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The Acute Effects of Warm-up with and Without Blood Flow Restriction Cuffs on Lower Body Temperature, Flexibility, and Vertical Jump Power

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THE ACUTE EFFECTS OF WARM-UP WITH AND WITHOUT BLOOD FLOW RESTRICTION CUFFS ON LOWER BODY TEMPERATURE, FLEXIBILITY, AND VERTICAL JUMP POWER

A Thesis

by

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THE ACUTE EFFECTS OF WARM-UP WITH AND WITHOUT BLOOD FLOW

RESTRICTION CUFFS ON LOWER BODY SKIN TEMPERATURE,

RANGE OF MOTION, AND VERTICAL JUMP PERFORMANCE

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ABSTRACT

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Purpose: The purpose of this study was to determine the effect of blood flow restriction warm-ups (BFR-WU) on skin temperature (ST), range of motion (ROM), and vertical jump (VJ) performance.

Methods: Forty-seven participants performed WU's with unilateral BFR application. Each participant took part in five different WU durations. Measurements of ST, ROM, VJ were taken at baseline, post-WU, and post-8min.

Results: Significant conditions main effect ($p<0.05$), condition*time ($p<0.05$), WU-duration*condition ($p<0.01$), and conditions*time*sex interactions ($p<0.05$) were found by repeated measures ANOVA.

Conclusion: The current findings reveal that BFR-WU's react differently throughout time, when compared to NBFR-WU, for ST and VJ performance, but not ROM. The length of duration was only significant for hamstring skin temperature and did not affect VJ performance or ROM. The BFR condition yielded continuous increases in VJ performance throughout time, while the NBFR condition has post-WU increases and post-8min decreases. BFR-WU significantly reduced quad and hamstring ST post-WU, indicating a reduction skin blood flow with BFR use.

DEDICATION

This thesis would not have been possible if it had not been for my passion for exercise science and perseverance through difficulties. Throughout this thesis, I learned the meaning of a powerful ten two-letter word statement “if it is to be, it is up to me”. I would like to dedicate this thesis to myself but dedicate the mind-set of perseverance to the family that raised me. All those who put in the time to teach me life lessons. My brothers, whom I raise the bar to. This passion and perseverance go to you.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION

New methods to aid in athletics and fitness continue to appear as our understanding of the human physiology evolves. However, great methods, combined with false instruction, can be detrimental to efficiency (Buekers, Magill, & Hall., 1992). It is vital to prevent the false use of new methods by evolving our understanding of how they may positively or negatively impact our physiology. Through scientific investigation of these methods, it is possible to elucidate the ranges of hormesis. Ranges of hormesis describe the upper and lower beneficial limits of use. While staying within these proposed ranges results in a desired dose-response and going beyond those ranges results in a toxic or inadequate response.

A significantly successful and growing training method called blood flow restriction (BFR) is said to be only partially understood (Karabulut, Abe, Sato, & Bemben., 2007). Investigators have stated that it should be introduced with caution, can be well-tolerated by the elderly, can cause extreme soreness, and can cause rhabdomyolysis (Fry et al., 2010; Iversen et al., 2010; Karabulut et al., 2013b; Tabata et al., 2016; Wernbom et al., 2012). Because of the varying responses to BFR use, it is hypothesized to abide by the law of hormesis (Loenneke, Thiebaud, Abe, & Bemben., 2014). This suggests that there are inadequate, desirable, and toxic dose-response ranges of BFR use. Safe and unsafe ranges of use, along with methods to measure them, have been investigated by Sato, the inventor, since its development in 1966 (Sato., 2005). Controls for the initial restrictive pressure (IRP) and final resting pressure (FRP) of the cuff are among the most important to BFR use (Karabulut et al., 2013a; Karabulut et al., 2014; Loenneke et al., 2015). These controls are made possible by pneumatic bladders that line the inside of the elastic KA-ATSU cuff. The bladders are connected to pressure sensors that can increase, decrease, and display intra-bladder pressure throughout the placement process (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan).

While BFR is recommended to aid in resistance training (RT) with protocols shown to be significantly effective, protocols for use in warm-ups (WU) are not well established (Cook et al., 2007; Colomer-Poveda et al., 2017; Fry et al., 2010; Karabulut et al., 2013b; Karabulut et al., 2014; Takarada et al., 200b; Yasuda et al., 2006; Yasuda et al., 2009; Yasuda et al., 2012). Traditional WU literature has elucidated desired ranges of hormesis that enhance mechanisms of performance such as tissue temperature, vertical-jump (VJ), and range of motion (ROM) (Bishop, 2003a; Bishop, 2003b). Variables that are recommended to control such as WU-duration, WU-intensity, and athletic status, can vary the desired dose-response relationship (Bishop, 2003b; Chiu et al., 2003). This study proposes to begin the probing of WUs with BFR between 5-15min for possible ranges of inadequate, beneficial, and toxic use for skin-temperature (ST), VJ, and ROM. These variables will be measured through non-touch infrared thermometer (Exergen Corporation, Temporal Scanner, TAT-2000C), Tendo Power Analyzer (TENDO Power Analyzer V- 316), Vertec Device (Sport Imports, Vertec Vertical Jump Trainer, Vertec2), and goniometer (Baseline Evaluation Instruments, Goniometer, 8-inch plastic 360-degree ISOM) respectively. Because there is a lack of comprehensive BFR-WU protocols, the purpose of this study was to provide evidence to support or oppose the use of KA-ATSU bands in WU's.

Purpose

The purpose of this study was to 1.) Determine optimal BFR-WU durations 2.) Determine if BFR-WU's are appropriate for enhancing a desired response 3.) Determine if condition differences dissipate over time.

Statement of the problem

Without scientifically established protocols for blood flow restriction (BFR) use in warm-ups (WU), further instructive errors may occur and can be detrimental to performance (Buekers et al., 1992). BFR has been used, researched, and recommended for use in WU's, but does not have well-established protocols in WU's (KAATSU GLOBAL INC., 2017; Karabulut et al., 2017). This is a problem because WU's with BFR are shown to significantly alter mechanisms of performance such as caloric expenditure after low-intensity cycling for 15 minutes, excessive post oxygen consumption (epoc) magnitude post treadmill walking, but not vertical-jump after a 5-minute WU (Amaral et al., 2016; Karabulut et al., 2017; Mendonca et al., 2015). Not having comprehensive BFR-WU protocols is a problem because it has been shown to affect mechanisms of performance significantly more than traditional WUs (Amaral et al., 2016; Karabulut et al., 2017; Mendonca et al., 2015). In order to recommend BFR-WU's it was essential to investigate what durations are beneficial or detrimental to mechanisms of performance.

Significance

BFR literature has a lack of observations that provide evidence to support or oppose the use of BFR to bring about ideal environments of enhanced lower range of motion (ROM) or vertical-jump (VJ) performance in response to warm-ups (WU). If any of the proposed physiological responses to be recorded are significantly affected by BFR, it could lead to the use of BFR in WU's to elicit a desired response. If a WU with BFR increases ROM over a WU without, it would be beneficial to understand the effects of BFR on skeletal muscle-stiffness. Muscle-stiffness, a flexibility related condition, has been associated with increased injury rates in athletes and keeps employees from their occupation (Larsson et al., 1998; Larsson et al., 1999; Watsford et al., 2010; Witvrouw et al., 2003). Besides benefiting populations on different ends of the health and fitness spectrum, BFR-WU research can further elucidate its physiological aspects that are not fully understood and optimal zones of use that have yet to be elucidated (Gibson et al., 2013; Karabulut et al., 2007). The physiological response to ST can help elucidate the total contribution of venous blood flow on thermoregulation of the skin between WU's with and without BFR. If different duration BFR-WU's are shown to be beneficial, detrimental, or insignificant, as shown before to VJ (Amaral et al., 2016). Further research in single effort events or long-term events can be justified as it has been shown that a similar practice, ischemic-preconditioning (IP), is more beneficial in swimming events than sprinting events (Gibson et al., 2013; Jean-St-Michel et al., 2011). This study aims to elucidate any ranges where using BFR in WU's, improve the efficiency of its use.

Assumptions

1. Accurate information was provided by participants on all medical and health related questionnaires.
2. Participants were fasted 8 hours prior to testing.
3. Participants were hydrated during testing ($\leq$ 1.010).
4. Participants maintained their training status.
5. Participants refrained from lower body training 48 hours prior to testing.
6. All calibrated instruments provide accurate results.

