppler and nerve conduction velocity testing I wanted to know whether WBV actually does have any effect on blood perfusion. The study in chapter 4 was conducted and the results of chapter 4 suggested that vibration massage produced greater vasodilatation and tissue oxygenation compared to active recovery, and this may improve peripheral nerve function rather than WBV training in the squat position, which is what we used in the diabetic studies. Therefore, the most effective vibration parameters and positions of training including massage vibration require further investigation.

Chapter 4 results revealed the acute effect of WBV on local blood flow. This study found WBV training after strenuous exercise produced recovery effects on blood lactate, muscle power, muscle strength, flexibility, exertion and muscle soreness similar to traditional recovery programs. Although the results in performance recovery of both WBV and the active programs are similar, mechanisms behind recovery in those groups may be different. By monitoring oxygenation changes during the recovery programs, the study found that both WBV and the active recovery program increased local muscle blood flow. Additionally, WBV training increased muscle oxygenation, while the active recovery program decreased muscle oxygenation. These findings indicate WBV with stretching and/or massage (resting legs on platform) protocols provide more relaxation of the muscle compared to the active program and may be better at increasing oxygen content of muscle during the recovery. In conclusion, this study showed the acute effect of WBV was to increase both muscle blood flow and muscle oxygenation that may be useful for athletes during recovery. However, future investigation is needed particularly into the vibration parameters used and the different body positions required during WBV.

Finally, despite some reports of adverse effects (Crewther, et al., 2004; Cronin, et al., 2004), I found no adverse effect of WBV in either the diabetic or athlete performance experiments. I feel the progressive training approach taken in the chapter 3 and 4 may have helped patients
to become accustomed to vibration and therefore reduced the likelihood of adverse effects. Diabetic complications such as retinopathy or nephropathy may be susceptible to vibration training. The experiment in rhesus monkey showed chronic vibration (12 Hz, 5 hours a day, 5 day a week) produced intermittent hematuria and proteinuria, possibly from renal subcapsular haemorrhage (Wasserman & Badger, 1973). In human, the adverse effects of WBV in diabetic patients may be similar to exercise. Vigorous exercise may trigger vitreous haemorrhage or retinal detachment in severe diabetic retinopathy, and may increase urinary protein excretion (Sigal, et al., 2006). The adverse effects of high load WBV on diabetic complications should be investigated in the future, and commercial use of such training for diabetic patients should be closely monitored.

In summary, the thesis investigated the effect of WBV on multiple organ systems in athletes (healthy) and type II diabetic patients. I have summarized the overall thesis in the following diagram (Figure 5.1) which illustrates the health effects of WBV on increasing muscle contraction, hormonal and vasodilatation changes. (a) WBV stimulates reflex muscle contraction and enhances testosterone and growth hormones, thereby increasing muscle mass, muscle strength and power. The meta-analytic study provided strong evidence of a positive effect of WBV on jump height that may be useful for improving sport performances in athletes and for improvement of strength in sarcopenia patients and with age. (b) WBV increases muscle contraction and stimulates muscle glucose uptake by improving beta cell function and insulin sensitivity leading to improved glycemic control in type II diabetic patients. The diabetic study showed no substantial change of FBS, HbA1c, fasting insulin and increase insulin sensitivity after WBV training. However, substantial improvement of FBS and insulin sensitivity were found in poorly controlled diabetics, and substantial improvement of FBS and HbA1c were found in relatively new diagnosed diabetic patients which suggests WBV training may have a use for such subjects. (c) WBV generates vasodilatation effects by increasing endothelium-derived vasodilators and decreasing vasoconstrictors that may increase peripheral blood flow and reduces peripheral vascular resistance. We found a decrease in diastolic blood pressure and a decrease in peak systolic velocity in the femoral artery. This effect may help diabetic patients reduces cardiovascular risk from atherosclerotic complications. (d) The vasodilatation effect of WBV leading to increase tissue perfusion may be useful for improving diabetic peripheral nerve function. However, the effect of WBV on peripheral nerves remains unclear, no substantial change of latency, amplitude and velocity of lower limbs nerves were found in our study. (e) Vasodilatation effect of WBV may enhance vascular blood flow and muscle oxygenation which may be useful for performance recovery.
after strenuous exercise in athletes. The last study showed that a WBV recovery program increased muscle blood flow compared to passive recovery and increased muscle oxygenation compared to the active recovery program. However, I found little difference in lactate concentration, muscle strength, flexibility, fatigue and exertion between the WBV and the active recovery programs. The effect of a WBV recovery program may be more pronounced in the aerobic recovery therefore further research is required to ascertain this information.
Figure 5.1 Summary of the thesis (WBV, whole body vibration; HbA1c, glycosylated hemoglobin; S/D, systolic/diastolic ratio; O$_2$Hb, oxygenated hemoglobin; HHb, deoxygenated hemoglobin; tHb, total hemoglobin; TOI, tissue oxygenative index)
Conclusions

1. From the meta-analysis I found that WBV training has a moderate to large positive effect on jump height compared to no exercise, or a typical cardiovascular or weight lifting training program.

2. Higher frequencies, higher amplitudes, longer exposures per session and longer training periods are more likely to improve jump height than lower frequencies, lower amplitudes, shorter exposures per session and shorter training periods.

3. Non athletes are likely to improve jump height more than athletes.

4. Regular WBV training for 12 weeks substantially decreased FBS and increased insulin sensitivity in the poorly controlled type II diabetic patients (HbA1c ≥ 8).

