

THE EFFECTS OF PRACTICAL MUSCLE BLOOD FLOW RESTRICTION
TRAINING ON RUNNING PERFORMANCE AND PHYSIOLOGY

A Thesis

Presented to

The Faculty of Health Science

Eastern Institute of Technology

In Partial Fulfilment

of the Requirements for the Degree

Master of Health Science

By

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January 2016

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature:

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Acknowledgements

Without the help and support of many amazing individuals, this thesis would not have been possible. I wish to thank each and every one of you who played a role with this project in some way or another. In particular, I would like to express my utmost gratitude to my supervisor, Dr Carl Paton. Your knowledge, ideas, persistence and guidance took my understanding of sport science and research to a new level. To Lee-Anne Taylor, my secondary supervisor, thank you for your ideas, input and for proofing my work, making sure it actually made sense. To all of the participants who so kindly offered their time and energy, I could not have done this without you. May you all find fortune with your future endeavours. I would also like to thank the Eastern Institute of Technology and other thesis members who helped me realise my goals. Lastly, to my beautiful wife Jessica, who supported me financially and emotionally throughout this journey, I am forever grateful. You forced me to stay the path even though there were times when I thought quitting was the best option.

Abbreviations

1RM	One Repetition Maximum
BFR	Blood Flow Restriction
BMI	Body Mass Index
CK	Creatine Kinase
CSA	Cross Sectional Area
CON	Control Group
EMG	Electromyography
GH	Growth Hormone
HIT	High-Intensity Interval Training
HR	Heart Rate
La	Lactate
MAS	Maximal Aerobic Speed
MHR	Maximum Heart Rate
MRI	Magnetic Resonance Imaging
NE	Norepinephrine
PCr	Phosphocreatine
pBFR	Practical Blood Flow Restriction
Pi	Inorganic Phosphate
PRV	Peak Running Velocity
Q_{\max}	Cardiac Output
RER	Respiratory Exchange Ratio
TTE:	Time to Exhaustion
$VO_{2\max}$	Maximal Oxygen Uptake

Units of measurement

μg^{-1}	Microgram
$\text{km}\cdot\text{h}^{-1}$	Kilometres per Hour
$\text{l}\cdot\text{min}^{-1}$	Litres per Minute
$\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	Millilitres per Kilogram per Minute
mm	Millimetres
mmHg	Millimetres of Mercury

Abstract

THE EFFECTS OF PRACTICAL MUSCLE BLOOD FLOW RESTRICTION TRAINING ON RUNNING PERFORMANCE AND PHYSIOLOGY

Performing training sessions in combination with blood flow restriction (BFR) has been shown to improve muscle mass and strength development. However few studies have investigated BFR effects on aerobic performance. The purpose of this study was to determine the effect of BFR on both aerobic and anaerobic capacity after completing eight sessions of running interval training. Sixteen recreationally trained, male and females (age 24.9 ± 6.9 years, height 172.9 ± 7.8 cm, weight 75.1 ± 13.8 kg) initially completed an incremental treadmill test to determine maximum oxygen uptake (VO_{2max}) followed by a time to exhaustion test (TTE) at peak running velocity to determine anaerobic capacity. Participants were then pair-matched based on their VO_{2max} and randomly assigned into either a practical blood flow restriction (pBFR) group ($n = 8$) or a control (CON) group ($n = 8$) for four weeks of training. The interval sessions consisted of two to three sets of 5-8 minute (30 seconds work, 30 seconds rest) runs at 80% of peak treadmill test velocity ($9.6 - 12.0$ km.h⁻¹). Following the initial training session (two sets of 5-min), 1-minute was progressively added to each set until the fifth session, where a third set was employed, beginning at 5-minutes. For the final two weeks, time was subsequently increased in the same manner as the first four sessions until a final session (three sets of 8-min) was completed. Elastic knee wraps was used for practically occluding the lower limbs in the pBFR group and wrap tightness was subjectively set at a pressure of 7/10. One-way ANOVA was utilised to determine both within-group and between-group differences pre-post training. In addition, mean percentage changes and 90% confidence limits were estimated and magnitude of changes was analyzed using the Cohen effect size statistic. Maximal oxygen uptake increased in both the pBFR (6.3%) and CON (4.0%) cohorts following training. Similarly TTE increased by 26.9% and 17.0% respectively for the pBFR and CON groups. However there were no significant differences ($p > 0.05$) in assessed physiological and performance measures between groups. Effect size statistics showed small beneficial improvements in peak running velocity ($D = 0.34$) and TTE ($D = 0.31$) in favor of the pBFR group compared to CON. In conclusion, eight sessions of running interval

training with, and without blood flow restriction improved physiology and performance measures in recreationally trained individuals. Subjects using BFR experienced small positive adaptations in performance measures compared to the CON group. Further research using a larger sample size is required in order to elucidate the potential positive impact of BFR during training.

CHAPTER ONE: Preface

1.1 Introduction

Blood flow restriction (BFR) training commonly known as KAATSU training (meaning added pressure) or vascular occlusion, was originally pioneered by Dr. Yoshiaki Sato during the late 1960's. Whilst kneeling during a Buddhist memorial, Dr. Sato realised that the swelling and discomfort experienced in his calf area was not unlike the sensation he felt during physically demanding calf raises. Consequently, he began investigating the effects that BFR had on a muscle during resistance training (Sato, 2005). Blood flow restriction is a novel method of training that involves reducing arterial blood flow to a muscle, whilst occluding venous return (Pope, Willardson, & Schoenfield, 2013). Consequently, intramuscular oxygen delivery is reduced and decreased metabolite clearance is observed (Pope et al., 2013), creating a more stressful environment that may provide a potent stimulus required for adaptation (Suga et al., 2009). Blood flow restriction is realised by applying external pressure to the proximal portion of the limbs and is commonly achieved using blood pressure cuffs (Loenneke, Fahs, Rossow, Sherk, et al., 2012; Loenneke, Wilson, Wilson, Pujol, & Bemben, 2011) or via more practical methods, such as elastic knee wraps, or rubber tubing (Loenneke, Kearney, Thrower, Collins, & Pujol, 2010; Sato, 2005).

1.2 Thesis rationale and significance

1.2.1 Blood flow restriction and resistance training

To date, most studies looking at the effects of blood flow restricted exercise have focused primarily on resistance training on the basis that reductions in blood flow may lead to muscular adaptations despite lower intensities than traditional resistance training (Abe, Beekley, Hinata, Koizumi, & Sato, 2005; Fujita et al., 2007; Fujita, Brechue, Kurita, Sato, & Abe, 2008; Takarada, Nakamura, et al., 2000; Takarada, Takazawa, et al., 2000). The American College of Sports Medicine (ACSM) recommend using loads upwards of 70% one repetition maximum in order to stimulate muscular and strength adaptations in normal conditions (American College of Sports Medicine, 2009), however loads of this magnitude are contraindicated in

individuals who cannot tolerate high mechanical stress due to injury, old age or other reason/s. The purpose of BFR is to provide an alternative method for stimulating hypertrophy and therefore the application of BFR with low intensity resistance training has received more attention in recent literature. There are a number of proposed physiological mechanisms attempting to explain how resistance training with BFR can stimulate positive changes in muscle mass and strength including, earlier activation of fast-twitch muscle fibres, increased duration of metabolic acidosis, exaggerated hormonal response and intracellular swelling that may lead to muscle growth (Pope et al., 2013). These proposed mechanisms are discussed further in section 2.3 of the literature review (chapter 2).

1.2.2 Blood flow restriction and cardiorespiratory endurance training

The ability of BFR to stimulate significant and worthwhile adaptations in strength and hypertrophy during low-intensity resistance training, has led exercise scientists to investigate the effectiveness of BFR during cardiorespiratory modes of exercise. Under normal conditions, it is well known that the repeated stimulation of the cardiovascular system over a period of time induces cardiorespiratory, metabolic and skeletal muscle adaptations that enhance aerobic performance (Ferguson-Stegall et al., 2011; Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010). Endurance training enhances oxygen delivery to the mitochondria and increases the regulation of intramuscular metabolism (Jones & Carter, 2000). At the cardiovascular level, an increase in maximal cardiac output represents the most important adaptation responsible for improved aerobic capacity (Bassett & Howley, 2000), while adaptive responses at the skeletal muscle level include shifts in muscle fibre type and enhanced mitochondrial biogenesis. An increase in the number of mitochondria may improve aerobic performance via increased fatty acid oxidation and attenuated muscle glycogenolysis (Margolis & Pasiakos, 2013).

Since BFR appears to trigger muscular strength and hypertrophy adaptations following resistance training at lower intensities, it is feasible that the hypoxic environment and increased metabolic stress presented by BFR could also create a training response that will improve aerobic and anaerobic performance. The previous few authors who have examined the effects of blood flow restriction on cardiorespiratory measures have observed improvements in maximal oxygen uptake

(Abe, Fujita, et al., 2010; Park et al., 2010) and time to exhaustion (TTE) (Abe, Fujita, et al., 2010; Corvino, de Oliveira, Dos Santos, Denadai, & Caputo, 2014) following differing training protocols, however not all researchers have demonstrated these improvements (Keramidas, Kounalakis, & Geladas, 2012).

With specific relevance to athletes, injured individuals and individuals with other conditions where high-intensity exercise are contraindicated, training at a lower intensity, whilst still creating an effective training response could have positive implications for the individual. In particular, discovering worthwhile improvements in aerobic and anaerobic capacity could have a significant impact in sports that require a high level of cardiorespiratory fitness. In all sports, injuries are a common occurrence and obviously some sports carry a greater risk than others. If the injury is minimal, the athlete may be able to continue training at lower intensities with BFR; if BFR proves effective, the athlete may be able to provoke a greater training response than training under normal, non-occluded conditions. This may allow the athlete to return to competition faster and avoid the negative effects associated with detraining. Running based sports require a high level of aerobic and anaerobic fitness and forced detraining due to injury can result in rapid losses of maximal and submaximal exercise performance. Significant decreases in VO_{2max} have been reported to occur after just two to four weeks of training cessation (Neufer, 1989). In injured athletes or those who are physically unable to train at higher intensities, BFR training may provide an effective strategy for maintaining aerobic and anaerobic capacity.

Due to the novelty of blood flow restricted exercise, there is a gap in the literature that requires further research. To our knowledge, this was the first investigation to examine the effects of practical blood flow restriction in treadmill running. In respect of cardiorespiratory measures, other authors have explored the effects of BFR in cycling (Abe, Fujita, et al., 2010; Corvino et al., 2014; de Oliveira, Caputo, Corvino, & Denadai, 2015; Keramidas et al., 2012) and walking (Abe, Sakamaki, et al., 2010; Park et al., 2010), however running has received no attention.