Limitations

1. The study may not be representative of the population since all the participants were volunteers rather than sampled.
2. Subjects were asked to maintain their current lifestyle and training status; however, this was not monitored.
3. Health history and medical information were collected through self-report.

Delimitations

1. Individuals with signs or symptoms of CVD were not permitted to participate in the study.
2. Individuals younger than 18 and older than 50 were excluded from this study.
3. An active population was used.
4. The population was from the area of the Rio Grande Valley and surrounding areas.
5. Individuals were required to be 8-hours fasted and adequately hydrated before testing.

6. The warm-up was done on a cycle ergometer.
7. Only lower body ROM measurements were taken.
8. Participant's single leg vertical and power output was be measured; data cannot be generalized to bilateral (double leg) vertical trails or power output.

Research Questions

1. Was the length of BFR-WU important to optimizing performance?
2. Would there be differences between the BFR and NBFR conditions?
3. Will differences dissipate over time?

Hypotheses

1. There would be a length of BFR-WU duration where performance was optimized.
2. There would be differences between the BFR and NBFR conditions.
3. Differences would dissipate over time.

Operational Definitions

1. KAATSU: elastic bands with a pressure sensor that restrict blood flow while performing low-intensity exercise (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan).
2. Non-Blood flow restriction (NBFR): The control in a BFR study. This refers to a limb or group that is not affected by BFR.
3. Initial restrictive pressure (IRP): The pressure caused by the tightness of the cuff before inflation. (50-55mmHg).

4. Final restrictive pressure (FRP): the final and highest pressure of the BFR cuffs, which is used during cycle ergometer sessions. Measured by capillary refill time of ≤2 seconds in this study.
5. Physical activity readiness questionnaire (PAR-Q): A questionnaire designed to measure the participant's physical activity status.
6. Systolic blood pressure (SBP): The pressure against the walls of the arteries during systole (the contraction of the ventricles).
7. Diastolic blood pressure (DBP): The pressure against the walls of the arteries during diastole (the relaxation of the ventricles).
8. 90:90 Hamstring test: used to measure maximal knee extension while the hip is at a 90-degree angle.
9. Prone Knee Flexion test: Used to measure maximal knee flexion while lying prone (face down).
10. Dorsiflexion test: used to measure range of motion of ankle dorsiflexion, taken while the participant is seated upright on the floor with extended knees and instructed to completely flex the foot towards the body.
11. Vertec: Instrument used to measure a participant's maximal vertical jump. Participants mark their maximum vertical by pushing pre-measured veins over. (Sport Imports, Vertec Vertical Jump Trainer, Vertec2).
12. Tendo: Instrument attached to a participant by a provided belt that is used to measure maximum power output. (TENDO Power Analyzer V- 316).
13. Random counterbalanced method (RCM): a method used to reduce the learning curve or false responses that may alter results.

14. Countermovement (CMJ): A technique used to utilize the stretch shortening cycle in a maximal vertical jump test. The arms swing down with the quick flexing of the hips, knees, and downward motion of the trunk before jumping and reaching upward with the arms.
15. Warm-up (WU): An exercise technique used to prepare the body and mind for physical activity.
16. Passive Warm-up: A technique used to increase muscle temperature through external means (i.e. heating pads or sauna).
17. Active Warm-up: Short (5-15 min) moderate-intensity (40-60% Vo2) bouts of exercise that are designed to prepare the body for more intense bouts of exercise.
18. Capillary Refill Time (CRT): The time it takes for the capillaries of the skin to refill after outside compression. Observed through skin color change.

CHAPTER II

LITERATURE REVIEW

Introduction

The purpose of this literature review is to highlight the importance of further investigation into its major topics. A successful low-intensity alternative method to traditional resistance training, called blood flow restriction (BFR), has been shown to be effective in several studies (Cook et al., 2007; Colomer-Poveda et al., 2017; Fry et al., 2010; Karabulut et al., 2013b; Karabulut et al., 2014; Takarada et al., 200b;Yasuda et al., 2006; Yasuda et al., 2009; Yasuda et al., 2012). However, the physiological aspects of applying vascular restriction are described as not fully understood and optimal ranges of restriction for use in warm-ups (WU) have yet to be elucidated (Gibson et al., 2013; Karabulut et al., 2007).

Protocols for efficient traditional WU's have been well-reviewed and recommended (Bishop, 2003a; Bishop, 2003b). Active WU’s are used to affect factors such as blood-flow, temperature, range of motion (ROM), and vertical-jump (VJ) (Bishop, 2003a). As one becomes physically active in a WU, such as walking, shifts of blood flow are seen with each step (Rowell, 2004). Muscular contractions are needed for reperfusion of the muscle; they compress the intramuscular vessels during contraction and cause blood pulling in the venous system during relaxation (Anrep, 1935; Rowell, 2004). The repeated opening and closing of vessels during movement increase the flow of blood and heat from the skin to the site under mechanical stress, (Bishop, 2003a; Rowell, 2004; Kidston et al., 2013). Skin-temperature (ST) typically drops within the first few minutes as muscle temperature rises (Bishop, 2003a; Kidston et al., 2013). Later rises in core temperature are seen if there is no restriction of venous return from the limb participating in exercise (Raccuglia, Lloyd, Filingeri, Faulkner, Hodder, & Havenith., 2016). Along with shifting blood flow and increasing muscle temperature, this type of physical activity can increase range of motion (ROM) and muscular compliance, which is beneficial to multiple populations (Larsson et al., 1999; Witvrouw et al., 2003). Athletes have been shown to benefit from enhanced musculotendinous-unit (MTU) compliance with subsequent improvements in VJ height (Cavagna, 1977; Wilson et al., 1994). Increased compliance is also beneficial for those with myalgia who suffer from stiffness and pain (Larsson et al., 1999).

Furthermore, BFR has similar post-use benefits to stretching such as hyperemia and reduced resting twitch integrated electromyography (iEMG) (Behm et al., 2015; Karabulut et al., 2010; Matchanov et al., 1983; Yasuda et al., 2010). Passive tension is shown to increase with the increase of the width and length of the muscle (Magnusson et al., 1997; Matchanov et al., 1983). While BFR is shown to acutely increase the width of the muscle and increase passive tension for up to 4 days (Yasuda et al., 2009; Yasuda et al., 2012; Wernbom et al., 2012). This may imply that due to hyperemia and blood pooling, the muscle width or length may remain in an expanded state post-BFR use. It is clear that the restriction of blood flow while training causes an increase in passive tension (Wernbom et al., 2012), blood pooling (Karabulut et al. 2007), cytoskeletal expansion (Pope et al, 2013), and limb circumference expansion (Loenneke et al., 2012; Yasuda et al., 2012). BFR will cause physiological differences during WU. What is not clear is to what durations should be used to bring about a desired response. This is a problem when considering athletes because the specificity of the WU is vital to optimizing performance (McGowan et al., 2015). Differences in ST, ROM, and VJ with and without KAATSU-BFR will be observed through different durations to begin to elucidate optimal ranges for BFR-WU's.

Blood Flow Restriction

Blood Flow Restriction (BFR) is the method of applying external compression to the most proximal portion of a limb in order to restrict its blood flow to a desired moderate amount (Crisafulli et al., 2011; Jean-St-Michel et al., 2011; Karabulut et al., 2007; Loenneke et al., 2014). A complete occlusion method called ischemic-preconditioning (IP), used in three intervals of 5 minutes on and 5 minutes off, has improved performance and given a competitive edge in swim events (Crisafulli et al., 2011; Jean-St-Michel et al., 2011). IP has also been used in more than just the limbs, in a study that showed IP has protective effects on the heart during myocardial infarction (Ghosh, Standen, & Galiñanes., 2000). The use of maintained IP post-WU has been utilized to maintain warmth in the legs of athletes who have long wait times between the WU and competitive event (Raccuglia et al., 2016). Yoshiaki Sato invented a lower-intensity restriction of blood flow that impedes venous return but allows for arterial flow in 1966 (Sato et al., 2005; Loenneke et al., 2014). Sato wanted to use BFR in resistance training when he perceived that the sensation of blood pooling from exercise was similar to that of blood pooling in the lower limb after kneeling for some time. Using tourniquets, he began trials of resistance training while restricting blood flow. BFR training took years of trials to take BFR training from potentially hospitalizing to a safe, beneficial, and more measurable intensity of restriction. Through the use of the Sato's KAATSU-Master, restrictive pressures caused by the cuff can be controlled to fit the desired BFR intensity. The idea is to set a restrictive pressure that impedes venous outflow but not arterial inflow, in order to cause blood-pooling (Loenneke et al., 2014).