5. Regular WBV training for 12 weeks substantially decreased FBS and HbA1c in the relatively new diagnosed type II diabetic group (≤ 5 years).

6. Regular WBV training significantly decreased diastolic blood pressure and possibly decreased peak systolic blood velocity in the femoral artery in type II diabetic patients.

7. Twelve weeks of WBV did not improve the function of peripheral nerves of type II diabetic patients.

8. WBV overall, had equal effects to a traditional active recovery with recovery of lactate and power, strength, flexibility, rate of perceived exertion and muscle pain being very similar.

9. By monitoring NIRS, WBV using our protocol (stretching and massage) increased muscle blood flow and muscle oxygenation post exercise. A similar duration more traditional active recovery program, however, increased muscle blood flow but decreased muscle oxygen.
Limitations

1. In chapter 2 (the meta-analysis study), errors may have been introduced as some individual articles did not provide data including standardized mean difference, standard deviation of mean difference, p-value or confidence interval. This data was derived by measurements from the graphs provided or estimated by calculation from actual data provided.

2. In chapters 3, I had planned to measure isometric, isotonic and isokinetic strength of knee extensors muscle by using isokinetic dynamometer (Cybex 6000®) and subsequently investigate the correlation between muscle strength and diabetes control. However, the machine was damaged during the experiment. Therefore I could not complete this analysis.

3. In chapter 4, there was a lack of a “passive recovery” control group. We attempted to ameliorate this problem by introducing a subgroup of 6 subjects, however, a full group with more subjects is warranted.

4. In diabetic study, I did not select patients according to severity of disease before the experiment which probably introduced some bias. For example, WBV may have positive effects on mild diabetes and may not have any effects on those with severe peripheral neuropathy.

5. In the recovery study, I did not measure MVC 3-sec, jump test and flexibility test immediately after intensive exercise as the athletes were too fatigued. Not collecting this data immediately may have affected the results.
Future research

1. A meta-analysis of the effects of WBV on isometric, isotonic, isokinetic muscle strength, muscle endurance, and speed should be conducted. This meta-analysis is currently precluded because of the small number of independent studies and the high variety of methods and outcomes.

2. A sub-group analysis of the above meta-analysis should be conducted to analyse factors like type of machine, vibration parameters, position of training and WBV combined with exercise. Again this analysis is currently precluded because of the small number of reported studies.

3. Significant benefits of a decrease in fasting blood sugar and an increase of insulin sensitivity for poorly controlled diabetics has been found. While a decrease of HbA1c was observed it was not substantial. Future WBV training research of a longer duration such as 6 months, may detect a more profound effect on HbA1c.

4. A long term study on type II diabetics could be conducted to investigate the efficacy and adverse effects of WBV.

5. Future research on diabetics could compare WBV to cardiovascular exercise and WBV combined which may or may not better than cardiovascular exercise in ameliorating the adverse effects of diabetes.

6. Vibration training protocols for diabetics needs refining, including frequency, amplitude, duration, position of training and type of machine parameters to ensure the most efficacious training method.

7. WBV recovery effects should be studied for other performance outcomes such as isotonic, isokinetic strength, muscle endurance, speed, sport specific skills and metabolic outcomes such as H⁺, creatinine kinase activity.

8. Effects of WBV on recovery in real sporting situations (during a half time break in soccer or rugby) as the outcome may be different compared to a laboratory setting.

9. Vibration parameters to maximize performance recovery need further investigation so that the most efficacious parameters (including frequency, amplitude, duration, position and type of machine) can be identified.


Appendix A
Questionnaires

Jadad’s Score

Please read the article and try to answer the following questions (see attached instructions):

1. Was the study described as randomized (this includes the use of words such as randomly, random, and randomization)?
2. Was the study described as double blind?
3. Was there a description of withdrawals and dropouts?

Scoring the items:
Either gives a score of 1 point for each “yes” or 0 points for each “no.” There are no in-between marks.

Give 1 additional point if: For question 1, the method to generate the sequence of randomization was described and it was appropriate (table of random numbers, computer generated, etc.)

and/or: If for question 2 the method of double blinding was described and it was appropriate (identical placebo, active placebo, dummy, etc.)

Deduct 1 point if: For question 1, the method to generate the sequence of randomization was described and it was inappropriate (patients were allocated alternately, or according to date of birth, hospital number, etc.)

and/or: For question 2, the study was described as double blind but the method of blinding was inappropriate (e.g., comparison of tablet vs. injection with no double dummy)

Guidelines for Assessment

1. Randomization
A method to generate the sequence of randomization will be regarded as appropriate if it allowed each study participant to have the same chance of receiving each intervention and the investigators could not predict which treatment was next. Methods of allocation using date of birth, date of admission, hospital numbers, or alternation should be not regarded as appropriate.

2. Double blinding
A study must be regarded as double blind if the word “double blind” is used. The method will be regarded as appropriate if it is stated that neither the person doing the assessments nor the study participant could identify the intervention being assessed, or if in the absence of such a statement the use of active placebos, identical placebos, or dummies is mentioned.
3. Withdrawals and dropouts
Participants who were included in the study but did not complete the observation period or who were not included in the analysis must be described. The number and the reasons for withdrawal in each group must be stated. If there were no withdrawals, it should be stated in the article. If there is no statement on withdrawals, this item must be given no points.
INTERNATIONAL PHYSICAL Activity QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. This is part of a large study being conducted in many countries around the world. Your answers will help us to understand how active we are compared with people in other countries.