1.3 Research aims

On the basis that reducing lower body blood flow during cardiorespiratory exercise has been demonstrated to enhance aerobic and anaerobic adaptations, the purpose of this research is two-fold. Using a practical method of restricting blood flow to the lower body, we;

1) Aim to assess aerobic capacity by measuring the change in maximal oxygen uptake following eight sessions of running interval training on a treadmill.

2) Aim to assess anaerobic capacity by measuring the change in time to exhaustion following eight sessions of running interval training on a treadmill.

1.4 Thesis organisation

The thesis has been structured to answer the driving question; will running combined with practical blood flow restriction (pBFR) improve aerobic and anaerobic capacity following 8 training sessions? In an attempt to answer this question, this thesis has been organised into five chapters. Chapter 2 is a review of current literature which covers important concepts, findings and information pertaining to blood flow restriction training. Chapter 3 is the methodology, including subject information, and testing and training protocols. The results of the study are organised into chapter 4 and the discussion and conclusion can be found in chapter 5. All references can be found immediately after chapter 5 and these are presented in APA format (6th ed). Finally, all other information that was involved in this research such as ethics approval, the participant information sheet, medical questionnaires and raw data can be found in the appendices.

CHAPTER TWO: Literature Review

2.1 Aerobic capacity

2.1.1 Aerobic adaptations to training

Aerobic capacity (VO_{2max}) is one of the most extensively obtained variables in exercise physiology and in a laboratory setting it is measured as the maximal attainable rate of oxygen consumption (Vollard et al., 2009). Specifically, VO_{2max} is defined as the highest rate at which oxygen can be taken up and utilised by the body during severe exercise (Bassett & Howley, 2000), and is commonly referred to as the “gold standard” measure for aerobic capacity is expressed absolutely in $L \cdot min^{-1}$ or relatively in $ml \cdot kg^{-1} \cdot min^{-1}$ (Morrow & Freedson, 1994). Maximal oxygen uptake is commonly used to quantify training intensities and in scientific literature an increase in VO_{2max} represents the most frequent method of displaying a positive training effect (Bassett & Howley, 2000; Vollard et al., 2009).

It is well recognised that repeated bouts of exercise over a period of time elicit a number of physiological adaptations that consequently enhance aerobic capacity, leading to improved performance within that exercise activity. The magnitude of training improvements are dependent on the overall intensity, duration and frequency at which the exercise is performed, in conjunction with the initial level of aerobic fitness, age, genetic potential and gender of the individual (Jones & Carter, 2000). The physiological responses from aerobic exercise training include cardiovascular, skeletal muscle and metabolic adaptations (Ferguson-Stegall et al., 2011; Little et al., 2010). Changes associated with the cardiovascular system include, an increase in stroke volume and cardiac output (Ferguson-Stegall et al., 2011) and decreased resting and exercising heart rate (Hickson, Hagberg, Ehsani, & Holloszy, 1981). A raise in maximal cardiac output (Q_{max}) is the most significant adaptation in cardiovascular function, explaining individual differences in aerobic capacity (Bassett & Howley, 2000). High Q_{max} and VO_{2max} values associated with elite athletes are related to very high maximal stroke volumes since maximal heart rates are similar between highly-trained and sedentary individuals (Jones & Carter, 2000). Skeletal muscle adaptations include mitochondrial biogenesis, augmented oxidative enzyme activity (Ferguson-Stegall et al., 2011; Little et al., 2010) and muscle fibre changes (Wernbom, Augustsson, & Raastad, 2008). Enhanced mitochondrial biogenesis may improve aerobic capacity through up regulated oxidation of fatty

acids and attenuation of muscle glycogenolysis, delaying time to exhaustion (Margolis & Pasiakos, 2013). These training-induced changes in substrate metabolism following several weeks of endurance exercise have been well established (Burgomaster et al., 2008).

In spite of prolonged phases of aerobic training, performance decrements in both maximal and submaximal exercise arise within weeks of training cessation (Neufer, 1989). For an injured athlete seeking to rapidly return to competitive sport, detraining can pose a serious problem. Detraining can be defined as the partial or complete loss of training-induced anatomical, physiological and performance adaptations as a consequence of training reduction or cessation (Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004). Injuries range from mild to severe, limiting the amount, mode and intensity of exercise that can be performed, thus other non-traditional modes of exercise or alternate interventions may be used to allow the injured athlete to maintain fitness. Blood flow restricted exercise impairs exercise performance by inducing a more acidic intramuscular environment, producing greater fatigue levels despite reductions in training load and intensity (Cook, Clark, & Ploutz-Snyder, 2007; Cook, Murphy, & LaBarbera, 2013). Blood flow restricted training may have an ability to create training potential without maximising exertion, which has obvious implications for injured athletes who cannot endure high levels of mechanical stress.

2.1.2 Training for aerobic capacity

As previously mentioned, a number of factors affect aerobic training response, being, exercise intensity, duration, frequency and initial status of aerobic fitness. Among these, exercise intensity may be of crucial importance provided that minimal training volumes are achieved (Jones & Carter, 2000; Wenger & Bell, 1986). High-intensity exercise (60-84% VO_2 reserve) has proven to result in greater aerobic capacity increase than moderate intensity exercise (40-59% VO_2 reserve) (Swain & Franklin, 2002). High-intensity interval training (HIT) represents an alternate means to continuous endurance exercise despite a substantial decrease in training duration (Ma et al., 2013). In an effort to produce time-efficient aerobic adaptations, there has been a greater interest in interval training whereby exercise is performed at higher

intensities for shorter durations (Perry, Heigenhauser, Bonen, & Spriet, 2008). The purpose of HIT is to repetitively stress the physiological systems responsible for improving a specific exercise performance, typically to a greater degree than what is actually necessary during the activity (Laursen & Jenkins, 2002). A number of studies comparing interval training with continuous training have demonstrated significant increases in VO_{2max} in the HIT group (Esfarjani & Laursen, 2007; Gormley et al., 2008; Helgerud et al., 2007), suggesting that higher intensities are more effective at improving aerobic capacity than lower intensities.

Within field based sports such as rugby union, rugby league, football and hockey, the stop-start nature, frequent change of direction and varying movement speeds required to meet game demands suggests high-intensity aerobic power as a central factor for success (Baker, 2011). Since team sports are unpredictable in temperament, continuous endurance training even if performed at more difficult intensities may still lack specificity for the field sport athlete (Baker, 2011; Tabata et al., 1996). Evidence shows that the duration spent at or above 100% of an individual's maximal aerobic speed (MAS) plays a significant role in developing aerobic power (Dupont, Akakpo, & Berthoin, 2004; Dupont, Blondel, Lensele, & Berthoin, 2002). A study by Dupont et al (2004) examined the effects of high-intensity intermittent running intervals on aerobic and anaerobic qualities on in-season soccer players. The study protocol required players to run for 12-15 sets of 15 seconds at 120% of their own MAS, before resting for 15 seconds. The study was carried out over 20 weeks; weeks 1-10 served as a control period and during weeks 11-20, MAS intervals were performed. From the beginning to the end of the investigation, MAS increased significantly from 15.9 to 17.3 $km \cdot h^{-1}$, which represents an 8.1% improvement ($p < 0.001$). In addition, an earlier study by Berthoin, Mantéca, Gerbeaux, & Lensele-Corbeil (1995) which examined the effects of two different training programs on maximal aerobic speed and running time to exhaustion at 100% MAS. Male and female students ($n = 121$) aged between 14 and 17 years followed a 12-week aerobic training program, involving one session per week. Two training programs were proposed: moderate and intense. The authors reported a significant improvement in MAS (males 5.7%, females 5.4%, $p < 0.001$) in

the intense group only, validating their conclusion that MAS is a crucial factor needed to set training intensities for aerobic training.

It is important to note that maximal aerobic speed is typically obtained during field-based tests. Although there is some debate within literature as to how 100% MAS is determined, it is easily set by calculating the speed attained during the last successfully completed stage of the Montreal Track Running test (Baker, 2011). Alternatively, if the athletes' sport is intermittent in nature, then a shuttle-based test such as the YOYO IR1 test may be used. Similar to the Montreal Track Running test, the speed obtained during the final successful shuttle is recorded as 100% MAS (Heaney, 2012). Since the speed obtained during the final successful stage is taken as MAS in the above field tests, it would be logical to assume that the final speed reached during a treadmill test could also be termed MAS. However given that maximal aerobic speed is defined as the minimum speed required to elicit VO_{2max} (Billat, Renoux, Pinoteau, Petit, & Koralsztein, 1995), we felt that that this was not an accurate title given that VO_{2max} generally occurs before the final stage. Hence we felt the term peak running velocity (PRV) was a more accurate reflection of the relationship between running speed and our training intensities.

2.2 Blood flow restriction

To date, the main focus of BFR research has been on improving muscular hypertrophy and strength using training intensities as low as 20-30% of subjects' one repetition maximum (1RM) (Cook, Kilduff, & Beaven, 2014). A study by Abe et al (2005) examined the effects of BFR during low intensity (20% 1RM) leg curl and squat exercise, comparing blood flow restricted conditions to non-blood flow restricted conditions. After 14 days, significant increases ($p < 0.01$) in muscle size were observed within the gluteus maximus (9.1%), quadriceps (7.7%) and biceps femoris (10.1%) muscles, whilst no significant change was observed with the non-BFR cohort (- 0.6%, 1.4% and 1.9% respectively). Further, Yasuda et al (2011) reported increased pectoralis major and triceps brachii muscle volume (8.3% and

4.9% respectively) following six weeks of bench press training (three sessions per week) in blood flow restricted conditions.

It appears the low-intensity BFR training may provide an effective alternate option to traditional heavy resistance training paradigms for gaining muscular strength and hypertrophy. The American College of Sports Medicine (ACSM) guidelines recommend that in order to produce considerable gains in muscular strength and hypertrophy under non-occluded conditions, loads of or greater than 70% 1RM are required (American College of Sports Medicine, 2009). However, training with higher loads may not be possible or advisable in all populations; in fact high mechanical stress is contraindicated in individuals who are injured or convalescing post-surgery due to weakened musculotendinous structures (Clark et al., 2011; Loenneke, Wilson, & Wilson, 2010; Wernbom, Augustsson, & Thomeé, 2006). Further, BFR has been hypothesized by Loenneke & Pujol (2009) to present an effective mode of training during space flight, whereby microgravity exposure results in cardiovascular deconditioning and atrophy of skeletal muscle, despite astronauts employing aerobic and resistance training strategies.

Whilst BFR training has consistently been shown to improve muscle hypertrophy and strength, training studies examining the effects of BFR on cardiorespiratory endurance capacity are sparse (Takano et al., 2005a). Currently it appears that only low-intensity BFR aerobic training interventions have been examined. Additionally, to date, no research has assessed the effects of blood flow restricted training using a running based training intervention.