After having been developed and improved over the years, the use of the KAATSU-Master has become a rising practice. It is shown to be a successful alternative to traditional training techniques and just as IP, BFR through the KAATSU-Master has been shown to have protective effects on the affected muscles (Fry et al., 2010: Ghosh et al., 2000; Kubota et al., 2008; Sata et al., 2005; Takarada et al., 2000a). Because of its success, BFR is a topic of interest in recent studies that have associated it with many benefits. Its most notable benefit is its anabolic effects on the muscular organs of its affected limb. It has been used to aid in the development of muscle tissue (hypertrophy), reduce the atrophy of immobilized limbs, reduce sarcopenia in the elderly, and reduce post-surgery recovery time while requiring low-intensity resistance training or immobile isometric contractions (Fry et al., 2010; Kubota et al., 2008; Takarada et al., 2000a; Yasuda et al., 2012). Many studies provide evidence of the benefits of KAATSU BFR training. However, few studies provide evidence to justify its use in WU's as IP is (Crisafulli et al., 2011; Jean-St-Michel et al., 2011).

Mechanisms of BFR

To properly utilize the KAATSU-Master's in training or study, it is essential to understand its underlying mechanisms. Highlighted acute physiological responses of BFR include muscle swelling, reduced venous outflow, reduced stroke-volume, increased heart rate, blood pooling, increasing EMG, reduced maximal voluntary contraction, reduced maximal voluntary contraction iEMG, and metabolite accumulation (Karabulut et al., 2007; Loenneke et al., 2014; Yasuda et al., 2006; Yasuda et al., 2009; Yasuda et al., 2010; Yasuda et al., 2012).

Highlighted acute post-use mechanisms include hyperemia, increased excessive post oxygen consumption (epoc) magnitude, increase in muscle cell permeability, and lowered twitch iEMG (Karabulut et al., 2010; Mendonca et al., 2015; Pope et al., 2013; Wernbom et al., 2012; Yasuda et al., 2010). Highlighted adaptations include hypertrophy, angiogenesis, increase in capillary filtration, reduced atrophy, reduced joint swelling/inflammation, improved Vo2, and myonuclear proliferation (Evans et al., 2010; Fahs et al., 2012; Hunt et al., 2013; Karabulut et al., 2007; Kubota et al., 2008; Nielsen et al., 2012; Sata et al., 2005; Takarada et al., 2000a).

The mechanisms that are hypothesized to induce these benefits include muscle cell swelling, increased fast-twitch fiber motor-unit recruitment, cytoskeletal tension, metabolic stress, myonuclear and satellite cell proliferation, increases in growth hormone and insulin-like growth factor (IGF-1), and increases in muscle protein synthesis through mammalian target of rapamycin (mTOR) (De Freitas et al., 2017; Fry et al., 2010; Karabulut et al., 2007; Loenneke et al., 2012; Nielsen et al., 2012). Furthermore, Karabulut et al. (2007) states that several populations are currently benefiting from BFR, including the athletically trained, recreationally trained, untrained, the elderly, and those who are rehabilitating (Karabulut et al., 2007; Takarada et al., 2002).

BFR placement protocol

Since the invention of BFR training, investigators have presented overwhelming evidence of the need for protocols that increase the efficiency of its use (Karabulut et al., 2007; Sato., 2005). It is essential to understand what protocols are proven to be significant to the use of BFR when conducting studies on its effects because variations in protocols delimit the data collected in their respective studies to their specific protocols. Factors that should be taken under consideration when producing a protocol for BFR seem to all be related to mechanisms that modulate how it restricts blood flow. Variables such as size of cuff, initial restrictive pressure (IRP), systematic increases in pressure, final restrictive pressure (FRP), and composition of the limb applied to are suggested to have significant effects on mechanisms related to BFR and must be taken under consideration (Crenshaw, 1988; Karabulut et al., 2013a; Loenneke et al., 2013). The ability to accurately measure these factors is made possible through the pressure control system of the KAATSU-Master (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan). The control system is used during the placement to find the recommended ranges for IRP (10-60mmHg) and while systematic increases in pressure are applied (20mmHg increments of 30 seconds of restriction and 10 seconds of rest). FRP is found by reaching a skin capillary refill time of ≤3 seconds by the affected limb at the end of a 30 second inflation period (KAATSU GLOBAL I. D., Article.cfm?cms_ArticleID=290, 2019; KAATSU GLOBAL INC., 2017).

Range of Motion

When conducting studies that observe range of motion (ROM), it is essential to review literature of average ROM's and how different ROM's effects today's populations. ROM is needed for everyday living, quality of life (QOL), and sport-specific demands (Behm et al., 2015; Cunha et al., 2008). ROM is shown to decrease with decreases in physical activity such as in immobilized limbs and increase with physical activity (Bishop, 2003a; Tucker, 1978). This suggests that ROM abides by the principle of specific adaptations to the imposed demands (S.A.I.D principle) (Alter et al., 2004; DeVries et al., 1974). Limiting factors of ROM include the apposition of the joint, tendon, ligament, fascia, muscle mass, and joint compactness (Alter et al., 2004; Clarkson et al., 2000). Previous studies that investigated lower body ROM have found that out of 120 participants, average ROMs in degrees were 113° for hip flexion, 134° for knee flexion, and 18° for ankle dorsiflexion (Boone et al., 1979). Benefits of good ROM include increased QOL, blood flow reperfusion, and muscle compliance, and decreased chance of injury (Behm et al., 2015; Cunha et al., 2008; Witvrouw et al., 2003).

Warm-Up

Warm-ups (WU) are moderate-intensity exercises that are commonly used to physically and psychologically prepare a person for more intense exercise (Wright et al., 1961). Enhanced preparedness has made WU's an essential part of optimal athletic performance (Bishop, 2003b). However, they must be designed to elicit the specific physiological effects required for performance and not fatigue the athlete (Bishop, 2003b). When considering the fatiguability of the athlete, WU techniques can be divided into two categories, active and passive (Bishop, 2003a). General active WU's involve physical activity such as running and cycling at submaximal intensities (40-60% Vo2), for short durations (5-15 minutes) (Haff et al., 2015). Passive WU's involve using some external factors (i.e., sauna, hot shower, and heated leggings) to increase the temperature of the body or a specific area. The time spent on a warm-up can be divided into intervals of varying intensities or durations, depending on the specific needs of the upcoming event (Bishop, 2003a; Bishop, 2003b).

Physiological mechanisms involved in WU's are divided into two categories, temperature and non-temperature related (Bishop, 2003a). Temperature related include decreased stiffness, increased nerve-conduction rate, altered force-velocity relationship, increased anaerobic energy provisions, and increased thermoregulatory strain (Bishop, 2003a). Non-temperature related mechanisms include increased blood flow to the working muscles, elevation of baseline oxygen consumption, increased post-activation potentiation, and increased psychological preparedness (Bishop, 2003a). The most common way to achieve the majority of these is through increasing tissue temperature, hence the term ‘warm-up’ (Bishop, 2003a). Although active WU’s are preferred, these benefits can be achieved by increasing temperature through a passive WU (Böning et al., 1991; Barcroft et al., 1909; Kiens et al., 1989).

The benefits of WU’s have been investigated, and their mechanisms have been described. Oxygen delivery increases to the affected area by an increase in vasodilation and rightward shift of the oxyhemoglobin dissociation curve, which spares anaerobic energy early in competition (McCutcheon et al., 1999; McGowan et al., 2015). Power output increases are said to be caused by post-activation potentiation, enhanced nerve conduction rate, breaking of myosin-actin bonds, decreased viscous resistance, and reductions in muscle stiffness (Karvonen et al., 1992; Wright et al., 1961; Zakas et al., 2006). Energy provisions increase due to the metabolic effects of increased muscle temperature on aerobic metabolism and glycogenolysis (Fink et al., 1975; Koga et al., 1997).