The questions are about the time you spent being physically active in the last 7 days. They include questions about activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Your answers are important.

Please answer each question even if you do not consider yourself to be an active person.

THANK YOU FOR PARTICIPATING.

In answering the following questions,

- **vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal.

- **moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

This is the final SHORT LAST 7 DAYS SELF-ADMINISTERED version of IPAQ from the 2000/01 Reliability and Validity Study. Completed May 2001.
1a. During the last 7 days, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

Think about *only* those physical activities that you did for at least 10 minutes at a time.

__________ days per week ⇒ 1b. How much time in total did you usually spend on one of those days doing vigorous physical activities?

  or

□ none

__________ hours _______ minutes

2a. Again, think *only* about those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

__________ days per week ⇒ 2b. How much time in total did you usually spend on one of those days doing moderate physical activities?

  or

□ none

__________ hours _______ minutes

3a. During the last 7 days, on how many days did you **walk** for at least 10 minutes at a time? This includes walking at work and at home, walking to travel from place to place, and any other walking that you did solely for recreation, sport, exercise or leisure.

__________ days per week ⇒ 3b. How much time in total did you usually spend walking on one of those days?

  or

□ none

__________ hours _______ minutes

The last question is about the time you spent **sitting** on weekdays while at work, at home, while doing course work and during leisure time. This includes time spent sitting at a desk, visiting friends, reading traveling on a bus or sitting or lying down to watch television.

4. During the last 7 days, how much time in total did you usually spend **sitting** on a **week day**?

   _______ hours _______ minutes

   *This is the end of questionnaire, thank you for participating.*
แบบสอบถามการสื่อสารในวาระสถานกิจการ

วิเคราะห์พฤติกรรมสื่อสารในห้องประชุม ที่ 10

1. ในการสื่อสารให้แสดงความคิดเห็นอย่างมีเหตุผลและชัดเจน สืบทอดความคิดเห็นอีกครั้งหรือไม่ หรือไม่แสดงความคิดเห็นอีกครั้ง (กรุณาเลือกว่าทางเลือกที่ท่านท่านมีอยู่) 10 นาที

2. ดูปากคำที่ว่าจะตอบอย่างไรในวันนี้ (กรุณาเลือกว่าทางเลือกที่ท่านที่ท่านมีอยู่) 7 นาที
3. ในช่วง 7 วันที่ผ่านมา มีที่ว่างที่พักได้ไม่ลดลงในระหว่างวันหยุดบ่ายถึงกลาง เข้าถึงของบุคคล บ้านเจ้าของที่ไม่เข้ามา หรือเป็นคนเกี่ยวกับการหัน

______________________วันต่อสัปดาห์

______________________ไม่มีการลดลงในระหว่างวันหยุดบ่ายถึงกลาง (ข้ามไปข้อ 4)

4. ตามปกติแล้ว ท่านใช้เวลาที่พักได้ไม่ลักลอบวัชรยศรีในวันหยุดสัปดาห์ที่ผ่านมา

______________________ช่วงไม่ต่อวัน

______________________นาทีต่อวัน

☐ ไม่ทราบ/ไม่แน่ใจ

ให้บอกถึงเวลาที่ท่านใช้ในการพักได้ในช่วง 7 วันที่ผ่านมา ซึ่งรวมถึงที่ท่านพักและที่ท่านพักการเดินทางโดยการเดิน
จากที่ท่านพักไปสู่ที่พักต่อไป และการเดินทางในช่วงเวลาที่ท่านพักเพื่อการทำพักผ่อนหรือใช้เวลาอื่นใด ใน
ระยะเวลา

5. ในช่วง 7 วันที่ผ่านมา มีที่ว่างที่พักได้อย่างน้อย 10 นาทีในแต่ละครั้งของการพัก

______________________วัน องค์สัปดาห์

☐ ไม่ได้พัก (ข้ามไปข้อ 7)

6. ตามปกติท่านใช้เวลาในการพักได้ในช่วงวันหยุดสัปดาห์ที่ผ่านมา

______________________ช่วงไม่ต่อวัน

______________________นาทีต่อวัน

☐ ไม่ทราบ/ไม่แน่ใจ
คำถามข้อสุดท้ายจะเกี่ยวกับเวลาที่พนักงานในช่วงวันระหว่างสิบปลายที่ผ่านมา (ไม่รวมวันเสาร์และอาทิตย์)
รวมถึงเวลาที่ใช้ในการทำงานที่บ้าน ระหว่างการพักผ่อน ทั้งนี้อาจรวมถึงเวลาที่ใช้กิจกรรม กายวิบัติสั้นที่
การนอน หรือ การนั่ง หรือมั่นอยู่ที่ขี่

7. ในช่วง 7 วันที่ผ่านมา ท่านใช้เวลาที่บ้านอย่างไรภาพในการมั่นใจในช่วงวันระหว่างสิบปลาย

__________________________ ช่วงไม่ต้องวัน

__________________________ บางวันต้องวัน

☐ ไปทราบ/ไม่แน่ใจ

แบบสอบถามดีพิเศษที่นี้ จะจบขั้นตอนในความร่วมมือ
Self-Report Checklist

Please check (tick the box) if you know you have any diseases?

☐ Stroke  ☐ Heart disease  ☐ Diabetic retinopathy  ☐ Renal failure  ☐ Diabetic ulcer  ☐ Peripheral neuropathy  ☐ Lung disease  ☐ Back pain  ☐ Degenerative joint disease  ☐ Cancer  ☐ Psychological disease  ☐ Other (please specify……………………………………………………………………)

Please check (tick the box) if you have any symptoms during last 7 days?