2.2.1 Blood flow restriction: impacts on aerobic capacity

The effects of blood flow restriction training on strength and muscular hypertrophy are relatively well documented, however as previously identified, the benefits that BFR training has on cardiorespiratory endurance are less well known. Park et al (2010) was the first to investigate the effects of low-intensity BFR walk training on cardiorespiratory endurance, anaerobic capacity and muscular strength in elite athletes (Korean collegiate basketball players). Aerobic capacity was assessed via a maximal graded exercise test on a cycle ergometer. Anaerobic performance was

assessed by a Wingate anaerobic test; subjects were required to perform a single 30-second maximal intensity interval at a constant load relative to their body weight. The experimental training protocol required the players to participate in five sets of three-minute walks ($4\text{-}6\text{ km h}^{-1}$) in either an occluded or non-occluded condition. The treadmill gradient was set at 5% and players rested for one minute between sets. Training was performed twice daily, six days a week for two weeks. The results indicated significant increases in $\text{VO}_{2\text{max}}$ (11.6%, $p= 0.011$) and maximal minute ventilation (10.6%), $p= 0.019$) in the BFR condition only. Further, stroke volume increased by 21.4% and heart rate decreased by 13.7% in the BFR group. The authors note that interestingly, increases in maximal aerobic characteristics were analogous to findings from other studies carried out at higher intensities in non-occluded conditions, using similar training periods (Mier, Turner, Ehsani, & Spina, 1997; Spina et al., 1996). Despite the positive findings, the study design utilised by Park et al (2010) may be flawed. Both groups began training at 4-km h^{-1} , however speed was only increased in the experimental group resulting in an unfair test. Logically, the group training at a higher intensity will likely display a better training response. Therefore these results do not accurately highlight the adaptations that may have occurred with BFR training as it is difficult to deduce which factor stimulated the positive improvement in performance. Regarding anaerobic capacity, an increase of 2.5% was observed in the BFR group only. Similarly, Corvino, Oliveira, Santos, Denadai, & Caputo (2014) found positive increases in anaerobic capacity with BFR training. These authors reported a significant increase (53%, $p< 0.001$) in TTE following only four weeks (three sessions per week) of low-intensity (30% peak power output) blood flow restricted cycling intervals (two sets of 5-8 two minute repetitions). Post training TTE was also significantly different ($p< 0.01$) between BFR and the non-BFR group. The non-BFR group demonstrated no significant increase in time to exhaustion, suggesting that low-intensity interval training in normal conditions was not enough to stimulate cardiorespiratory adaptation. One author (Wenger & Bell, 1986) verified the intensity dependant relationship between maximal oxygen uptake and exercise intensity, suggesting 50% $\text{VO}_{2\text{max}}$ is the minimum intensity required to induce adaptation. This intensity threshold was not met, perhaps explaining why increases in $\text{VO}_{2\text{max}}$ were not observed in the control group.

An earlier investigation by Abe et al (2010) also examined the effects of BFR cycling on VO_{2max} . Participants trained three times per week for an eight-week period. The BFR intervention involved 15 minutes of constant work (40% VO_{2max}), while the non-BFR cohort completed 45 minutes of constant work at the same intensity. The main findings showed a 6.4% increase in maximal oxygen uptake and a 15.4% increase in time to exhaustion after the BFR intervention, whilst no change occurred within the control group (- 0.1 and 3.9% respectively). The researchers attempted to normalise differences between the groups by extending training duration within the non-BFR group. Wenger & Bell (1986) suggest that under low-intensity settings, longer duration (>35 minutes) efforts may produce greater adaptations than short duration, high-intensity bouts. These findings of Abe et al (2010) imply that although training duration was increased in the non-occluded cohort, VO_{2max} failed to improve. Similar to Corvino et al (2014), it is likely that under non-occluded environments, the overall intensity was insufficient to stimulate aerobic adaptation.

It is interesting that while Park et al (2010) and Abe et al (2010) both reported increases in VO_{2max} in BFR exercise, the study by Park actually exhibited greater aerobic adaptation (VO_{2max} = 11.6% versus 6.4%), despite using more highly trained athletes. Since trained athletes typically have greater aerobic capacity, the need for greater training intensities (80-100%) can be expected (Wenger & Bell, 1986). Although the mode of intervention varied between both studies, the intensity was relatively similar (~ 40% VO_{2max}). Cuff pressures were alike, beginning at 160 mmHg and progressing to a final pressure between 210 to 220 mmHg. Cuff width was not mentioned by Abe et al (2010) and as previously discussed; wider cuffs tend to occlude blood flow at lower pressures, subsequently affecting hemodynamics. A primary difference was in intervention duration. The study by Park et al (2010) utilised a two-week protocol, whilst the study by Abe et al (2010) was completed over an eight-week period. In spite of the time difference, both studies involved 24 sessions in total. Regarding VO_{2max} changes, this difference may be explained by Loenneke et al (2012), who propose high training frequency as an important factor in determining endurance outcomes.

Due to the limited literature on BFR training, research in certain areas is warranted. Most of the previous studies examining cardiorespiratory changes have used intensities lower than 50% VO_{2max} . However, one study by Keramidas, Kounalakis, & Geladas (2012) used an intensity that was 90% of the subject's VO_{2max} , obtained from an incremental cycle test to exhaustion. Subjects were randomly assigned to either the experimental BFR group (cuff pressure +90 mmHg), or the control group. Both groups trained three days a week for six weeks at the same relative intensity. Training consisted of a two minute interval at 90% VO_{2max} , followed by an active recovery period (50% VO_{2max}). Interestingly, no significant change was observed in VO_{2max} in either group, despite the higher intensity that was used. The authors compare their study to an investigation by Warburton et al (2004), who observed significant changes in VO_{2max} ($21 \pm 10\%$) following similar training. While perhaps somewhat similar in training methodology, the Warburton et al (2004) study was completed over 12 weeks, while the present study was only six weeks in duration. As VO_{2max} remained unchanged in both conditions, the interval duration may not have been adequate, even though a higher intensity was used. The time spent at or above 100% maximal aerobic speed (MAS) appears to be a decisive factor for developing aerobic power (Baker, 2011) and MAS has proven to be more successful than training only one interval continuously at 100% MAS (Dupont et al., 2002). Considerable increases in maximal minute ventilation were observed in both groups, however there was no significant difference between groups. Contrary to this, Park et al (2010) revealed a 10.6% increase in maximal minute ventilation in only the BFR group even though training intensity was much lower (40% versus 90%), although conclusions should not be drawn given the vast difference in methodologies.

2.2.3 Application and pressure of blood flow restriction

KAATSU or blood flow restriction is achieved by applying moderate external pressure at the base of the limbs with a specially made belt (Nakajima, Morita, & Sato, 2011). A mixture of apparatus has been used including blood pressure cuffs (Laurentino et al., 2008) and pneumatic tourniquet cuffs (Wernbom et al., 2006; Wernbom, Järrebring, Andreasson, & Augustsson, 2009); a recent shift in research has been on more practical occlusion methods, generally using elastic knee wraps (Loenneke, Balapur, Thrower, & Pujol, 2011; Loenneke, Kearney, et al., 2010;

Lowery et al., 2013). It is apparent that no universally accepted mode for conducting BFR training exists within literature; differences between cuff type, pressure and width, training intensities and volumes and intervention time vary between studies.

2.2.2 Cuff width

Some studies evaluating the effects of blood flow restriction have not reported the width of the pressure cuff used to occlude blood flow (Karabulut, McCarron, Abe, Sato, & Bembem, 2011; Loenneke, Fahs, Rossow, Sherk, et al., 2012; Patterson & Ferguson, 2011); this may be a factor and a point, which may be essential to address. A study by Loenneke, et al (2012) examined the effects of cuff width on arterial occlusion. Wide (13.5 cm) and narrow (5 cm) pressure cuffs were applied to the most proximal region of each leg and the same inflation protocol was used for each condition, requiring incremental increases of pressure. When arterial flow was no longer detected, cuff pressure was decreased in 10 mmHg increments until arterial flow was present. Arterial occlusion pressure was then recorded as the lowest cuff pressure where a pulse was undetectable (to the nearest 10 mmHg). The authors reported that wide BFR cuffs occluded blood flow at lower pressures, in contrast to narrow BFR cuffs. These results agree with earlier findings by Crenshaw, Hargens, Gershuni, & Rydevik (1988) who also demonstrated wider cuffs restricted blood flow at lower pressures. Crenshaw et al (1988) state that most nerve injuries occur at the perimeter of the cuff where an obvious gradient is present therefore tissue deformation may occur. Higher pressures increase the pressure gradient, thus if blood flow restriction can be achieved via safer methods, these methods should be explored and utilised. In addition, it has been suggested that wider cuffs illicit a greater pain response (Hagenouw, Bridenbaugh, Van Egmond, & Stuebing, 1986), however a later investigation by Estebe et al (2000) found that in fact a wider cuff (14 cm) was less painful than a narrow cuff (7 cm) when using lower pressures that were still effective at restricting blood flow.

2.2.4 External pressure

In order to conduct blood flow restricted training appropriate pressures are required. Numerous pressures have been used in previous research. Substantial

strength and hypertrophic adaptations have been observed with low pressures of 50 mmHg, while earlier investigations experimented with pressures as high as 250 mmHg (Pope et al., 2013). The large range of pressures utilised in the research may suggest that the absolute pressure required to result in muscular adaptations could be lower than thought (Loenneke, Wilson, et al., 2012). In agreement with this, Suga et al (2009) explored the effects of different cuff pressures; low (100 mmHg), moderate (150 mmHg) and high (200 mmHg) in 15 male healthy subjects. Following research by Takano et al (2005b), they also examined pressure relative to the individual (130% systolic blood pressure), as many studies had not considered this variable. The study findings support the use of moderate (150 mmHg and 1.3 times systolic blood pressure) pressures, demonstrating a similar increase in intramuscular metabolites compared to high-pressure conditions. Using non-relative pressures may result in varying degrees of blood flow restriction, given that the amount of tissue encompassing the vasculature influences the level of occlusion (Loenneke, Fahs, Rossow, Sherk, et al., 2012). Lastly, a study by Sumide, Sakuraba, Ohmura, & Tamura (2009) sought to examine optimal occlusive pressures in resistance training. Four different pressures were assessed; 0 mmHg (no pressure), 50 mmHg (low pressure), 150 mmHg (moderate pressure) and 250 mmHg (high pressure). Total muscle work increased within low and moderate groups, adding further evidence that suggests high pressures (>200 mmHg) may not be required.