Response to rhythmic Muscle Contractions

The stretch and shortening caused by contracting muscles are shown to be essential to the blood flow through the innervating vasculature (Anrep et al., 1935). Rhythmic muscular contractions increase stroke volume and heart rate are seen and are considered a significant factor in cardiovascular disease (CVD) (Crisóstomo et al., 2014; Katayama et al., 2014). The force of each contraction is a contributing factor to the magnitude of arterial flow post contraction (Järvholm et al., 1988). During a concentric contraction, the innervating arterials are compressed, and the blood within them is pumped against backpressure into connecting veins

(Rowell, 2004). Although, the contraction phase and its force, is not the only mechanical factor to the blood flow of the innervating arterials of the muscle (Ellis et al., 1990; Järvholm et al., 1988). When relaxed and extended during the eccentric phase, the passive tension developed by the flattening of the perimysial crimp fold contributes to the development of negative pressure and pulls open compressed arteries (Cho et al., 2017; Rowell, 2004; Shleip et al., 2006). If extended further into a stretch, blood flow can also be reduced by compression of the arteries and subsequently cause ischemic conditions (Behm et al., 2015). The described rhythmic motion of stretch and shortening creates fluctuating pressures against surrounding vasculature (Kiens et al., 1989; Korthuis et al., 2011; Rowell, 2004). The dynamic movement has also been shown to increase muscular compliance and reperfusion (Behm et al., 2015; Rowell, 2004). Within four heartbeats after the onset of contractions, 100-900mL of blood is delivered to the heart by muscle pump venous return, prior to reflexive sympathetic activity (Rowell, 2004). Subsequent reflexive sympathetic activity acts to vasoconstrict the periphery in order to return blood to the central veins and heart (Farrell et al., 2012; Kidston et al., 2013; Stewart et al., 1998). The muscle pump and vasoconstriction venous return is then redistributed to the working muscles (~2.2L*min-1) that are undergoing vasodilation (Bishop et al., 2003; Farrell et al., 2012; Kidston et al., 2013; Stewart et al., 1998; Rowell, 2004).

Vertical-Jump

The vertical-jump (VJ) is an individual's ability to propel their self vertically. This ability is important to the future health of the lower body and athletic team coaches (Visnes et al., 2012; Klavora, 2000). VJ height is one test given by coaches, for its predictive validity for athletic ability (Haff et al., 2015). It is used to predict future outcomes of athletic performance and to place team members in appropriate positions or rankings (Graham, 1994). A high-level VJ ability is essential in sports that require explosive power (i.e., volleyball, football, basketball, soccer, and baseball) and sport-specific skills that need to be performed higher than the opposing team (i.e., spike, block, rebound, catch, and pass) (Graham, 1994). It has been shown that the greatest VJ height abilities are found in volleyball players (Klavora, 2000). To improve or research the VJ, an understanding of how to test it, contributing factors, training protocols, and limiting factors are essential. Factors that affect VJ, broadly include biomechanics, training mode, and body composition (Baker, 1996; Markovic, 2007).

Mechanisms of the vertical jump

Factors that contribute to the performance of vertical-jump (VJ) are the stretch-shortening cycle (SSC), series elastic component (SEC), parallel elastic component (PEC), contractile component (CC), stretch-reflex, motor-unit recruitment, muscular strength, eccentric intensity, and eccentric-concentric transition (Albert, 1991; Anderson et al., 1993; Asmussen et al., 1974; Baker et al., 1996; Bosco et al., 1982; Garhammer et al., 1992; Markovic et al., 2010). The SSC increases VJ height through a rapid downward (eccentric) movement that pre-loads and stores energy in the SEC of the agonist muscle as well as the elicitation of the stretch-reflex (Anderson et al., 1993; Haff et al., 2015; Wilk et al., 1993). The contribution to VJ height from the SSC can be seen in the difference between the countermovement-jump (CMJ) and static jump that does not utilize the SSC (Baker, 1996). The SEC is where the majority of the pre-stretch energy from the SSC is stored and is comprised primarily of the tendons (Albert, 1991; Anderson et al., 1993; Haff et al., 2015). A smaller portion of the pre-stretch energy from utilizing the SSC is stored in the PEC, which is comprised of the fascia tissue of the muscle (epimysium, perimysium, endomysium, and sarcolemma) (Albert, 1991; Anderson et al., 1993; Blazevich et al., 2012). The intensity of the eccentric phase is a significant contributor to the amount of energy stored in the SEC and PEC from the SSC. It is shown that participants with more intense eccentric phases have significantly higher VJ (Sheppard et al., 2007). To utilize the energy stored during the SSC for increases in VJ height, the transition from the eccentric to the concentric phase (amortization phase) must be quick. As the length of the amortization phase increases, the stored energy is rapidly lost through heat and there is no benefit seen for VJ height (Cavagna, 1977).

The stretch-reflex response from the SSC is caused by a proprioceptive nerve (muscle spindle); the nerve senses the rapid stretch of an intense eccentric-phase and reacts to it with a reflexive contraction stimulus (Bosco et al., 1982; Wilk et al., 1993). A study that elucidated the significance of the SSC and rapid movements showed that athletes who attain higher VJ also produce greater eccentric-concentric velocities with less force production (Garhammer et al., 1992). Although athletes with higher velocities produce less force than athletes with lower velocities scores (260%BW and 290%BW, respectively), the magnitude of the force impulse is greater in the high-velocity group (5/4BW and 3/4BW, respectively) (Garhammer et al., 1992).

While the previously mentioned factors contribute to VJ through eccentric pre-loading, the following factors give a greater contribution through the concentric phase. The production of force and velocity in the concentric phase is significantly affected by the motor-unit recruitment pattern of the CC (Behm et al., 1993; Markovic et al., 2010). The recruitment of type II fibers is shown to have significantly higher velocity and force production rates than type 1 fibers (Bottinelli et al., 1994). The higher velocity production rate of type II fibers is believed to come from the increase in myosin heavy chain protein density and cross-bridge cycling (Farrell et al., 2012). It has been shown that training at high velocities, alters recruitment patterns (Behm et al., 1993). The neural adaptation to high-velocity training causes high thresh-hold fibers (type II) to be selectively activated first and significantly increase skill velocities (Nardone et al., 1989). It is proposed that recruitment patterns are adaptable and influenced by the velocity of the skills performed (Nardone et al., 1989). This proposal is in agreement with previous research that showed more experienced athletes could create greater impulse force than less experienced athletes (Garhammer et al., 1992).

Limiting factors to the vertical-jump (VJ) include volume, intensity, fatigue, and stretching (Bradley et al., 2007; Hertogh et al., 2005; Nesser et al., 2007; Reeser et al., 2006). A training volume that causes fatigue, decrements in performance, and increases the risk of injuries is considered overtraining (Fleck et al., 1982; Haff, 2015; Ziv, 2010). Studies that looked the stretching effects on VJ showed that 15 seconds of static stretching (SS) had no significant effect on the CMJ, while SS for 30 seconds and proprioceptive neuromuscular facilitation (PNF) for 25 seconds significantly reduced post VJ scores (Bradley et al., 2007; Knudson et al., 2001).

Conclusion

In conclusion, the review was able to provide previous evidence in BFR and recommend the investigation in its uses for more than just resistance training. While there is evidence of the benefits of BFR and its acute effects on the body from WUs, ranges of beneficial use during WU require more exploration. Benefits of WU such as temperature, increase ROM, and enhanced performance are main effects that should be observed during the use of BFR.

CHAPTER III

METHODOLOGY

Subjects

Forty-seven participants, 24 men and 23 women took part in the study. Participants were recruited from the Rio Grande Valley and surrounding areas. All participants were recruited through word of mouth, fliers, and in-class announcements following a verbal script. Verbal scripts were used to gain permission from the professor to announce the study to classrooms and to recruit from the classroom. Requirements to participate in the study included residence in the Rio Grande Valley or surrounding areas, a physically active status, to have been between the ages of 18-50 years old, and to have been free of signs and symptoms of CVD disease, disabilities that prevent participants from being endurance tested. Participants who were taking medication known to regulate metabolic diseases, under 18 or over 50 years of age and those who had a disease, disabilities, or risk factors that prevent them from being endurance tested were excluded from the study. Participants completed a screening process that included informed consent, PAR-Q, and health status questionnaire the day prior to participation in the cycle ergometer sessions. Participants were informed of all the protocols of the study in which they participated in. The study was approved by the University of Texas at Rio Grande Valley Institutional Review Board.