☐ Headache  ☐ Fainting  ☐ Dizziness  ☐ Weakness  ☐ Numbness  ☐ Blurred Vision  ☐ Chest pain  ☐ Difficulty to breath  ☐ Abdominal pain  ☐ Nausea  ☐ Diarrhea  ☐ Back pain  ☐ Lower limb pain  ☐ Fever  ☐ Sore throat  ☐ Cough  ☐ Insomnia  ☐ Weight loss  ☐ Other symptoms (please specify……………………………………………………………………)

Hospitalizations: Please list recent hospitalizations (Women; do not list normal pregnancies)
........................................................................................................................................................................................................................................................................................................

Any other medical problems/concerns not already identified? Yes ☐ No ☐ (Please list below)
........................................................................................................................................................................................................................................................................................................

..............................
EXERCISE SAFETY QUESTIONNAIRE

FOR YOUR SAFETY PLEASE ANSWER THE FOLLOWING QUESTIONS AS THOROUGHLY AS YOU CAN. IT IS IMPORTANT TO CHECK EACH ITEM CAREFULLY.

PERSONAL INFORMATION

Name: ____________________________________________________________________________

Sex:     M / F          Age: ____________________________               Birth Date: _____/_____/____

Weight (kg) ____________Height (m) ___________Waist (cm) __________  Hip (cm) __________

Address:__________________________________________________________________________

Telephone: _____________ (hm) ______________ (wk)

Email:_______________________________

Emergency: Contact Name: _________________________________Telephone: ______________

1. Have you ever had any injury, illness, back or joint injury, muscular pain that may be aggravated by vigorous exercise? Yes/No

2. Have you ever had: Arthritis, Asthma, Diabetes, Epilepsy, Hernia, Ulcer or Dizziness? Yes/No

3. Have you ever had a heart Condition, High Blood Pressure, Stroke, High Cholesterol, pains in the chest? Yes/No

4. Have any immediate family members had heart problems prior to age 60? Yes/No

5. Are you taking any prescribed medication? Yes/No

6. Have you been hospitalized recently? Yes/No

7. Do you any physical disabilities that will limit your ability to participate in vigorous to maximal exercise? Yes/No

8. Have you ever been going to your normal training sessions and participate vigorous to maximal exercise regularly? Yes/No

9. Is there any reason not mentioned above that may prevent or affect your ability to perform physical exercise? Or have you recently been advised not to participate in exercise? Yes/No

IF YOU ANSWERED YES TO ANY OF THESE QUESTIONS PLEASE PROVIDE MORE INFORMATION

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________
I ___________________________state to the Environment Society and Design Faculty of Lincoln University that I have finished details of any medical condition I have had, and all recent medical treatment received by me. I also state that all questions stated in this form have been answered to my satisfaction.

Signed_____________________________________               Date________/________/_______
Witness____________________________________               Date_______/________/________
### Rate of Perceived Exertion (RPE) Scale

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Very very light</td>
</tr>
<tr>
<td>7</td>
<td>Very light</td>
</tr>
<tr>
<td>8</td>
<td>Very light</td>
</tr>
<tr>
<td>9</td>
<td>Fairly light</td>
</tr>
<tr>
<td>10</td>
<td>Fairly light</td>
</tr>
<tr>
<td>11</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>12</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>13</td>
<td>Hard</td>
</tr>
<tr>
<td>14</td>
<td>Hard</td>
</tr>
<tr>
<td>15</td>
<td>Very hard</td>
</tr>
<tr>
<td>16</td>
<td>Very hard</td>
</tr>
<tr>
<td>17</td>
<td>Very very hard</td>
</tr>
<tr>
<td>18</td>
<td>Very very hard</td>
</tr>
<tr>
<td>19</td>
<td>Very very hard</td>
</tr>
<tr>
<td>20</td>
<td>Very very hard</td>
</tr>
</tbody>
</table>
Muscle Soreness Ratings

Name.................................................................................. Testing Session........................................................

Please record your overall perceived soreness of muscles in both legs by doing a full squat to the ground and placing a ● on the appropriate position on the line to indicate your level of soreness experienced.

E.g. I do not have any soreness

<table>
<thead>
<tr>
<th></th>
<th>Visual Analogue Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>My soreness could</td>
</tr>
<tr>
<td></td>
<td>not be worse</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Researcher Use Only</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>I do not have any soreness</th>
<th>My soreness could not be worse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post immediately</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post 30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post 60 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post day 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post day 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post day 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

Ethical Approval
The Project Entitled: Health effect of whole body vibration in diabetes: a randomized controlled trial

Principle Investigator: Dr. Nuttaset Manimmanakorn, MD.

Address: Rehabilitation Medicine Department, Faculty of Medicine, Khonkaen University

Documents Acceptance:

1. KKU Application form 2, Thai version 1.4, dated 7 January 2010
2. Protocol Final version 1.0, dated 1 December 2009
3. Informed Consent Form: Final version 1.2, dated 3 February 2010
4. Informed Assent Form: Final version 1.0, dated 1 December 2009
5. Case Report Forms version 1.0, dated 8 January 2010
6. Curriculum vitae
7. Data Collection Form version 1.0, dated 1 December 2009

Has been reviewed and approved by the Ethics Committee of the Khon Kaen University, based on the Declaration of Helsinki and ICH-GCP.