2.2.5 Practical occlusion

A focal point of recent vascular occlusion research has been on applying more practical methods that may be used outside clinical settings. The majority of strength and conditioning coaches, athletes and the general fitness population may find BFR devices impractical and expensive. Practical BFR (pBFR) via elastic knee wraps was first proposed by Loenneke & Pujol (2009). Since then studies have continued exploring the effects of practical occlusion on muscle hypertrophy and strength. Lowery et al (2013) examined the effects of pBFR in college-aged male subjects who had a minimum of one year of resistance training experience. Elastic knee wraps were applied to the upper arms at a perceived pressure of 6-7 out of 10 and training between low-intensity BFR and high-intensity non-BFR cohorts was controlled to ensure equal volume. The findings demonstrated significant increases in

muscle thickness in both pBFR and high-intensity non-BFR conditions. Between baseline and week four, muscle thickness increased by 6.9% and 8.6% respectively and between week four and week eight, muscle thickness increased by a further 4.1% and 4.0% respectively. The primary results of their study propose that blood flow restriction via practical modes can enhance muscle hypertrophy to a similar extent as high-intensity resistance training can.

2.2.6 Duration and frequency

Hypertrophic adaptations have been demonstrated after only seven days of KAATSU training. A case report by Abe, Beekley, Hinata, Koizumi, & Sato (2005) considered hypertrophy and strength changes following seven days of bi-daily low-intensity KAATSU resistance training. The subject, a 47 year old male, completed three sets of 15 repetitions on leg extension exercise separated by a 30 second rest period. The intensity was set at 20% of the subject's 1RM. Initial cuff pressure used on day one was 160 mmHg, increasing by 20 mmHg per day until a maximal pressure of 220 mmHg was achieved on day four. Magnetic Resonance Imaging (MRI) was used to measure muscle cross sectional area (CSA) and muscle volume, while strength was determined via an isokinetic dynamometer. Following seven days of KAATSU training, increases in quadriceps CSA (3.5%) and muscle volume (4.8%) were observed. Additionally, absolute and relative isometric strength increased from 257 Nm to 303 Nm, and 3.58 Nm/cm² to 4.09 Nm/cm² respectively.

A similar study by Fujita, Brechue, Kurita, Sato, & Abe (2008) examined KAATSU training on muscular strength and hypertrophy effects using a larger cohort (16 young males). Eight subjects performed low-intensity resistance training with BFR, while the other eight subjects performed the same training without BFR. The protocol involved bi-daily training, 12 sessions within a six-day period. Training sessions were supervised and separated by at least four hours. Resembling the previous study (Abe, Beekley, et al., 2005), intensity was set at 20% 1RM for the leg extension exercise. The BFR pressure protocol was also conducted in a likewise manner, beginning at 160 mmHg and increasing daily by 20 mmHg to a maximum pressure of 220 mmHg. The study found significant improvement in muscle CSA and volume between pre and post testing (3.5% and 3.0% respectively, $p < 0.05$) in the

BFR group, whilst no change was observed in the non-BFR group. Strength improved by 6.7% on the leg extension exercise in the BFR group while no change was observed in the non-BFR condition. When combined with BFR, even lower intensities associated with walking can lead to substantial increases in muscular strength and lower body hypertrophy (Abe, Sakamaki, et al., 2010).

A meta-analysis by Loenneke et al (2012) found that research regarding hypertrophy used relatively consistent durations (< 4 – 10 weeks), however strength changes did not respond in the same manner, becoming apparent around the ten week mark. Under traditional resistance training circumstances, neural changes responsible for strength gain are believed to occur within the first few weeks. The reviewers suggest that under occlusive conditions, traditional adaptive concepts may be reversed. Further, the authors propose that studies demonstrating strength improvement (like the ones mentioned previously) were achieved through hypertrophic mechanisms, not via neural pathways.

2.3 Mechanisms of action

Understanding the precise mechanism(s) responsible for adaptations in muscular hypertrophy, strength and endurance following blood flow restriction training are still in progress. It is hypothesised that the enhanced response to BFR interventions may primarily be dependent on the following mechanisms; 1) metabolite accumulation and concomitant increases in anabolic hormone concentrations and 2) preferential recruitment of fast-twitch (type II) muscle fibres. (Loenneke, Fahs, Rossow, Abe, & Bemben, 2012; Loenneke, Wilson, et al., 2010; Pope et al., 2013; Scott, Slattery, Sculley, & Dascombe, 2014; Takarada, Nakamura, et al., 2000). Secondary mechanisms that have been demonstrated to show changes following occlusion stimuli include, heat shock proteins, nitric oxide synthase-1 and myostatin expression (Loenneke, Wilson, et al., 2010). A full review of changes have previously been conducted by both Loenneke et al (2010) and Pope et al (2013).

The proposed mechanisms have primarily been discussed in relation to vascular occluded resistance training, therefore may or may not elucidate adaptations observed in aerobic modes of exercise. Cardiorespiratory endurance training with

reduced blood flow has been shown to enhance oxidative enzymes, capillary density, stroke volume, glycogen storage and decreased resting heart rate (Pope et al., 2013). These adaptations are similar to central and peripheral adaptations observed in traditional aerobic exercise (Corvino et al., 2014). The improvement in these variables have been shown to improve VO_{2max} (Abe, Fujita, et al., 2010; Park et al., 2010) and time to exhaustion (Corvino et al., 2014) in blood flow occluded walking and cycling modes using lower intensities.

2.3.1 Metabolic stress

Metabolic stress has been purported to be a key factor believed to encourage muscle growth, perhaps through stimulating the activation of other mechanisms (cell swelling, intracellular signalling, fast-twitch fibre recruitment) (Pearson & Hussain, 2015). Applying external pressure decreases oxygen supply to the muscle, subsequently increasing anaerobic energy contribution (Scott et al., 2014), which increases concentrations of lactate (La) (Anderson & Rhodes, 1989). Additionally, amplified phosphocreatine (PCr) depletion, augmented inorganic phosphates (Pi) and a decline in pH is demonstrated with BFR training (Scott et al., 2014). On an acute level these responses speed up time to fatigue under occluded conditions, however these metabolic stressors may provide a potent catalyst for obtaining training effect in chronic situations.

A study by Suga et al (2012) compared multiple set, low-intensity (20% 1RM) BFR exercise with multiple set, high-intensity (65% 1RM) and multiple set low-intensity (20% 1RM) non-BFR exercise and examined the level of intramuscular metabolic stress. The findings of the study suggest that low-intensity BFR resistance training can achieve levels of intramuscular metabolic stress comparable to high-intensity resistance exercise. Additionally, the BFR condition exhibited significantly greater levels of inorganic phosphate and significantly lower intramuscular pH levels compared to the low-intensity non-BFR group (27.0 ± 1.5 versus 11.2 ± 0.7 , $p < 0.001$, and 6.84 ± 0.07 versus 7.03 ± 0.002 , $p < 0.001$ respectively). Other studies have also confirmed that metabolic stress caused by low-intensity BFR exercise may equal high-intensity exercise-induced metabolic stress (Fujita et al., 2007; Takarada, Nakamura, et al., 2000; Tanimoto, Madarame, & Ishii, 2005). Findings from Suga et

al., (2009) earlier study do not support the above conclusions, however the earlier study only utilised a single set, whilst the subsequent study incorporated three sets.

Blood, muscle and plasma lactate accumulate within the muscle in response to BFR training, which is important since acidic intramuscular environments have been shown to stimulate the release of growth hormone (GH) (Loenneke, Wilson, et al., 2010). An investigation by Takarada et al (2000) examined the effects of BFR resistance training comparing BFR and non-BFR bi-lateral leg extensions at the same intensity (20% 1RM). Subjects performed five sets of 14 repetitions to exhaustion. Plasma concentrations of GH, La, norepinephrine (NE) and creatine kinase (CK) were recorded among other measures. Lactate levels displayed a transient two-fold increase following the BFR intervention, whilst no change was observed in the control group. Remarkably, after only 15 minutes of exercise, plasma concentrations of GH increased up to almost 290 times resting rate ($\sim 40 \mu\text{g/l}$). Norepinephrine levels were also significantly elevated in the experimental group. The authors suggest that a causal relationship may exist between La and GH/ NE response, based on similar time course changes in concentrations. More recently, Takano et al (2005a) investigated hormonal responses to short-term low-intensity vascular occluded exercise. Takano (2005a) observed increases in GH approximately 100 times greater than resting concentrations, a level much lower than reported by Takarada et al (2000) despite similar training intensities (20%), exercise modes (bi-lateral leg extension) and occlusion devices (specially designed tourniquets; 33 mm wide, 800 mm long). The primary differences were observed between cuff pressure (140-160 mmHg versus ~ 214 mmHg), intervention (four sets of 30 repetitions to exhaustion versus five sets of 14 repetitions to exhaustion) and subjects (untrained versus athletes). Their findings conversely do not suggest that augmented GH responses were related to an increase in La concentrations. The authors found no significant differences between La and GH concentrations, instead reporting a significant relationship ($r = 0.57$, $P < 0.05$) between La levels and vascular endothelial growth factor (VEGF). In addition, Reeves et al (2006) displayed heightened GH release following BFR training, however no significant differences in blood lactate concentrations between cohorts were observed, implying that changes in blood lactate does not always predict GH response.

2.3.2 Muscle fibre recruitment

Under normal conditions, Henneman's size principle states that slow-twitch muscle fibres (type I) are predominantly recruited at lower intensities, and as force production increases, type II fibres are progressively activated to sustain muscle contraction (Henneman, Somjen, & Carpenter, 1965). Although only low-intensities were used, a number of studies have observed increased muscle activation with BFR, measured via electromyography (EMG) (Takarada, Nakamura, et al., 2000; Yasuda et al., 2009). The increased activation of type II fibres may be a result of metabolic stress and insufficient supply of oxygen (Pearson & Hussain, 2015). While the precise mechanisms whereby metabolite accumulation leads to increased type II fibre recruitment remains unknown, hypotheses include; 1) hypoxic intramuscular settings cause type I oxidative fibres to easily fatigue, consequently necessitating greater recruitment of fast-twitch fibres (Scott et al., 2014), and 2) accumulation of hydrogen ions inhibit muscle contractility, thus encouraging activation of fast-twitch muscle fibres (Schoenfeld, 2013). Suga et al (2012) reported increased skeletal muscle fibre recruitment, represented by the splitting of Pi peaks. The splitting of Pi peaks were progressively augmented over multiple sets reaching equivalent levels of the high-intensity cohort; this perhaps explains why their earlier study (Suga et al., 2009) failed to show similar levels of metabolic stress and fast-twitch fibre recruitment.

During time to exhaustion aerobic based tests, blood flow occlusion severely reduces oxygen delivery, which may subsequently lead to progressive type II fibre recruitment required to sustain force development. After training in hypoxic conditions, specific adaptations may take place which could improve high-intensity exercise tolerance (Corvino et al., 2014).