Inclusion Criteria

1. Participants who were between the ages of 18-50.
2. Participants who were physically active.
3. Participants without signs or symptoms of CVD.
4. Participants who volunteered at The University of Texas at Rio Grande Valley or surrounding areas.

Exclusion Criteria

1. Those who were younger than 18 years of age or older than 50 years of age.
2. Those who were sedentary.
3. Those who had signs or symptoms of CVD.
4. Those who lived outside of the Rio Grande Valley or surrounding areas.

Recruitment

Participants were recruited from the Rio Grande Valley and surrounding areas through University of Texas at Rio Grande valley classroom professor permission script, in person recruitment script, fliers, and word of mouth. Participation in this study was voluntary and participants were allowed to withdraw at any time.

Experimental Protocol

All volunteers met in the Neuromuscular Performance Laboratory (M-1 building, room 216), where all study sessions were held. Sessions took place while the participant was fasted (for at least 8 hours), hydrated (ad libitum), and refrained from strenuous activity of the lower body 48 hours before each session. The participant was considered hydrated when a urine refractometer score of ≤ 1.010 was obtained from their sample. This study contained a total of 6 sessions lasting approximately 60 minutes each.

In the first session, the participants filled out questionnaires, were verbally familiarized with the study procedures, signed an informed consent, had their anthropometric measurements taken, and were physically familiarized with the study procedures. Participants that completed the questionnaires, informed consent, and anthropometric measurements with no contraindication to taking part in the study moved on to the active familiarization of the procedures. The anthropometric measurements taken included resting heart rate, blood pressure, height, weight, and body composition. To be actively familiarized, the participant practiced skin temperature (ST) readings range of motion tests, blood flow restriction (BFR) placement, cycling at 50 rotations per minute (RPM), tendo placement, and bilateral/unilateral vertical jumps (VJ).

These tests included: ST's that were taken between the hip and knee at the rectus and bicep femoris as well as at the belly of the calf muscle. The 90:90 hamstring flexibility test started by placing the hip and knee of one leg at 90 degrees of flexion using a goniometer and then instructing the participant to completely extend the knee while maintaining 90 degrees of hip flexion. The 90:90 hamstring flexibility measurement was taken by placing the center of the goniometer at the lateral condyle of the femur and pointing one arm at the greater trochanter of the femur and the other at the lateral malleolus. The straight leg lift test started by having the participant lie flat on their back and instructing them to raise one leg by bending at the hip as far as possible with the knee locked. The straight leg lift measuring was taken by placing the center of the goniometer at the greater trochanter of the femur and pointing one arm at the lateral condyle of the knee and the other at the midaxillary line. The lying prone knee flexion test began by having the participant lay face down, with one leg placed vertically with the foot flat on the floor and instructing the participant to completely flex at the knee that remains on the adjustable bed. The lying prone knee flexion measurement was taken by placing the center of the goniometer on the lateral condyle of the knee and aiming one arm at the lateral malleolus and the other at the greater trochanter of the femur. The dorsiflexion test started by having the participant sit upright on the adjustable bed with extended knees and instructing them to flex the foot towards the body. The dorsiflexion measurement was taken by placing the center of the goniometer at the point of the heel and aiming one arm down the achilleas tendon and the other was aligned with the bottom of the foot. All ROM capability tests were measured in degrees using a goniometer.

Left and right leg VJ height and power output were taken via Vertec and Tendo sports machine, respectively. The leg with the highest vertical jump height on the first session was recorded as the dominant leg. Single-leg VJ height and power output tests began by attaching the Tendo sports machine to the waist of the participant by a provided Velcro belt and setting the Vertec device to the recorded standing reach height. The participant was instructed to stand upright on either the dominant or non-dominant leg first, which was chosen using the random counterbalanced method (RCM). The participant began the unilateral-VJ with a countermovement (CMJ), rapidly swinging both arms down while flexing the hip and knees to a quarter squat and then explosively jump while swinging the arms up and pushing over the highest pre-measured horizontal marker on the Vertec device with their hands. Three jumps on each leg were performed. The highest jump height, average power, partial average power, peak power, average velocity, peak velocity, and peak force of the three jumps were recorded for each leg.

During active familiarization, measurements specific to each participant such as the height of the Vertec device, cycle ergometer seat height, bilateral/unilateral VJ max were taken. The location of the greater trochanter of the femur was used to adjust for cycle ergometer seat height and standing reach height was used to adjust for Vertec height.

Visits 2 through 6 included official testing and data collection began. Sites of ST and ROM recordings were marked to ensure consistency throughout the three rounds of recordings (baseline, post-WU, and post-8min). Recordings included ST, ROM, and unilateral VJ tests. After round one of the recordings, BFR cuff placing protocol lasting ~10 minutes took place. The dominant or non-dominant leg was chosen to be the BFR exercised leg using the RCM. While the subject sat at the end of a chair, the BFR cuff was placed on the uppermost portion of the thigh and tightened to the initial restrictive pressure (IRP) of 50-55 mmHg. After being tightened, the cuff's air pressure was raised by increasing increments of 20 mmHg. Increments were held for 30 seconds and then deflated for 10 seconds until the final restrictive pressure (FRP, the final and highest pressure used during testing) was reached. The FRP was determined by a capillary refill time (CRT) of $\leq$2 seconds at the vastus medialis. After placing the cuff, the participants previously documented seat height was set, and they were instructed to perform a BFR-WU for 5, 8, 10, 12, or 15-minutes chosen using the RCM on all cycle ergometer sessions and did not repeat times. Cycle ergometer WU's were at a cadence of 50 rpm and had 1kp of resistance for women and 1.5kp for men.

After the BFR-WU, the participant was walked to sit at the edge of a chair and the BFR cuff was deflated and removed. Round 2 of recordings, lasting approximately 8 minutes, followed immediately after BFR removal and was immediately followed by round 3 of recordings to observe any time differences in ST, ROM, or single-leg vertical power output of the BFR exercised leg and non-BFR (NBFR).

The research team was required to calibrate all the equipment (which was performed regularly per instructions provided by the manufacturer), know how to use the equipment properly, and have all documentation done to conduct research.

Instruments

Kaatsu-Master

The Kaatsu-Master elastic cuffs were positioned around the most proximal portion of the thigh. The cuffs have pneumatic bags along the inner surface that are connected to an electronic air pressure control system (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan). Though this control system, the cuff was tightened to the initial restrictive pressure (IRP) of 50-55 mmHg. After being tightened, the cuff's air pressure was raised by increasing increments of 20 mmHg. Increments were held for 30 seconds, and then deflated for 10 seconds until the final restrictive pressure was reached (FRP, the final and highest pressure used during testing). The FRP was determined by the capillary refill time (≤2 seconds) of the quadricep in this study. The Kaatsu cuffs were used uni-laterally for each session.

Leg monark cycle

A cycling warm-up protocol was performed using a cycle ergometer (Ergomedic 828E; Monark, Vansbro, Sweden). During each session, participants completed a warm-up at a cadence of 50rpm with 1kg of resistance for females and 1.5kg for males. The cycle ergometer warm-up durations included 5, 8, 10, 12, or 15 minutes and were chosen using the random counterbalanced method for each session without repeating times.

Goniometer

A goniometer was used to measure the precise angles attained at the lateral condyle of the knee for the 90:90 hamstring, at the greater trochanter of the femur for the leg lift, at the lateral condyle of the knee for the lying prone knee flexion, and at the lateral malleolus of the ankle for the dorsiflexion test. Each site where the center of the goniometer is placed, were marked to ensure accuracy between times. (Baseline Evaluation Instruments, Goniometer, 8-inch plastic 360-degree ISOM).

Vertec device

The Vertec device has pre-measured horizontal vanes that swivel when pushed. The Vertec was set the participants standing reach height before every session. To measure each participants' vertical jump height capability, they attempted to knock over the highest possible vane while performing a maximal vertical jump. (Sport Imports, Vertec Vertical Jump Trainer, Vertec2).

Temporal scanner thermometer

This skin thermometer was used to take the skin temperature (ST) of the rectus femoris, bicep femoris, and belly of the calves on each leg. Each ST site was marked to insure for accuracy between times. (Exergen Corporation, Temporal Scanner, TAT-2000C).