Date of Approval: 5 February 2010
Date of Expire: 16 December 2010

Associate Professor Jiraporn Srinakarin, M.D.
Chairman,
The Khon Kaen University Ethics Committee for Human Research
Application No: 2009-52  

Title: Health effect of whole body vibration in diabetes: a randomized controlled trial

Applicants: Nuttaset Maninmanakorn

The Lincoln University Human Ethics Committee has reviewed the above noted application.

Dear Nuttaset

Thank you for your detailed response to the questions which were forwarded to you on the Committee's behalf.

The project is approved subject to you including in the Research Information Sheet the following sentences:
"Exercise testing can very rarely cause irregularity of the heart beat, or even more rarely cardiac arrest. As the exercise test is being conducted in a hospital setting full recovery from such events is likely". Please advise me of your response to this addition.

I am pleased to give final approval to your project and may I, on behalf of the Committee, wish you success in your research.

Yours sincerely

Professor Grant Cushman
Chair, Human Ethics Committee

cc: Mike Hamlin, Jenny Ross

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.
Application No: 2010-26

Title: Whole body vibration training for promoting exercise recovery

Applicant: Nuttaset Manimmanakorn

The Lincoln University Human Ethics Committee has reviewed the above noted application.

Dear Nuttaset

Thank you for your detailed response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed.

I am pleased to give final approval to your project and may I, on behalf of the Committee, wish you success in your research.

Yours sincerely

[Signature]

Professor Grant Cushman
Chair, Human Ethics Committee

cc: Assoc Profs M Hamlin, J Ross

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.
Appendix C

Information Sheet, Consent Forms
ชื่อโครงการวิจัย:Whole body vibration ต่อสุขภาพของผู้ป่วยเบาหวาน
หัวหน้าโครงการวิจัย: ผศ.นพ. ณัฐเศรษฐ มนิมนากร

มาตรการ:

โรคเบาหวานเป็นโรคที่เป็นปัญหาสำคัญ ในประเทศไทยความชุกของโรคเบาหวานอยู่ที่ 9.6% หรือมีจำนวน 2,400,000 คนในปี 2000 โรคเบาหวานเป็นโรคที่มีความผิดปกติทำให้เกิดระดับน้ำตาลในเลือดสูง มีอิทธิพลต่อพัฒนาการและสุขภาพของผู้ป่วย โรคเบาหวานแบ่งได้เป็น 2 ชนิด ชนิดที่ 1 เกิดจากความผิดปกติของเซลล์ที่ผลิตอินซูลิน ที่ต่อมที่ 2 เป็นชนิดที่พบบ่อยที่สุด ซึ่งเกิดจากความผิดปกติของการหลั่งอินซูลิน หรือเกิดจากการที่เซลล์ต้านต่ออินซูลิน การที่มีระดับน้ำตาลในเลือดสูงเป็นเวลานาน จะทำให้เกิดภาวะแทรกซ้อน ได้แก่โรคหัวใจ, โรคหลอดเลือด, โรคเบาหวาน, โรคตา, โรคไต และโรคประสาท

การรักษาโรคเบาหวานประกอบด้วยการควบคุมอาหาร การออกกำลังกาย และการใช้ยา ปัจจุบันมีการนำเครื่องออกกำลังกายแบบสั่น (Whole body vibration) มาใช้เพื่อเพิ่มประสิทธิภาพการรักษาผู้ป่วยเบาหวาน แต่ผลงานวิจัยที่ผ่านมาเหมือนกันจะสามารถนำมาขยายตัวในเลือดได้ แต่จะยังไม่ได้ข้อสรุป ดังนั้น จำเป็นต้องมีการวิจัยเพิ่มเติมเพื่อนำเครื่องมือนี้มาใช้รักษาผู้ป่วยเบาหวานและป้องกันภาวะแทรกซ้อนจากโรคนี้

วัตถุประสงค์ของการวิจัย:

1. เพื่อศึกษาผลของการออกกำลังกายแบบสั่นในการลดระดับน้ำตาลในเลือดและเพิ่มอินซูลินในผู้ป่วยเบาหวาน
2. เพื่อศึกษาผลของการออกกำลังกายแบบสั่นต่อการเพิ่มความแข็งแรงของกล้ามเนื้อ การไหลเวียนของเลือดและเพิ่มความเร็วของเส้นประสาทส่วนปลาย

การเข้าร่วมโครงการวิจัยของคนเป็นไปด้วยความสมัครใจ

การเข้าร่วมโครงการเป็นความสมัครใจ หากท่านไม่ยินดีเข้าร่วม ไม่มาตรฐานใดๆ ต่อการรักษาพยาบาล ทั้งในปัจจุบันและอนาคต และหากท่านต้องการจะถอนตัวออกจากโครงการได้ทุกเวลาโดยไม่มีผลกระทบต่อการรักษาพยาบาล

ขั้นตอนการปฏิบัติตามท่านเข้าร่วมโครงการวิจัย:

ถ้าท่านตัดสินใจเข้าร่วมในการวิจัยและเข้าร่วมเป็นหลักฐานในแบบยินยอมอาสาสมัครแล้ว ท่านจะต้องมีการสัมภาษณ์และบันทึกข้อมูลความเจ็บป่วย ตรวจระดับน้ำตาลในเลือดและฮอร์โมนอินซูลิน และตรวจความแข็งแรงของกล้ามเนื้อ ปอด และหัวใจ โดยการปั่นจักรยาน ตรวจความแข็งแรงของเส้นประสาทส่วนปลายโดยใช้ไฟฟ้ากระตุ้นและตรวจการไหลเวียนของเลือดโดยใช้เครื่องอัลตราซาวด์ ท่านจะถูกสุ่มให้ไปร่วมในการวิจัย แล้วจะถูกสุ่มเข้าร่วมในกลุ่มทดลองหรือกลุ่มควบคุม