2.4 Safety issues and complications regarding blood flow restriction training

Since research has established the effectiveness of blood flow restricted training with specific reference to muscular strength, hypertrophy and endurance, attention has turned toward investigating potential safety issues. A National Survey carried out across KAATSU training centres in Japan (Nakajima et al., 2006) sought to shed light on the relatively unknown safety status concerning BFR training. Based on the results of their survey, 12,642 individuals had received KAATSU training

(male 45.4%, female 54.6), aged between <20 years old (17.8%) to >80 years old (4.4%). The occurrences of side effects were as follows; venous thrombus (0.055%), pulmonary embolism (0.008%) and rhabdomyolysis (0.008%). Additionally, temporary side effects reported were as follows; subcutaneous haemorrhage (13.1%), numbness (1.297%) and cold feeling (0.127%). The authors conclude that KAATSU is a safe and promising training method, for persons not only with varying physical conditions, but also athletes and ordinary individuals. A review by Loenneke et al (2011) examined existing literature and highlighted possible safety issues. Changes in blood flow, nerve conduction velocity, increased oxidative stress and muscle damage were examined risk areas. Based on physiological sense, central considerations regarding BFR training may be related to hemodynamics and alterations in nerve conduction. Blood flow restriction training modifies blood flow causing blood to pool in response to restricted venous return which could potentially damage valves (Loenneke, Wilson, et al., 2011). In addition numbness associated with BFR, may be a result of cuff pressure causing ischemia and blockage in nerve conduction (Clark et al., 2011).

Concerns have been raised regarding BFR use in individuals with compromised cardiac function. A study by Renzi, Tanaka, & Sugawara (2010) examined the effects of leg blood flow restriction during walking on cardiovascular function, using healthy participants. Increased heart rate, decreased stroke volume and significantly higher blood pressure levels were observed during the BFR session. Further, an increase in myocardial oxygen demand index (double product) was three times greater under occluded conditions. These changes may place unnecessary circulatory burden on the individual, hence the authors conclude that BFR exercise should be cautiously prescribed in those facing compromised cardiac conditions.

There is speculation that muscle damage is increased during BFR training (Loenneke, Wilson, et al., 2011). A later review by Loenneke, Thiebaud, & Abe (2014) assessed available evidence on studies whose foremost objective was to determine if BFR training produced muscle damage. Evidence from these evaluated studies do not suggest that BFR in combination with low-intensity exercise increase occurrences of muscle damage. Symptoms of muscle damage include decreased

force output, increased muscle soreness and swelling and high concentrations of myoglobin and CK in the blood. Studies have shown that muscle damage markers, CK and myoglobin are not elevated following low-intensity BFR training (Abe, Yasuda, et al., 2005; Takarada, Nakamura, et al., 2000), while other studies have reported values upwards of 1000 U/L following non-BFR leg extensions (White et al., 2008; Wilson et al., 2009). It is likely that although BFR creates greater metabolic stress, lower-intensities induce less mechanical stress that would have otherwise caused high levels of muscle damage. Rhabdomyolysis involves the dissolution of skeletal muscle, which subsequently leaks into circulation. While there is no recognised cut-off in serum level, clinicians generally diagnose rhabdomyolysis when CK levels are five times higher than normal (Bagley, Yang, & Shah, 2007). Out of almost 13,000 individuals surveyed, only one case of rhabdomyolysis was reported from BFR training (Nakajima et al., 2006).

In order to minimise any harmful damage or complications, a number of key considerations should be adhered to during implementation of KAATSU training. Based on the National Survey (Nakajima et al., 2006) and further experiences, Nakajima, Morita and Sato (2011) published a review detailing a number of key considerations; the authors also introduced risk score system that can be used for determining KAATSU suitability. Whilst there is limited long-term research regarding BFR and safety, initial findings are promising.

CHAPTER THREE: Methodology

3.1 Subjects

Sixteen healthy males ($n = 10$) and females ($n = 6$) with a mean (\pm SD) age 24.9 ± 6.9 years volunteered to participate in the study (Table 1). All subjects were physically active and participated frequently in a range of recreational activities. Prior to participation, subjects were informed of the procedures, possible risks and gave their written informed consent to participate. Subjects were also required to complete a medical questionnaire to ensure suitability; volunteers who suffered from chronic disease such as hypertension, diabetes, deep vein thrombosis or peripheral vascular disease were excluded from the study. Participants were pair matched based on their aerobic capacity and gender into either the practical blood flow restriction group (pBFR, $n = 8$) or the control group (CON, $n = 8$). One participant in the pBFR group was forced to terminate post-testing time to exhaustion early due to ankle pain. The Eastern Institute of Technology Research Ethics Committee approved this study; reference 23/15. The participant information sheet, informed consent, medical questionnaire and ethics approval are presented in the appendices.

3.2 Research design

The study was a simple matched-pair parallel group design. Each participant initially reported to the Eastern Institute of Technology Sport Science Laboratory to complete baseline testing and become familiarised with the running interval training intervention to be used in the study. The experimental protocols consisted of pre and post training measurements of maximal aerobic capacity (VO_{2max}) followed by a time to exhaustion test performed at pre-test peak running velocity from the maximal test. The running interval training protocol was performed two days per week for four weeks (total of eight sessions). Prior to each testing session, subjects were instructed to avoid any strenuous physical activity for at least 24 hours. Subjects were also instructed to refrain from eating and avoid caffeine-containing beverages or supplements, two hours before testing commenced.

3.3 VO_{2max} and TTE test protocol

Each subject completed a standardised warm up consisting of five minutes of treadmill running (females began at $5\text{-km}\cdot\text{h}^{-1}$ and males began at $6\text{-km}\cdot\text{h}^{-1}$). The

speed was increased by 1-km.h⁻¹ each minute for five minutes. Following this, subjects were required to complete a series of dynamic stretches for two sets of 15 repetitions; leg swings (front to back and across the body), lunge, body weight squat, walking knee to chest and calf raises.

The maximal treadmill (Technogym, Germany) protocol required the speed to increase by 1-km.h⁻¹ every minute until subjects' volitional exhaustion. The treadmill gradient was fixed at 1% in order to simulate on-road conditions (Jones & Doust, 1996). Prior to the subject's arrival, calibration of a metabolic system (Metalyzer 3B, Cortex Biophysik, Germany) was performed in accordance with the manufacturer's instructions using room air and known Alpha gas (15% O₂ and 5% CO₂) standards.

Subjects were fitted with a heart rate monitor (Polar electro Oy, Finland) and attached to the metabolic system. Testing began at either 5-km.h⁻¹ or 6-km.h⁻¹ depending on the subject's perceived ability. The treadmill speed was increased by 1-km.h⁻¹ each minute, until volitional exhaustion occurred. Throughout the entire test, expired air was measured breath by breath. The test was deemed to be maximal if a respiratory exchange ratio (RER) of >1.1 was reached. Following the maximal testing, subjects completed 15 minutes of passive recovery before the TTE test commenced. For this test, subjects were required to run for as long as possible at the peak velocity that they successfully completed during the VO_{2max} test. During TTE testing, time console was covered in order to minimise any psychological effect and mental strategy that may have influenced the results.

3.4 Training protocol

After completion of pre-testing, subjects were match-paired based on their gender and aerobic capacity, before being randomly placed into either the pBFR or control group. The subjects in the pBFR and CON groups participated in four weeks of supervised running interval training on a treadmill. Training was carried out twice weekly, with at least two full days of rest in between sessions i.e. Monday and Thursday, or Tuesday and Saturday. Training intensity was set at 80% peak running velocity (PRV) reached during the maximal treadmill test. During the training

sessions subjects completed repeated bouts of 30-second efforts interspersed with a 30 second-passive rest. The training volume was increased progressively by 2-3 intervals every session as outlined below:

Week 1

Session 1: 2 x 5 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Session 2: 2 x 6 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Week 2

Session 3: 2 x 7 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Session 4: 2 x 8 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Week 3

Session 5: 3 x 5 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Session 6: 3 x 6 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Week 4

Session 7: 3 x 7 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Session 8: 3 x 8 minutes (30 seconds work: 30 seconds rest) @ 80% PRV

Subjects in both groups rested for 150 seconds between each set, primarily to allow a short break from wearing the wraps in the pBFR cohort, and to allow adequate time for re-wrapping. Each participant wore a heart rate monitor (Polar A300, Finland), which recorded each session.

3.5 Occlusion protocol

Our practical occlusion protocol was based on recent work by Wilson, Lowery, Joy, Loenneke, & Naimo (2013) who quantified subjective elastic wrap pressures using ultrasound measures. The authors assessed the level of blood flow restriction by placing an ultrasound probe in the popliteal region of the leg; this was selected, as it was the closest to the femoral blood vessels since the elastic wraps that were placed proximally on the thigh obstructed readings. Prior to wrapping, the participants in their study were introduced to the perceived pressure scale. 0 out of 10 meant that no pressure was felt, 7 was described as a moderate pressure, with no pain, and a pressure of 10 out of 10 was described as intense pressure and pain. The elastic wraps were placed proximally on the femur, near the inguinal crease. The

authors assessed the level of venous and arterial blood flow restriction on the above 3 different pressures and found that a perceived pressure of 7 out of 10, fully restricted venous return but did not completely restrict arterial blood flow.

Prior to beginning the first training session, subjects in the pBFR group were familiarised with the wrap usage and pressures as used by Wilson et al (2013) perceived pressure was explained until each individual understood what was required. Subjects completed a 5-minute warm-up run at a low intensity and completed dynamic stretches before the training session commenced. Elastic wraps (Get Strength Heavy Duty Knee Wraps, Waiuku, New Zealand; 76 mm wide) were placed proximally on the subjects' thigh (pBFR group) and with each wrap pressure was increased until a perceived pressure of ~7 out of 10 occurred. The same researcher wrapped each subject, and supervised all training sessions. As part of this investigation, subjects were counselled to refrain from beginning any new training programs. They were instructed to continue with their normal training routine and maintain normal nutritional behaviours.

3.6 Data analysis

Simple group statistics are shown as means \pm between-subject standard deviations. Statistical analyses for within-group and between-group changes pre to post testing were performed by one-way analysis of variance (ANOVA). Differences were considered significant at $P < 0.05$. In addition mean effects of training and their 90% confidence limits were analysed using magnitude based analysis techniques via a made for purpose spreadsheet (Hopkins, 2003), by way of the unequal-variances t statistic computed for change scores between pre and post-tests in the two groups. The spreadsheet also provided the effect size statistics (D) that were interpreted using the recommendations of Cohen (1988). The qualitative inference based on D was interpreted using the following guideline.

Trivial: 0-0.2

Small: 0.2-0.5

Medium: 0.5-0.8

Large: 0.8-1.2

Very large: 1.2+

CHAPTER FOUR: Results

4.1 Results

Seventeen recreationally active individuals were eligible to participate in this study. During the second week of training, one subject was forced to withdraw due to illness. Additionally, one subject completed pre-testing, training and post VO_{2max} testing before terminating TTE testing early due to ankle pain. Because of this, the participants TTE data was excluded from data analyses. Baseline anthropometric data are reported in Table 1. Lastly, one subject from CON completed all testing and training, however had incomplete HR data due to the monitor's failure to consistently pick up an accurate heart rate. This subjects' HR data has been excluded from the analysis.