Tendo power analyzer

This instrument was attached to a participant by a provided belt and used to measure the average-power, partial-average-power, peak-power, average-velocity, peak-velocity, and peak-force of each vertical jump. The greatest scores in each category was taken out of three jumps. (TENDO Power Analyzer V- 316).

Statistical Analysis

A 4-way analysis of variance (ANOVA) with repeated measures (condition [BFR vs. NOBFR], time [pre vs. post vs. 8-min post], duration [5min vs. 8min vs. 10min vs. 12min vs. 15min], and gender [male vs. female]) was used to determine if significant differences exist in flexibility, temperature, and vertical power output. When analysis revealed a significant difference, post-hoc analyses with Bonferroni were used to determine the origin of the significant difference. An alpha of ≤ 0.05 was used to determine statistical significance. Statistical analysis was performed using SPSS for Windows. Data were expressed as mean ± SE, unless otherwise defined.

CHAPTER IV

RESULTS

Subject Characteristics

Forty-eight male & female subjects were recruited for the study from the University of Texas Rio Grande Valley and surrounding areas. Table 1 shows descriptive statistics that were taken from the study population.

Table 1. Descriptive Measures

Variables	Age	Height (cm)	Weight (kg)	BMI	Bi-VJ (cm)
Male (n=24)	24.9 (±4.5)	173.5 (±6.9)	86.9 (±17.7)	28.9 (±6.1)	51.6 (±7.6)
Female (n=23)	22.7 (±4.1)	159.5 (±6.6)	59.1 (±11.6)	23.1 (±3.4)	38.8 (±4.7)

Values are reported as (±SD).

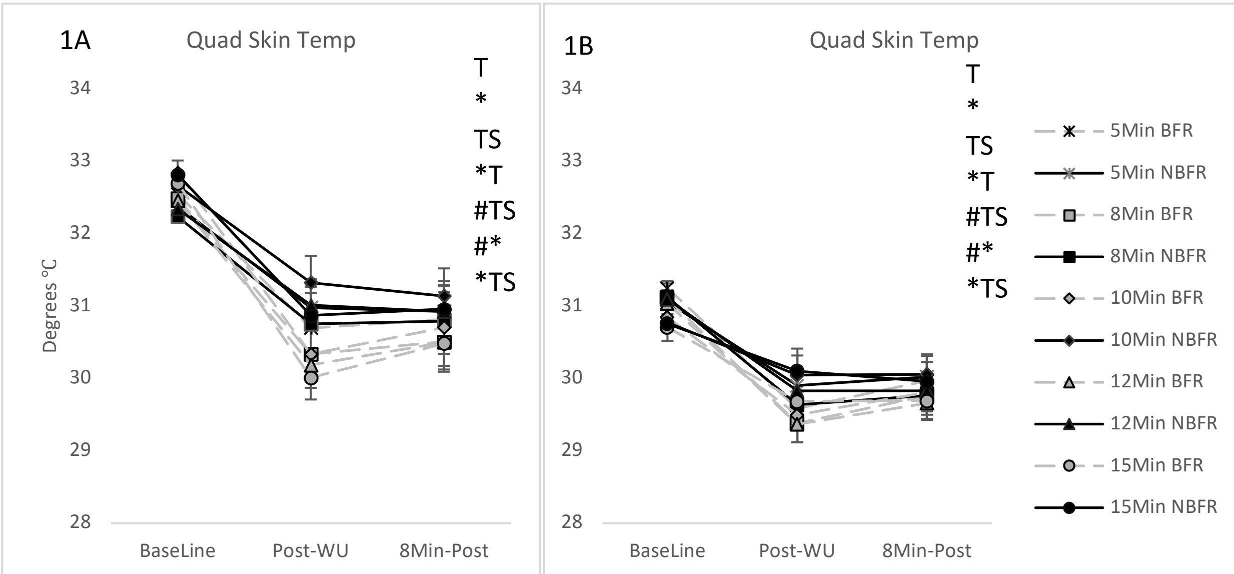
Temperature Response

Quad skin temperature

Figures 1A & 1B show the changes in quad skin temperature (QST) during different conditions and durations for males and females, respectively. One-Way ANOVA allowed the researcher to determine significant differences between genders for quad skin temperature (QST)

($p<0.01$). One-Way ANOVA did not yield any significant baseline QST differences ($p>0.05$) between conditions. The BFR and NBFR legs were not significantly asymmetric before being affected by BFR. Repeated measures ANOVA yielded significant condition and time main effects ($p<0.01$) but did not detect a significant duration main effect ($p>0.05$) for QST. QST responded to WU by decreasing from baseline to post-WU and increasing from post-WU to post-8min but remained below baseline levels in both conditions. However, the BFR condition had greater percent-drops and increases from baseline to post-WU and from post-WU to post-8min when compared to the NBFR condition. Repeated measures ANOVA yielded significant WU-duration*condition ($p<0.01$), conditions*time ($p<0.01$), conditions*time*sex ($p<0.05$), time*sex ($p<0.05$), and duration*time*sex interactions ($p<0.05$). The significant time*sex interaction ($p<0.05$) showed that males maintained the highest QST throughout the study and had a greater total percent-change from baseline to post-WU in both conditions. A significant condition*time interaction ($p<0.01$) revealed that the BFR condition increased the QST response to WU in both genders. Greater QST percent drops were seen from baseline to post-WU and greater percent increases from post-WU to post-8min. A significant duration*condition interaction ($p<0.01$) showed that as durations increased from 5 to 10min, the total percent-difference between conditions and their total percent-change from baseline to post-WU and from post-WU to post-8min in response to WU also increased. As durations increased to the 12 and 15min sessions, their percent-change and difference began to decrease. A significant duration*time*sex interaction ($p<0.05$) confirmed that males had a greater percent change from baseline to post-WU for all durations when compared to females and females had a greater percent-change from post-WU to post-8min for the 5 and 8min sessions. The total percent-change from baseline to post-WU and from post-WU to post-8min was greatest in women for the 5-min session and the greatest for males on the 15min session. Additionally, as durations increased, male QST continued to decrease while the female's QST began to increase. Causing their absolute temperatures to reach for each other. In agreement with the time*sex interaction, a significant condition*time*sex interaction ($p<0.05$) further revealed that the BFR condition increased the magnitude of the percent-difference between gender responses. Although using BFR during WU increased the response for both genders, the condition*time*sex interaction shows that BFR effected the male response significantly more. The BFR condition and greater durations both increased the magnitude of the difference in response to WU between males and females. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, duration*conditions*sex, durations*time, durations*conditions*time, or duration*conditions*time*sex interactions ($p>0.05$).

Figure 1A. QST for Male & Figure 1B. QST for Female



Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

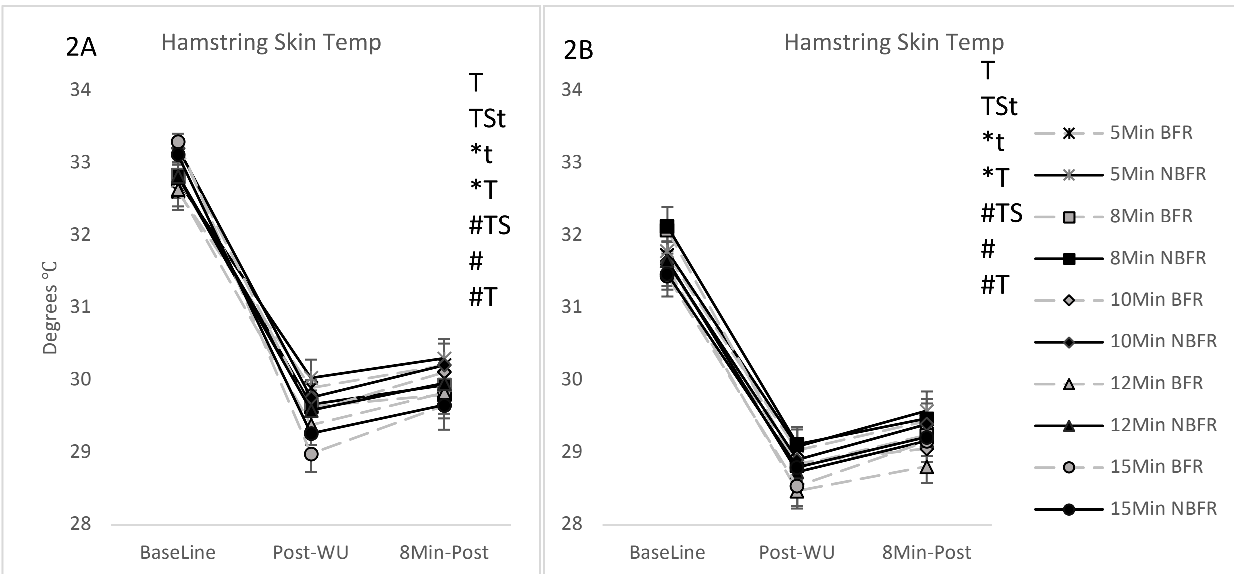
Significant time main effect T ($p<0.01$), significant condition main effect * ($p<0.01$), significant time*sex interaction TS ($p<0.05$), significant condition*time interaction *T ($p<0.01$), significant duration*time*sex interaction #TS ($p<0.05$), significant duration*condition interaction #* ($p<0.01$), and significant condition*time*sex interaction *TS ($p<0.05$). Values reported as mean ±SE.