ความเสี่ยงและ/หรือความไม่สบายที่อาจเกิดขึ้น:

อาสาสมัครบางคนอาจมีปัญหา ต่อข้อ ปวดหลัง ปวดตามข้อสะโพก ข้อเข่า ข้อเท้า อาการดังกล่าวไม่ใช่สาเหตุการขอเลิก ยอม revoke ตามท่านสามารถถอนตัวจากการวิจัยได้เมื่อต้องการ
ประโยชน์ที่อาสาสมัครจะได้รับ

การทำงานจะได้รับการตรวจเป็นพิเศษ ตรวจระดับน้ำตาลในเลือดและฮอร์โมนอินซูลิน ตรวจความแข็งแรงของกล้ามเนื้อ ปอด และหัวใจ ตรวจการทำงานของระบบทางเดิน ตรวจความแข็งแรงของกล้ามเนื้อ ปอด และหัวใจ ตรวจการทำงานของระบบทางเดิน โดยไม่เสียค่าใช้จ่าย ค่าใช้จ่ายในการวิจัย /ค่าชดเชยเดินทาง/ค่าเสียเวลา ค่าเดินทางสำหรับการใช้เครื่องออกกำลังกายครั้งละ 50 บาท (สัปดาห์ละ 3 ครั้ง ระยะเวลา 3 เดือน)

การรักษาความลับ

ข้อมูลผู้ป่วยถือว่าเป็นความลับ มีระบบรักษาความลับ โดยใช้ระบบฐานข้อมูล การเชื่อมต่อข้อมูล จัดระบบป้องกันการเชื่อมต่อจากผู้ไม่ได้รับอนุญาต การเชื่อมต่อข้อมูล 2 ส่วน จะทำได้โดยไม่ได้รับอนุญาตจากทีมวิจัย เมื่อจำเป็นเท่านั้น การเผยแพร่ข้อมูลส่วนตัวของผู้ป่วย ต้องได้รับอนุญาตจากผู้ป่วยเท่านั้น

ชื่อ/ที่อยู่โทรศัพท์ของผู้รับผิดชอบโครงการวิจัยที่ติดต่อได้สะดวก

ผศ.นพ.ณัฐเศรษฐมนิมนากร
ภาควิชาเวชศาสตร์ฟื้นฟู คณะแพทยศาสตร์ มหาวิทยาลัยขอนแก่น
โทร 043-348392-043 และ โทรสาร 043-348392
เบอร์ภายใน 4123, 4124

หมายเหตุ:
1. ผู้วิจัยควรมอบแบบยินยอมอาสาสมัครพร้อมแบบคำชี้แจงอาสาสมัครอย่างละ 1 ชุด ให้อาสาสมัคร หรือ ผู้ปกครองด้วย
2. เมื่อเกิดการวิจัยทางคลินิก (เพื่อการรักษาหรือเกิดอุบัติเหตุ) เกี่ยวกับอาสาสมัครซึ่งต้องการข้อมูลเพิ่มเติมหรือการช่วยเหลือ (เช่นผู้เยาว์ หรือผู้ป่วยโรคประสาท) อาสาสมัครจะได้รับการช่วยเหลือจากทีมวิจัย ด้วยวิธีที่เหมาะสมที่อาสาสมัครต้องการ เข้าใจได้ และยินยอมให้อาสาสมัครรับคำแนะนำและร่วมใจในการยินยอมด้วยตนเอง
แบบยินยอมอาสาสมัคร

ข้าพเจ้า (นาย, นาง, นางสาว)…………………………………นามสกุล…………………………………อายุ………ปี
อยู่บ้านเลขที่…………พื้นที่…………ตําบล…………อำเภอ………………จังหวัด…………
เป็น ตัวผู้ป่วยเอง/บาดเจ็บมาจากผู้ดูแลของ………………………………………………………อายุ………ปี
ได้รับแจ้งค่าอธิบายจาก…………………………………………………………………………….(ชื่อผู้ให้ข้อมูล)

เกี่ยวกับการเป็นอาสาสมัครในโครงการวิจัย เรื่อง ผลของเครื่องออกกำลังกายแบบสั่น (Whole body vibration) ต่อผู้ป่วยเบาหวานได้รับทราบถึงรายละเอียดของโครงการวิจัยเกี่ยวกับ
- วัตถุประสงค์และระยะเวลาที่ทำการวิจัย
- ขั้นตอนและวิธีการปฏิบัติที่ข้าพเจ้าต้องปฏิบัติ
- ผลประโยชน์ที่ข้าพเจ้าจะได้รับ
- ผลข้างเคียงหรืออันตรายที่จะเกิดขึ้นจากการเข้าร่วมโครงการ

และข้าพเจ้าสามารถถอนตัวจากการศึกษาได้โดยไม่เสียสิทธิ์ใดๆ ในการรับการรักษาพยาบาลที่จะเกิดขึ้นตามไปในโครงการต่อไปนี้ในบริษัทและอนาคต ณ สถานพยาบาลแห่งนี้หรือสถานพยาบาลอื่น และหากเกิดมีอาการข้างเคียง ข้าพเจ้าจะรายงานให้แพทย์หรือเจ้าหน้าที่ที่กำลังปฏิบัติงานอยู่ในขณะนั้นทราบทันที