Table 1. *Demographic data.*

	pBFR- Training Group ($n = 8$)	CON- Training Group ($n = 8$)	All participants ($n = 16$)
Age (yr)	21.9 \pm 3.5	28 \pm 8.3	24.9 \pm 6.9
Height (cm)	171.6 \pm 8.1	174.1 \pm 7.8	172.9 \pm 7.8
Weight (kg)	76.3 \pm 16.4	73.9 \pm 11.5	75.1 \pm 13.8
BMI ($kg.m^{-2}$)	25.7 \pm 3.6	24.6 \pm 2.4	25.1 \pm 3.0

Table 2 reports the changes in physiological and performance variables that occurred following four weeks of running training. Across all physiological and performance measures, there was no significant ($p < 0.05$) difference in changes between the experimental and control groups. Furthermore no significant change occurred pre-post testing within groups. Table 2 also displays the Cohen effect sizes for pre-post changes, which provide a clearer analysis of the magnitude of change between groups.

Table 3 displays mean differences between groups with confidence levels set at 90%. Cohen effect size, p value and qualitative inference are also reported in Table 3. There were no significant difference between pre and post testing VO_{2max} and VE_{max} within the pBFR ($p = 0.43, 0.60$ respectively) and CON ($p = 0.42, 0.92$ respectively) conditions. When comparing between groups, no significant differences

were found in VO_{2max} ($p = 0.39$) and VE_{max} ($p = 0.30$). However the pBFR group observed a 6.3% and 6.8% improvement in VO_{2max} and VE_{max} respectively, while the control group demonstrated a 4.0% and 0.6% increase in these variables. While data suggests a positive relationship between VO_{2max} and VE_{max} pre to post, changes between these outcomes were classified as trivial and small ($D = 0.18, 0.24$ respectively).

Table 2. Pre and post physiological and performance variables: all $p > 0.05$.

	pBFR- Training Group ($n = 8$)				CON- Training Group ($n = 8$)			
	Pre	Post	% Δ	Cohen's D	Pre	Post	% Δ	Cohen effect size (D)
Physiological variables								
VO_{2max} (ml.kg ⁻¹ .min ⁻¹)	46.1	49.0	6.3	0.36	46.6	48.4	4.0	0.37
VE_{max} (l.min ⁻¹)	133	141	6.8	0.24	122.8	124.5	0.6	0.04
Economy (ml.kg ¹ .km ⁻¹)	3.8	3.5	- 8.2	0.34	4.9	4.8	- 0.2	0.05
Performance variables								
TTE (seconds)	157	190	26.9	0.85	166.6	194.6	17.4	0.62
Peak Velocity (km.h ⁻¹)	13.8	14.3	4.0	0.39	14.1	14.3	1.2	0.15
Incremental Test Duration (seconds)	535	568	6.3	0.47	558.8	570.0	1.8	0.17

Running economy improved from 3.8 to 3.5 ml.km⁻¹ in the experimental group corresponding to an 8.2% change. The control group also improved but by only 0.2%; however between groups this finding was not statistically significant. Between both groups, the TTE and PRV improved with pBFR participants running 26.9% further and 4.0% faster in comparison to the control group (17.4%, 1.2%) and between groups, a mean difference of 8.1 ± 10.6 and 2.8 ± 3.9 was observed in TTE and peak velocity respectively.

Table 3. Between group comparisons of physiological and performance variables: all $p > 0.05$.

	pBFR – CON Mean % difference ± 90% confidence limit	P-value	Cohen effect size (D)	Qualitative inference
Physiological variables				
VO _{2max} (ml.kg ⁻¹ .min ⁻¹)	2.2 ± 4.5	0.39	0.18	Trivial
VE _{max} (l.min ⁻¹)	6.1 ± 10.2	0.30	0.24	Small
Economy	- 8.1 ± 31.0	0.58	0.26	Small
Performance variables				
TTE (seconds)	8.1 ± 10.6	0.19	0.31	Small
Peak Velocity (km.h ⁻¹)	2.8 ± 3.9	0.23	0.34	Small
Incremental Test Duration (seconds)	4.4 ± 6.9	0.22	0.40	Small

Table 4 displays mean data obtained from four weeks of running. Raw data detailing individual subjects' training percentages can be found in appendix 5. There were trivial effect sizes ($D = 0.16$) between pBFR and CON groups in actual mean training intensity when reported as a percentage of VO_{2max}. Table 4 also includes mean training HR data across all sessions, and mean training HR as a percentage of max HR reached during initial maximal testing. As previously mentioned, we have excluded one subject from CON due to equipment failure/error. The experimental group possessed a significantly ($p = 0.03$) greater training HR (141.6 bpm) in comparison to CON (133.5 bpm).

Table 4. Actual individual training intensity, average training HR (BPM) and mean training HR as a % of maximum HR obtained during pre-testing. *Significant difference.

	pBFR- Training Group ($n = 8$)	CON- Training Group ($n = 8$)	P- Value	Difference (%)	Cohen effect size (D)
Actual individual training intensity (% of VO _{2max})	82.6 ± 2.1	83.1 ± 4.2	0.70	0.6	0.16
Mean training HR over eight sessions (BPM)	141.6 ± 7.9	133.5 ± 10.4	0.11	6.07	0.88
Mean training HR as a % of maximum HR (%)	76.0 ± 5.0	69.6 ± 5.1	0.03*	9.2	1.27

Figure 1 shows the individual changes in key physiological and performance measures for both the experimental and control group

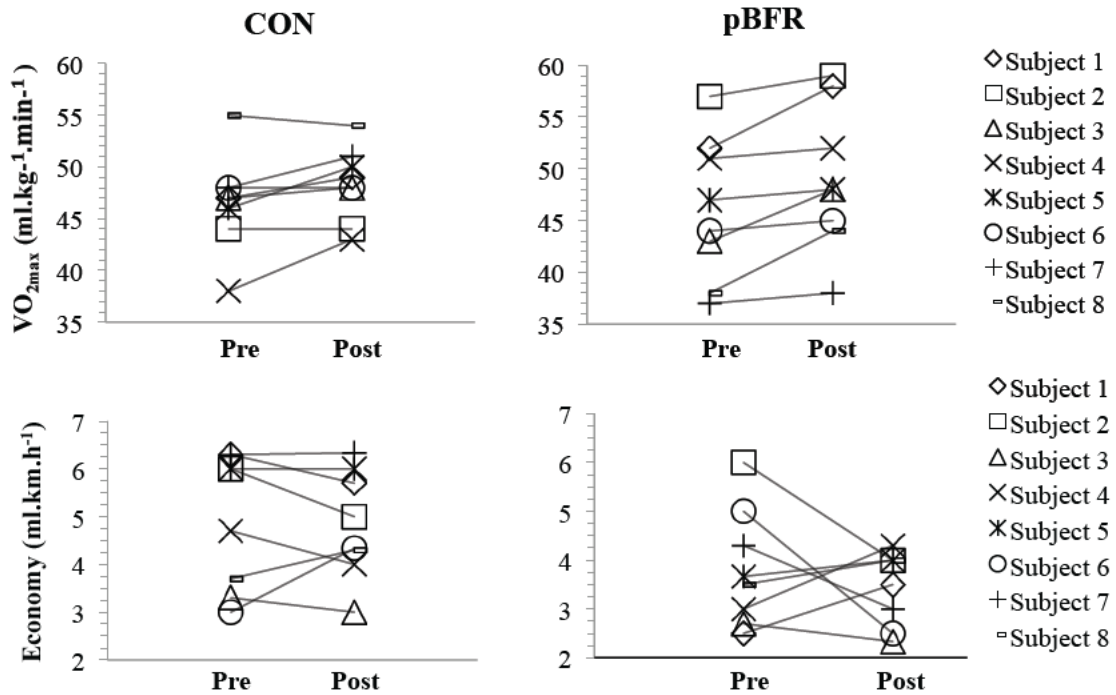


Figure 1. VO_{2max} and economy responses within subjects following four weeks of running interval training with and without blood flow restriction.

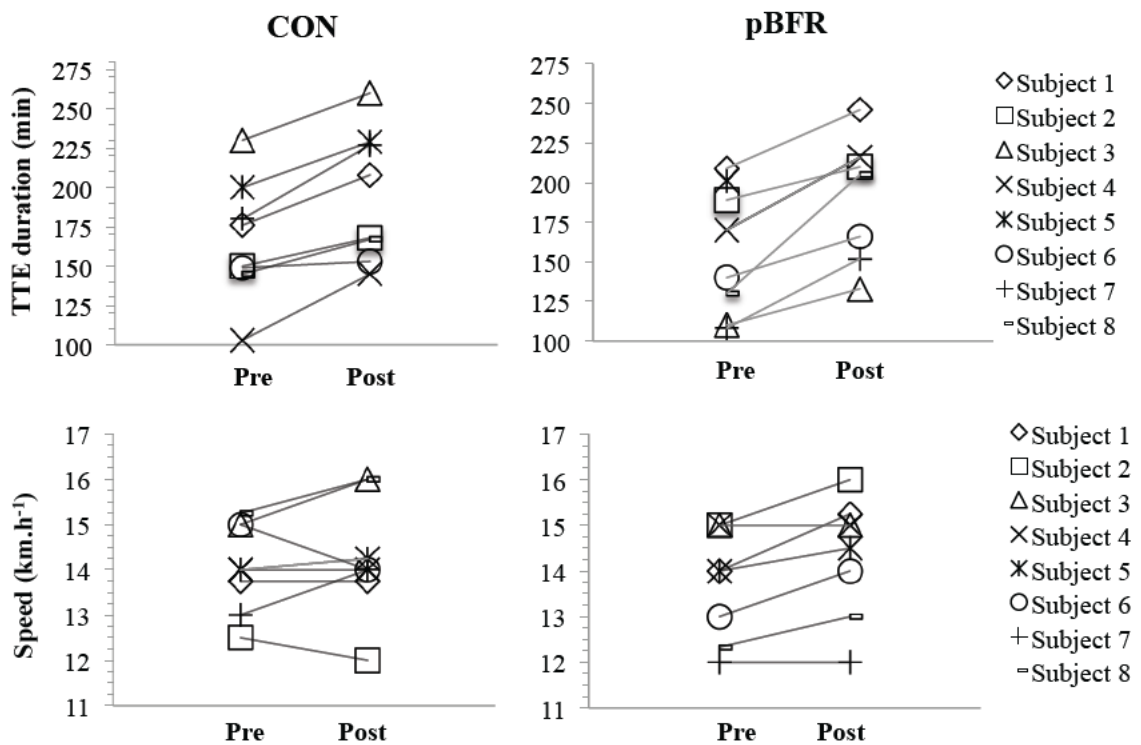


Figure 2. TTE and peak velocity responses within subjects following four weeks of running interval training with and without blood flow restriction.