Hamstring skin temperature

Figures 2A & 2B show the changes in HST during different conditions and durations for males and females, respectively. One-Way ANOVA allowed the researcher to determine significant differences between genders for hamstring skin temperature (HST) ($p<0.01$) except the 8-min session for both the BFR ($p=0.077$) and NBFR ($p=0.053$) conditions. Males had significantly higher HST than females for all sessions except the 8-min session. One-Way

ANOVA did not yield any significant baseline HST differences ($p>0.05$) between conditions. The BFR and NBFR legs were not significantly asymmetric before being affected by BFR. Repeated measures ANOVA yielded a significant time ($p<0.01$) and duration ($p<0.05$) main effect but did not detect a significant condition main effect ($p=0.06$) for HST. HST responded to WU by decreasing from baseline to post-WU and increasing from post-WU to post-8min but remained below baseline levels in both conditions. Furthermore, the percent change from baseline to post-WU was 7x greater than post-WU to post-8min in all conditions. As the magnitude of the durations increased, so did the magnitude in percent change in HST from post-WU to post-8min. Repeated measures ANOVA yielded significant duration*time*sex, duration*time, and conditions*time interactions ($p<0.05$). A duration*time interaction showed that the lowest average HST and the greatest average change were seen in the greatest duration sessions (15min). A duration*time* sex interaction ($p<0.05$) showed that females had a greater total percent-change from baseline to post-WU and from post-WU to post-8min for the 5 and 8min sessions. While males had greater and increasing percent-changes from the 10-15min sessions. One small and novel finding was that females yielded their greatest percent-change in a lower duration (8min), lowest percent-change in a greater duration (10min), and lowest ST on the 12-min session. Additionally, from the 12 to 15min sessions, males continued to decrease in average ST, and females began to rise, causing their absolute temperatures to reach for each other. A condition*time interaction ($p<0.05$) showed that the magnitude of the response to WU between conditions was significantly different. Percent-change in HST from baseline to post-WU was greater in the BFR condition. From post-WU to post-8min, conditions had similar increases in temperature. However, the BFR condition remained below the NBFR condition. The BFR condition and greater durations both increased the magnitude of the response to WU. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 2A.HST for Male & Figure 2B. HST for Female



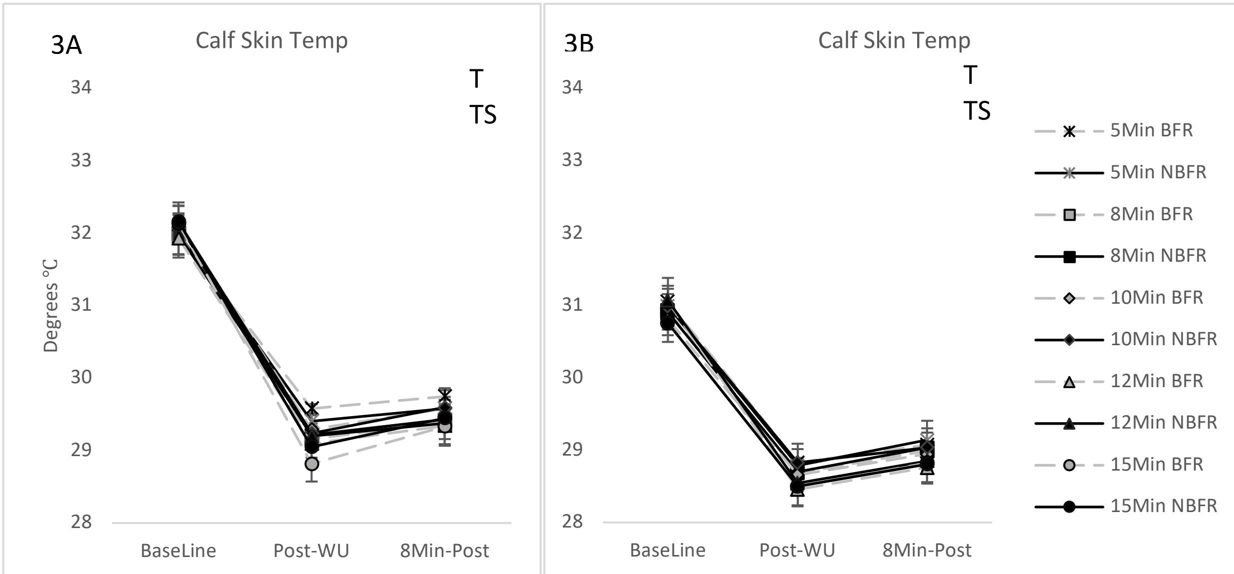
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T (p<0.01), trend for time*sex interaction TSt (p=0.06), trend for condition main effect *t (p=0.06), significant condition*time interaction *T (p<0.01), significant duration*time*sex interaction #TS(p<0.05), significant duration main effect # (p<0.05), and significant duration*time interaction #T (p<0.05). Values reported as mean ±SE.

Calf skin temperature

Figures 3A & 3B show the changes in CST during different conditions and durations for males and females, respectively. One-Way ANOVA allowed the researcher to determine significant differences between genders for calf skin temperature (CST) ($p<0.05$). Males had significantly higher CST when compared to females. One-Way ANOVA did not yield any significant baseline CST differences ($p>0.05$) between conditions. The BFR and NBFR legs were not significantly different before being affected by BFR. Repeated measures ANOVA yielded a significant time main effect ($p<0.01$) but did not detect a significant condition or duration main effect ($p>0.05$) for CST. CST responded to WU by decreasing from baseline to post-WU and increasing from post-WU to post-8min but remaining below baseline levels in both conditions. Repeated measures ANOVA yielded a significant time*sex interaction ($p<0.05$). Males maintained the highest CST throughout the study and had greater percent-changes from baseline to post-WU and less percent changes from post-WU to post-8min in both conditions. The CST of women increased to a greater magnitude from post-WU to post-8min, but it was less than the CST for males. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions ($p>0.05$).