ข้าพเจ้าได้อ่านและเข้าใจค่าอธิบายข้างต้นแล้ว จึงได้ลงลายมือชื่อเป็นอาสาสมัครของโครงการวิจัยดังกล่าว

ลายมือชื่ออาสาสมัคร…………………………………………………………
(…………………………………………)

ลายมือชื่อผู้คุมหลัก……………………………………………………
(…………………………………………)

ลายมือชื่อผู้ให้ข้อมูล……………………………………………………
(…………………………………………)

พยาน………………………………………………………………………………(ไม่ใช่ผู้อธิบาย)
(…………………………………………)

วันที่…………เดือน……………พ.ศ.…………

หมายเหตุ: (1) ในกรณีที่อาสาสมัครเป็นเด็กต่ำอายุไม่ถึง 18 ปีสามารถตัดสินใจได้ ให้ลงลายมือชื่อลงลายมือชื่ออาสาสมัคร (เด็ก) และผู้ปกครองตัวยินดี
(2) พยานต้องไม่ใช่แพทย์หรือผู้วิจัย
(3) ผู้ให้ข้อมูลต้องมีคุณสมบัติอย่างน้อยไม่เป็นแพทย์หรือผู้วิจัยเพื่อป้องกันการเข้าร่วมโครงการด้วยความแท้จริง
(4) ในกรณีที่อาสาสมัครไม่สามารถลงลายมือชื่อได้ ให้ใช้การประทับลายมือแทนดังนี้

พยาน………………………………………………………………………………(ไม่ใช่ผู้อธิบาย)
(…………………………………………)

วันที่…………เดือน……………พ.ศ.…………

ชื่ออาสาสมัคร…………………………………(ชื่อผู้ให้ข้อมูล)
(…………………………………………)

พยาน………………………………………………………………………………(ไม่ใช่ผู้อธิบาย)
(…………………………………………)

วันที่…………เดือน……………พ.ศ.…………
Research Information Sheet

Project name: Health effects of whole body vibration in diabetics

You are invited to participate as a subject in the above project. Your participation is voluntary and you or your data may be withdrawn at any time during the study, up until the results are analysed (May 2010). If you decline to involve in the research, it will not affect your treatment.

The aim of this project is:
This study is a part of my PhD research, which aims to investigate the effects of whole body vibration exercise on the strength, fitness, blood sugar, nerve conduction and vascular blood flow in diabetes type II patients. If these effects are positive, they are likely to improve your health, to reduce blood sugar and to reduce diabetic complications.

Your participation in this project will involve:

You will be interviewed for some personal data such as age, contact details, medical history and physical activity. If you have serious health problems such as uncontrolled hip, knee, ankle pain, and serious medical problems, you will be excluded from this study.

You will be randomised to either a vibration therapy group or control group. If you are in vibration therapy group, you will receive whole body vibration therapy by standing on vibratory platform for 15 minutes per day, 3 days per week over a 3 month period. If you are in control group, you will go about your normal daily activity without any vibration therapy.

You will spend about 15 minutes in the clinic when we will obtain a 5-10 ml of blood sample to monitor fasting blood sugar and fasting blood insulin. The blood sample will be taken by way of a needle prick a total of 4 times at pre test, after 1st month, after 2nd month and post test.

You will be tested for muscle strength, fitness, nerve conduction velocity and blood flow two times during the study (pre and post test). This testing will take about 2 hours of your time for pre test and again 2 hours for the post test.

The muscle strength test of your leg will be measured by special machine (Biodex). You will be asked to extend your leg or lift a weight as much as you can. The fitness test will be measured by calculation from your heart rate while you are riding on a stationary bicycle. Nerve conduction velocity will be measured by using electrical stimulation on both your legs while you are lying on the bed in laboratory. Peripheral blood flow will be measured by finding the ratio of blood pressure of leg and arm.

In the procedure of research, there are risks of:

- Additional bleeding, minor bruising or swelling after the needle prick
- A small amount of pain/discomfort felt during pricking and electrical stimulation
- Minor musculoskeletal soreness during strength test
- Hypoglycaemia, fainting and chest pain during fitness test
- Back pain and lower limbs pain during vibration training, which may continue subsequent to training
The results of the project may be published, but you may be assured of complete anonymity, furthermore only aggregated data will be used in any publications. To ensure anonymity and security the following steps will be taken:

Data will be transferred from the data sheets to a computer, which will be password protected. The data sheets and consent forms will be placed under secure storage in the researcher’s office and after the study, placed in the Lincoln University Archive Room. These will be destroyed after 6 years.

The Project is being carried out by:

**Name of Principal Researcher:** Mr. Nuttaset Manimmanakorn  
**Contact details:** Rehabilitation Medicine Department, Faculty of Medicine, KhonKaen University, KhonKaen, 40002, Thailand  
Home phone 66 43 258213, Office 66 43 348392 Mobile 66 898898628  
Email: nuttaset.manimmanakorn@lincolnuni.ac.nz

**Name of Supervisor/Group Leader/Divisional Director:**  
Associate Prof. Dr. Mike Hamlin  
**Contact Details:** Department of Social Science, Parks, Recreation, Tourism & Sport, 6th Floor Forbes Building, PO Box 84, Lincoln University, 7647 Christchurch, New Zealand  
Phone 64 3 3253820  
Email: mike.hamlin@lincoln.ac.nz

They will be pleased to discuss any concerns you have about participation in the project.