CHAPTER FIVE: Discussion

5.1 Discussion

The aim of this investigation was to explore changes in physiological and performance measures following four weeks of running interval training with or without practical blood flow restriction. The key findings showed that training with pBFR led to small but potentially beneficial improvements in TTE and peak running velocity in comparison to CON. Maximal oxygen uptake also increased in both the pBFR (6.3%) and CON (4.0%) to a similar extent. Training heart rate data revealed that subjects in the experimental group trained at a significantly higher percentage of their peak HR, despite both groups working at the same relative exercise intensity.

5.1.1 Maximal aerobic capacity

With respect to maximum oxygen consumption measures both groups improved pre to post but there was no significant differences observed between treatments in our present study. In the pBFR group, VO_{2max} and VE_{max} increased by 6.3% and 6.8%, while CON VO_{2max} and VE_{max} improved by 4.0% and 0.6% respectively. These findings are similar to Keramidas et al (2012), who observed no significant change in VO_{2max} between groups and within groups following a 3-session weekly, 6-week interval training program using cycle ergometers. Interestingly, no change at all was reported in either group despite utilising higher intensities (50% and 90% VO_{2max}) and untrained subjects. These authors did however report a significant increase in VE_{max} in both groups while in our present study, only the pBFR group displayed an increase in VE_{max} (6.8%, $p = 0.60$). Since VE_{max} improved in both of Keramidas et al (2012), groups without a concomitant increase in VO_{2max} , it appears that maximal minute ventilation is not a causal factor in improving aerobic power. In agreement, Reybrouck, Heigenhauser & Faulkner (1975) state that increases in VE_{max} may suggest training-induced respiratory adaptations, although these may not be critical to improving aerobic capacity.

Other authors have reported increases in maximal aerobic capacity following blood flow restricted training. Park et al (2010) investigated the effects of two weeks BFR walk training in collegiate athletes, and reported a significant ($p < 0.05$) increase in VO_{2max} (11.6%) and VE_{max} (10.6%) in the experimental group, while the control group showed no response likely due to insufficient training stimuli ($< 40\%$ VO_{2max}). The observed improvement in the experimental condition is unsurprising

based on differences in both groups training methodology. Each group trained twice daily, six days per week for two weeks (five sets of 3-minutes, 5% gradient) and began walking at 4-km.h⁻¹, however speed was progressively increased in only the experimental group until a final velocity of 6-km.h⁻¹ was obtained. Throughout the intervention, the non-occluded group's exercise intensity remained unchanged at 4-km.h⁻¹, which seems nonsensical in regard to carrying out a fair and valid test. It is logical to assume that the group training at a greater intensity will show better adaptation irrespective of any further treatment, therefore the attribution of improved physiological measures resulting purely from BFR should not be considered accurate. In addition it is important to note that while their intervention only lasted for two weeks, participants completed 24 total sessions, which is a much greater training volume (frequency x duration) than our present study utilised.

To add to these findings, Abe et al (2010) reported that VO_{2max} increased by 6.4 % following eight weeks of low-intensity BFR cycle training, while no change in VO_{2max} was reported in the control group. In respect of mean percentage change, we present very similar changes (6.3%) in VO_{2max}, however our findings did not reach statistical significance. Failure to reach significance is possibly due to differences in individual training response and greater levels of individual responses between subjects. A more recent study by de Oliveira et al (2015) investigated the effects of four different interval training protocols (LOW, BFR, HIT, HIT+BFR) in aerobic capacity and muscle strength. VO_{2max} was significantly improved in BFR (5.6%) and HIT+BFR (6.5%) groups. The HIT group without BFR displayed the greatest improvement in VO_{2max} (9.2%) and as expected the low-intensity, non-occluded group remained unchanged (0.4%).

Although our investigation did not reach statistical significance, the effect size for VO_{2max} change between the groups was 0.18, which while trivial is approaching a small beneficial effect. A possible reason for the greater improvement in VO_{2max} in the pBFR may be due to the groups working at different training workloads. Although our present study used 80% of pre-testing peak treadmill velocity for both groups, Table 4 reveals that between groups, mean training HR as a percentage of MHR, was significantly higher ($p = 0.03$) in the experimental group

compared to CON. Previous research (Abe, Kearns, & Sato, 2006; Renzi et al., 2010; Takano et al., 2005b) has also reported greater heart rate responses in under blood flow restricted conditions.

Our intervention required subjects in both groups to run at 80% of their peak running velocity reached during initial testing, however this does not mean that they all trained at the same percentage of their VO_{2max} . Depending on the individual differences between subjects anaerobic threshold, VO_{2max} can occur earlier or later in the test; the ability of the anaerobic system will obviously play a role in how long the subject can continue in the maximal test. Subjects who reach VO_{2max} earlier but still manage to continue running for a longer period of time, will reach a greater velocity and thus may train at a greater percentage of their VO_{2max} , despite running at 80% peak velocity. The differences in individual training intensity (as a % of VO_{2max}) may have contributed to the wide range of individual responses (see Figure 1) and the reason that no clear significant effect on VO_{2max} was observed. In particular, subject 4 from the CON group saw an increase in VO_{2max} of $5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (13.2%), which elevated the group's overall mean; this large individual response may skew the results somewhat. Although there was no significant difference in between-group training intensity, Appendix 5 shows that this same subject (subject 4) from CON was actually training at an average intensity of 89.6%, 6.5% greater than the control group mean. In contrast, the pBFR groups highest true subject intensity was 84.5, only 1.9% higher than the pBFR group average. Table 4 displays mean HR data and actual training intensity (% of VO_{2max}).

It is understood that training-induced responses in VO_{2max} can be the result of central and/or peripheral metabolic adaptations (Abe, Fujita, et al., 2010); however improved cardiac output represents the most significant adaptation resulting in greater aerobic capacity (Bassett & Howley, 2000). Previous authors have reported an increased HR, reduced stroke volume and maintenance of cardiac output during BFR training (Takano et al., 2005b). Unfortunately we did not have the equipment necessary to assess stroke volume and cardiac output, however training HR was significantly higher in the pBFR group ($p = 0.03$), suggesting that practical occlusion may have the desired effect: decrease blood flow and oxygen delivery, increasing

overall work that cardiorespiratory structures must carry out. While not measured in our study, this increase in workload potentially resulted in muscular adaptations often observed during improved aerobic and anaerobic capacity.

The limited literature investigating cardiorespiratory exercise with BFR makes quantifying exercise variables i.e. load, volume, intensity and frequency, challenging. The few studies that exist would suggest that at lower exercise intensities i.e. walking or low-intensity cycling, blood flow occlusion elicits a greater training effect. As exercise intensity increases, it would appear that BFR has a less pronounced effect and that it may be more beneficial to train under non-occluded conditions. It is logical to assume that BFR could in fact hinder subjects from reaching training intensities that they otherwise may have reached with normal blood flow. Since training intensity directly influences training response, subjects may not display comparable increases in aerobic capacity relative to their non-occluded counterparts.

5.1.2 Anaerobic capacity

An indirect measure of anaerobic performance was assessed by the time to exhaustion test, which improved in both groups (pBFR = 26.9%, $p = 0.09$ and CON = 17.4%, $p = 0.19$) and displayed a small effect size ($D = 0.31$) in favour of pBFR. Within group effect size for the experimental and control cohort was very large ($D = 0.85$) and large ($D = 0.62$) respectively, classified according to Hopkins magnitude based effects scale (Hopkins, 2002). The increase in both group TTE performance pre to post could have been influenced by a learning effect. Individual differences in the learning effect add to within-subject variability and can reduce the reliability of performance tests (Hopkins, 2000). To reduce the learning effect, subjects were blinded from seeing their TTE times.

Other studies have also found improvement in TTE following BFR training. The previously discussed study by Keramidas et al (2012) found significant improvement in cycle endurance time to fatigue in both groups following six weeks of interval training. Likewise Abe et al (2010) observed a 15.4% improvement in TTE following BFR training, while their control group demonstrated no change. In

addition, Corvino et al (2014) found significantly improved TTE in the BFR only group following four weeks of blood flow restricted low-intensity training. These authors postulated that increased metabolic and physiologic strains induced by BFR could have triggered adaptations responsible for delaying exercise exhaustion. Such adaptations may include increased muscle buffer capacity, increased capillary density and increased activation of type II muscle fibres. Keramidas et al (2012) observed greater peak power output (PPO) in both BFR and CON groups, and speculated that improved TTE performance could be related to the increase in PPO. While PPO increased, O₂ saturation and oxyhaemoglobin levels decreased. Subsequently, increased muscle buffering capacity post-training allowed exercising muscles to produce higher PPO at the same VO_{2max}. Our investigation revealed small changes in VO_{2max} with larger effects occurring in TTE performance. We did not measure changes in muscle oxygenation and haemoglobin concentration, however we did observe small effect ($D = 0.34$) in running economy in the BFR group only. Despite no significant change in VO_{2max}, increased PPO and improved running economy suggest that training with BFR leads to decreased oxygen consumption for the same given velocity.

Localized hypoxia induced by BFR perhaps represents an important trigger for physiological and performance related adaptations. The application of external pressure to the limbs decreases oxygen supply to the muscle, which potentially leads to increased energy contributions via anaerobic pathways (Scott et al., 2014). Studies have reported decreased pH (Suga et al., 2009) and increased lactate accumulation (Fujita et al., 2007; Takano et al., 2005b) associated with hypoxic conditions promoted during BFR training. Therefore improvements in TTE performance could be related to adaptations induced by these metabolic stresses. While the method of hypoxia is different from our study, simulated altitude, which causes hypoxia, has been shown to decrease lactate concentrations and increase muscle buffer capacity (Gore et al., 2001). The ability of intra and extracellular buffer systems to remove and buffer accumulated hydrogen ions (H⁺) may allow individuals to reduce performance decrements otherwise associated with H⁺ build up (Bishop, Edge, & Goodman, 2004).

The oxygen-deficient intramuscular environment that results during BFR training may stimulate an increase in capillarization, positively improving localised muscular endurance (Pope et al., 2013). It is widely accepted and understood that cardiovascular endurance training stimulates an increase in capillary density (Daussin et al., 2008; Klausen, Anderson, & Pelle, 1981), which allows greater oxygen extraction by the working muscles. Sundberg (1994) examined the effects of ischemia using single-legged cycle training and found that only the ischemically-trained leg showed increased capillary density, indicating that a combination of reduction in blood flow and exercise may have greater stimulatory effect than exercise alone.