The project has been reviewed and approved by Lincoln University Human Ethics Committee and the KhonKaen University Ethics Committee.
Consent Form

Name of Project: Health effects of whole body vibration in diabetics

I have read and understood the description of the above-named project. I understand that I will be required to complete a pre and post test and four blood tests during the study. If I am in the experimental group, my involvement will require me to be available for 3 months (3 days per week, 15 minutes per day) for whole body vibration training. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved. I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided up until the time the results are analysed (May 2010).

Name: ...........................................................................................................

Signed:............................................................. ....Date:...........................................
The aim of this project is:
This study is part of my PhD research, which aims to investigate effect of whole body vibration training after high intensity exercise on the ability of the body to remove blood lactate, increase muscle oxygenation, improve muscle strength, flexibility and sport performance, and reduce potential of muscle soreness, compared with a conventional recovery programs. The goal is to improve the ability of your muscle to recover after intensive exercise.

Whole body vibration is a new tool for health improvement. It is now widely used in physiotherapy, rehabilitation and sport science. Whole body vibration is applied via a platform which transmits oscillatory motion to the person who usually stands on the platform.

Your participation in this project will involve:
You will be a voluntary participant in both whole body vibration and conventional recovery programs. You will be randomised to either a vibration group or control group (the conventional recovery program), and then after 1 week of a wash out period you will reverse groups. In both groups, you will perform high intensity bicycle exercise about 10-15 minutes in duration, followed by recovery program. If you are in vibration group, you will stand on a vibration platform for 10 minutes after the exercise. If you are in conventional program, you will do light intensity exercise for 5 minutes and stretching exercise for 5 minutes. You will be asked to complete the following tests: blood lactate, muscle strength, muscle power, muscle flexibility, sport performance and vascular blood flow. Each test will take approximately 5-10 minutes each. You will do these tests pre and immediately post exercise then at, 30 minutes and 60 minutes post exercise. You will be asked to rate muscle soreness at the same time of other tests and day 1, day 2 and day 3 after exercise by phone or e-mail.

Some personal data will be collected such as age, contact details, and medical history. If you have serious health problems such as uncontrolled hip, knee, ankle pain, or any serious medical problems, you will be excluded from this study.

The lactate test is completed by analysing a drop of blood taken from your finger tip. You will be pricked at the finger tip by thin lancet with standard aseptic technique.

Your quadriceps muscle strength will be measured by using load cell. You will be asked to extend your leg against the machine as much as you can (similar to performing a knee extension in the gym). You will be asked to ride on bicycle for testing your muscle power calculated by force or bicycle resistance. Your jump height will be tested by jumping as high as you can. To evaluate your flexibility, we will measure the range of motion of your hips, knees and ankle joints, and the distance reached forward by your hand as far as possible during sitting on the floor with leg straight out ahead will be measured.
Your vascular blood flow will be measured by using near infrared spectroscopy. The probe of near infrared light will be placed on your leg. The ability to transmit and absorb this light in body tissue will be used to calculate muscle oxygenation and to predict arterial blood flow. You will be asked to rate muscle pain or soreness by using visual analogue scale after exercise.

Overall, testing will take approximately 2 hours by the time we complete all the performance, and physiological testing. Since we require you to come back a week later and complete the testing again, the total amount of time required of you for this study is about 4 hours.

The results of the project may be published, but the identity of volunteers will not be revealed. The data sheets and consent forms will be kept separate and secure during the study and then stored in the Lincoln University archive room. Your data stored on a computer for analysis will be protected by security password. The published result will be available to all participants.

You may at any time withdraw from the project, including withdrawal of any information you have provided up to the time of data analysis (November 2010).

The Project is being carried out by:

**Name of Principal Researcher:** Mr. Nuttaset Manimmanakorn  
**Contact details:** Home phone (03) 3257573, Office 3253838 ext 8375 or Mobile (021) 2311501 Email: nuttaset.manimmanakorn@lincolnuni.ac.nz, nuttaset@hotmail.com

**Name of Supervisor/Group Leader/Divisional Director:**  
Associated Prof. Dr. Mike Hamlin  
**Contact Details:** Phone (03) 325-3820

The project has been reviewed and approved by Lincoln University Human Ethics Committee.
Consent Form

Name of Project: Whole body vibration training for promoting exercise recovery

I have read and understood the description of the above-named project and what will be required of me as a condition of participation. I have also carefully read, checked and completed the information sheet.

As part of this study, I will be randomized to either a vibration group or normal recovery group, and then after a 1 week wash out period I will change into the other group. In both groups, I will be required to perform high intensity bicycle exercise followed by a cool down program. In the whole body vibration group, I will be required to stand on a whole body vibration platform for 10 minutes after the exercise. In the control group, I will be required to complete low intensity exercise for 5 minutes and stretching exercise for 5 minutes. Additionally, I will be required to complete blood lactic acid, muscle soreness, muscle strength, muscle power, muscle flexibility, sport performance and vascular blood flow tests both pre and post exercise and again after the recovery procedure and at 30 minutes, 60 minutes post testing. I will also be asked to rate muscle soreness prior to and after recovery, then again on day 1, 2 and 3. Altogether the amount of time I will need to devote to this research is about 4 hours (2 hours each week).

On this basis I agree to participate as a subject in this project, and I consent to publication of the results of the project with the understanding that my anonymity will be preserved. I also understand that I may at any time withdraw from the project, including withdrawal of any information I have provided up until initiation of data analysis (November 2010).

Name:

Signed:  Date:
Appendix D
Research Photos

Study 2
Study 3