Another adaptive process that could have played a role in increasing TTE is change in the muscle fibre recruitment pattern. Despite utilising lower intensities than our present study, other authors have reported increased muscle activation during BFR training (Takarada, Nakamura, et al., 2000; Yasuda et al., 2009). Further, Sundberg (1994) observed a greater depletion of type II muscle fibres and higher electromyographic activity in the ischemically trained leg only. Since training with BFR decreases force output and causes greater type II muscle fibre fatigue, it is likely that additional type II motor units are progressively activated to sustain power output. Subsequently, low-frequency adaptive processes (enhanced oxidative capacity and greater resistance to fatigue) may have occurred within type II fibres (Corvino et al., 2014).

Naturally, there have been questions and concerns raised over the safety of training with restricted blood flow, however researchers have since turned their attention toward addressing these issues. In particular, Nakajima et al (2006) carried out a national survey across KAATSU centres in Japan in order to quantify the incidence and severity of BFR related injuries. They concluded that BFR training was a safe and effective method for a variety of different populations. In the present study, there was no incidence of BFR related complications. Additionally, there were no reports of numbness, tingling or pain other than the occasional comment expressing mild discomfort.

5.2 Conclusion

In conclusion, the findings of this investigation demonstrate that four weeks of twice-weekly running interval training, performed with or without blood occlusion at the same relative intensity increases $\text{VO}_{2\text{max}}$ to a similar extent in both groups. Further, while both subject groups showed increases in time to exhaustion at peak running velocity, the blood occlusion group benefited to a small extent more than the control group.

5.3 Future studies

Blood flow restriction training is becoming increasingly popular in both resistance and endurance training settings, and given it is still a relatively novel training technique, more research is required. More studies, with larger sample sizes are required to further elucidate the possible mechanisms by which BFR may improve performance in athletic and rehabilitative settings. A better understanding of the acute and chronic physiological and performance-based responses may lead to better design of both endurance and strength training regimes.

5.4 Limitations

A difference between our study and previous studies investigating BFR on cardiorespiratory variables is the subjective method of occlusion utilised. A number of studies have observed significant changes in aerobic and anaerobic capacity, however these all used objective restriction methods (blood pressure cuffs, KAATSU devices) where cuff pressure was exact. Given that we did not objectively compare pressures between elastic wraps and blood pressure cuffs, there is a possibility that practical wrap pressures were not sufficient. However, our practical occlusion method has been previously quantified by Wilson et al (2013) who found that using a subjective pressure of 7/10 consistently restricted venous return, while not fully restricting arterial blood flow.

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APPENDICES

Appendix one: Participant information form



Information for Research Participants

Date: 15.08.15

Project Title:	The Effect of Blood Flow Restriction Training on Aerobic and Anaerobic Capacity
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To:	Research Participants
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Researcher(s):	Shalako Addis
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Affiliation:	School of Health and Sport Science, Eastern Institute of Technology
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Description of the research:

The aim of this research project is to investigate the effects of blood flow restriction (BFR) training on measures of physical fitness using running as the mode of training. Reducing blood flow to a muscle is commonly carried out with blood pressure cuffs or elastic tubing, which are placed at the base of the arms or legs. A reduction in blood flow is subsequently accompanied by a reduction in the amount of oxygen that is being delivered to the working muscles, which is believed to be a factor in muscular adaptations observed following resistance exercise. An interesting finding that has emerged from blood flow restriction research is that significantly lighter loads are all that is required to elicit gains in muscular size and strength.

While a growing amount of literature supports the use of BFR training during resistance exercise, there is a limited amount of research that has assessed the effects of BFR training on cardiovascular components of fitness. Therefore there is an opportunity to significantly contribute scientific findings in this particular area. Our research will combine BFR training with low-moderate intensity running in an effort to produce changes in aerobic and anaerobic fitness. Our findings from this research will allow us to make better training recommendations to athletes and coaches. Additionally, there are positive implications for injured athletes who are not able to train at higher intensities. Higher intensities are typically required to see adaptation and this may have more importance if the athlete has a greater training age and status. Athletes who can still train and experience significant gains while injured will most likely return to competition sooner and suffer less detraining effects.

What will participating in the research involve?:

Participating in this research will require the participants to complete a four week training block including pre and post testing. Training will require the commitment to two separate running interval training sessions per week, approximately 10-15 minutes in duration (excluding warm-up). During pre and post testing, we intend to measure aerobic performance using a maximal oxygen uptake test (VO_{2max}) via portable equipment and anaerobic performance using a time to exhaustion test (Tlim) which will be based off the speed at which VO_{2max} occurs. Following anaerobic assessment, a small blood sample will be taken via the finger-prick technique which will then be used for lactate analysis. Total testing time will be approximately 60 minutes.

What are the benefits and possible risks to you in participating in this research?

By participating in this research, you will receive four weeks of supervised training, laboratory testing measuring your current fitness level and an expected increase in fitness. Our research will contribute to science and further extend our understanding of a relatively novel training concept. As with all physical exercise, there is always a risk of injury or complication. Blood flow restriction training has been identified as a relatively safe method of training, given that training is monitored.

Your rights:

- You do not have to participate in this research if you do not wish to.
- If you are a student at EIT and decide to take part, you can withdraw from the research at any time and this will not affect treatment or assessment in any courses at EIT.
- Once you have completed the research you have a four week period within which you can withdraw any information collected from you.
- You are welcome to have a support person present (this may be a member of your family/whanau or other person of your choice)
- You may request a summary of the completed research

Confidentiality:

Data will be stored in a password protected electronic document in accordance with institutional policy. Any non-electronic forms of data or relevant documentation will be stored in a locked and secured cabinet on institutional premises. Identifiable information about you will not be made available to any other people without your written consent.

If you wish to participate in this research, or if you wish to know more about it, please contact

Contact Person:	Shalako Addis		
EIT School/Section:	School of Health and Sport Science		
Work phone #		Email address	
Mobile phone #			

Supervisor Name(s): (if applicable)	Carl Paton Lee-Anne Taylor		
Work phone #	06 9748000 ext 6116	Email address	cpaton@eit.ac.nz ltaylor@eit.ac.nz

Head of School/Manager:	Kirsten Westwood		
Work phone #	06 9748000 ext 5240	Email address	kwestwood@eit.ac.nz

For any queries regarding ethical concerns, please contact:
Chair, Research Approvals Committee, EIT. Ph. 974 8000

Appendix two: Informed consent



CONSENT FORM

Project Title: The Effect of Blood Flow Restriction Training on Aerobic and Anaerobic Capacity

Researcher(s): Shal Addis (Student) Carl Paton (Supervisor)

I have read and I understand the Information for Research Participants sheet dated 15/08/15 for volunteers taking part in this study. I have had the opportunity to discuss this study and am satisfied with the answers I have been given.

I understand I am able to withdraw all of my information until 1.10.15

I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the testing at any time and this will in no way affect my future academic progress/ employment

I understand that my participation in this study is confidential and that no material which could identify me will be used in any reports on this study.

I have had time to consider whether to take part, and know who to contact if I have any questions about the study.

I agree to take part in this research

I consent to my interview/activity being videotaped/audiotaped

I wish to receive a summary of the results

Yes	No
<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>

Signed: _____

Name: _____

Signature of Research Participant's Support Person (if applicable)

Date: _____

Witness: _____

I/We as researcher(s) undertake to maintain the confidentiality of information gather during the course of this research.

Signed _____

Dated _____

This study has been approved by the EIT Research and Ethics Committee on 28 August, 2015 Reference # 23/15

Appendix three: Medical questionnaire

Pre-exercise Screening Questionnaire

Name				
Address		Occupation		
		Day Phone		
		Evening Phone		
Contact Person (1)		Contact Person (2)		
Phone		Phone		
Today's Date		Doctor		
Date of Birth				
Gender	Age	H/R	B/P	
Height	Weight	BMI		
Please answer the following questions by placing a tick \checkmark in the appropriate box.				
Health Status			Yes	No
1	Have you ever had a stroke or heart condition?			
2	Have you ever had high blood pressure?			
3	Have any family members had heart problems before age 60?			
4	Have you experienced chest pain when engaged in physical activity?			
5	Have you experienced chest pain when not engaged in physical activity?			
6	Have you ever had, or do you currently have, high blood cholesterol?			
7	Have you ever suffered from asthma or breathing difficulties?			
8	Have you ever smoked – cigarettes, pipes or cigars?			
9	Are you pregnant or have you been pregnant within the last three months?			
10	Have you been hospitalised within the last six months?			
11	Are you currently taking any medication(s)?			
12	Have you ever had, or do you currently have, diabetes, epilepsy, hernia, dizziness or loss of consciousness?			
13	Have you ever had any disease or injury of the back, joints, bones or muscles that may be aggravated by exercise?			
14	Are you aware of any other health-related issues that may affect your participation in physical exercise?			
Please provide details of "Yes" answers in the space provided over the page.				

Pre-exercise Screening Questionnaire (part two)

Name		
Details of "Yes" answers, medications, possible contraindications to exercise, etc.		
Please answer the following questions by placing a tick ✓ in the appropriate box.		
Exercise Participation	Yes	No
1 Have you been participating in regular physical activity? If yes, what type?		
2 How would you describe your current physical condition? (Tick ✓ one or more boxes).		
unwell	overweight	unfit
healthy	fit	
3 What are your exercise goals? (Tick ✓ one or more boxes).		
fat reduction	improve fitness	maintain fitness
health / wellness	stress reduction	
muscle tone	increased mass	sport training
injury prevention	social contact	
<ul style="list-style-type: none"> • I have understood all the questions and have answered them to the best of my knowledge. • I certify that I have disclosed fully any conditions that may affect my participation in physical exercise. 		
Date	Staff Name	
Client Signature	Staff Signature	

Appendix four: Ethics approval



Reference Number 23/15

28 August 2015

Shalako Addis
Masterate Student
C/- School of Health Science
EIT

Dear Shalako

I am please to inform you that your research project "*The Effect of Blood Flow Restriction Training on Aerobic and Anaerobic Capacity*" was received and approved by the Research and Ethics Committee at their meeting held on 28 August 2015.

You are reminded that should the proposal change in any significant way, then you must inform the committee. Please quote the above reference number on all correspondence to the Committee.

The Committee wishes you well for the project.

Yours sincerely

Jeanette Fifield
Secretary- Research and Approvals Committee

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Appendix five: Raw data

True training intensity (% VO _{2max})	
pBFR	
Subject 1	84.5
Subject 2	78.7
Subject 3	80.0
Subject 4	84.2
Subject 5	83.0
Subject 6	83.2
Subject 7	83.5
Subject 8	83.5
CON	
Subject 1	83.5
Subject 2	76.8
Subject 3	81.4
Subject 4	89.6
Subject 5	87.8
Subject 6	84.2
Subject 7	80.0
Subject 8	81.4