Figure 3A. CST for Male & Figure 3B. CST for Female



Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

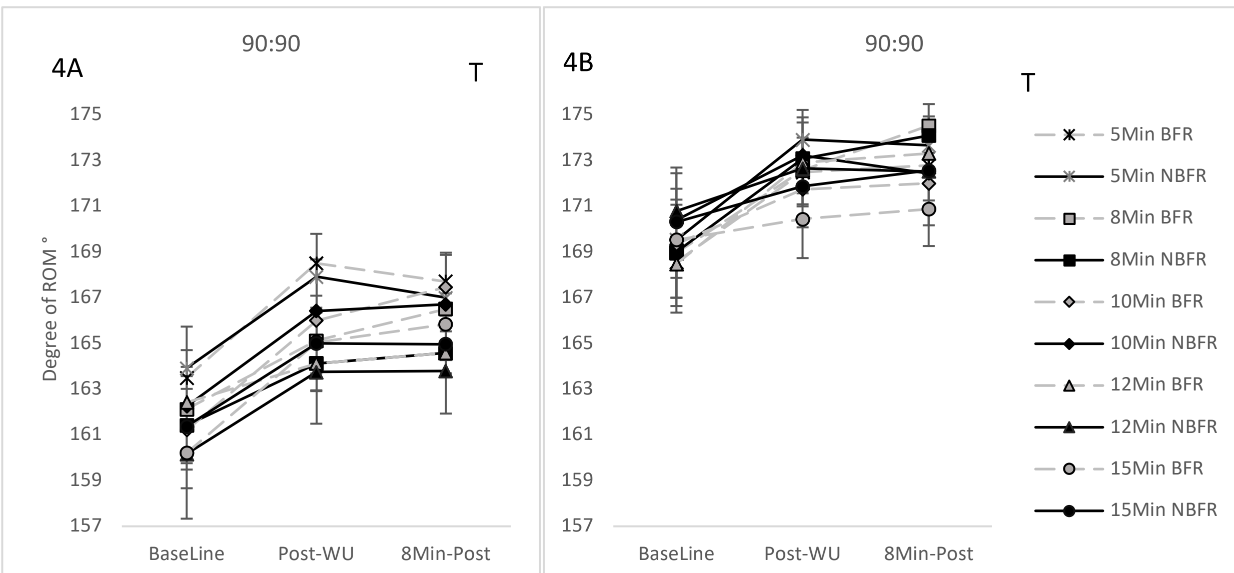
Significant time main effect T ($p<0.01$), and significant time*sex interaction TS($p<0.05$). Values reported as mean ±SE.

Range of Motion Response

90:90 Hamstring

Figure 4A & 4B show the changes in 90:90 hamstring range of motion (ROM) during different conditions and durations for males and females, respectively. One-way ANOVA allowed the researcher to determine significant baseline differences ($p<0.05$) in 90:90 hamstring ROM between genders for all sessions except the 5 and 12-min sessions for the BFR condition ($p>0.05$). Repeated measures ANOVA yielded a significant time main effect ($p<0.01$) but did not detect significant condition or duration main effects ($p>0.05$) for the ROM. ROM responded to WU by increasing from baseline to post-WU and from post-WU to post-8min. Furthermore, the percent change from baseline to post-WU was greater than the percent change from post-WU to post-8min in all conditions. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 4A. 90:90 Hamstring for Male & Figure 4B. 90:90 Hamstring for Female



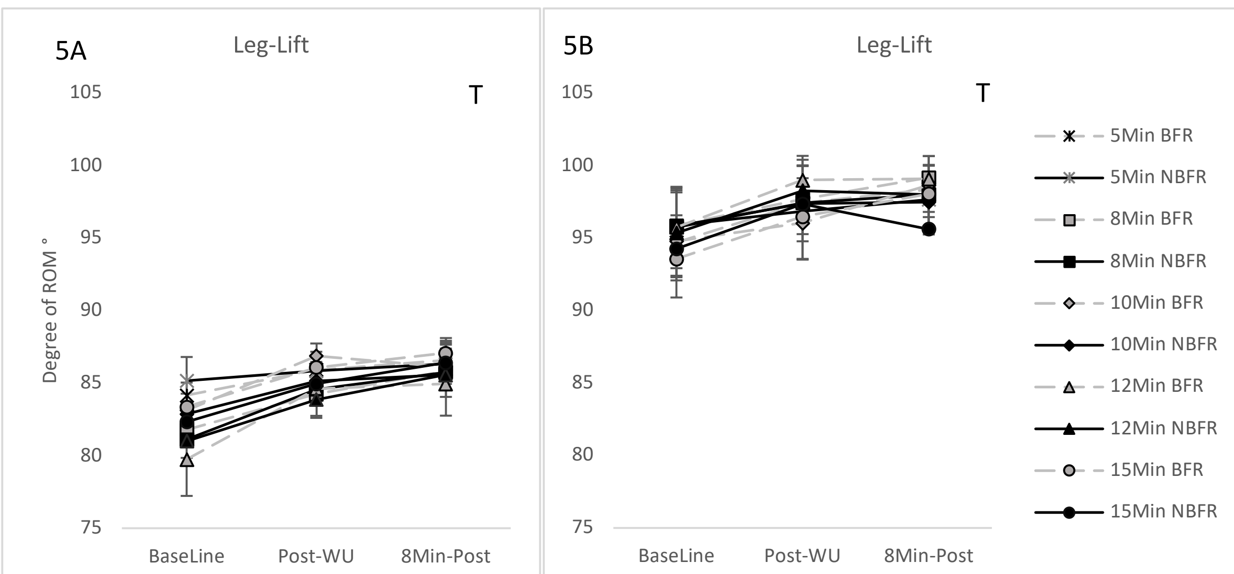
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T (p<0.01). Values reported as mean ±SE.

Leg-Lift

Figure 5A & 5B show the changes in leg-lift ROM during different conditions and durations for males and females, respectively. One-way ANOVA allowed the researcher to determine significant baseline differences (p<0.01) in leg-lift range of motion (ROM) between genders for all sessions. Males had significantly lower ROM than females. Repeated measures ANOVA yielded a significant time main effect (p<0.01) but did not detect significant condition or duration main effects (p>0.05) for ROM. ROM responded to WU by increasing from baseline to post-WU and from post-WU to post-8min. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 5A. Leg-Lift for Male & Figure 5B. Leg-Lift Hamstring for Female



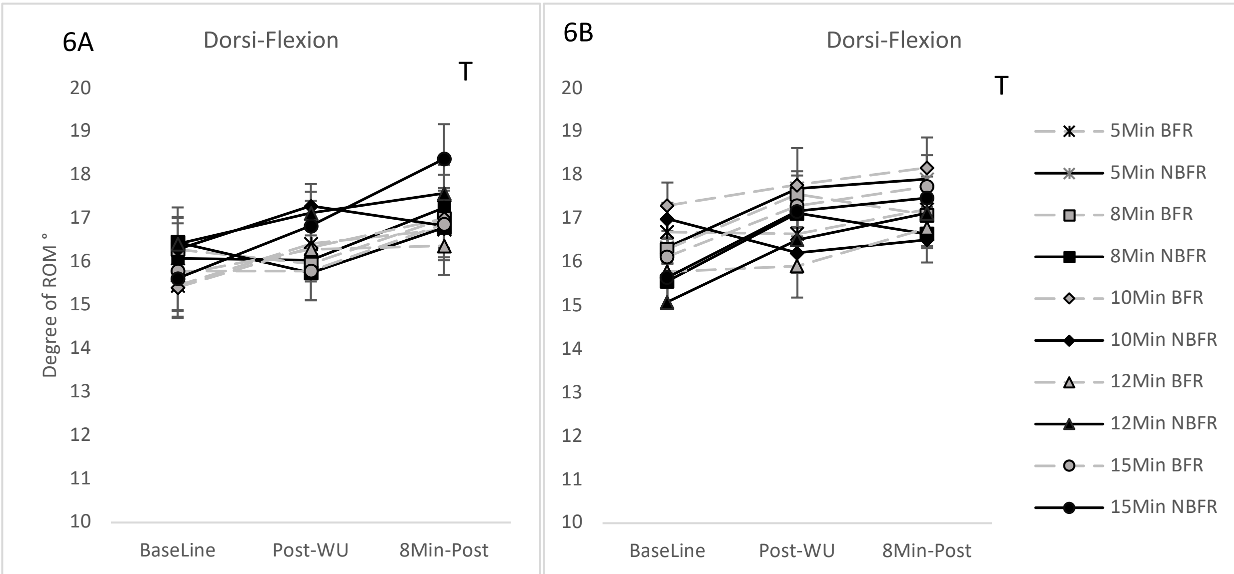
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T (p<0.01). Values reported as mean ±SE.

Dorsi-Flexion

Figure 6A & 6B show the changes in dorsi-flexion range of motion (ROM) during different conditions and durations for males and females, respectively. One-way ANOVA only detected significant baseline differences ($p<0.05$) in dorsi-flexion ROM between genders for the BFR condition on the 10-min session. Only in this session and condition did males have significantly lower ROM. Repeated measures ANOVA yielded a significant time main effect ($p<0.01$) but did not detect significant condition or duration main effects ($p>0.05$) for ROM. ROM responded to WU by increasing from baseline to post-WU and from post-WU to post-8min. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions ($p>0.05$).

Figure 6A. Dorsi-Flexion for Male & Figure 6B. Dorsi-Flexion for Female



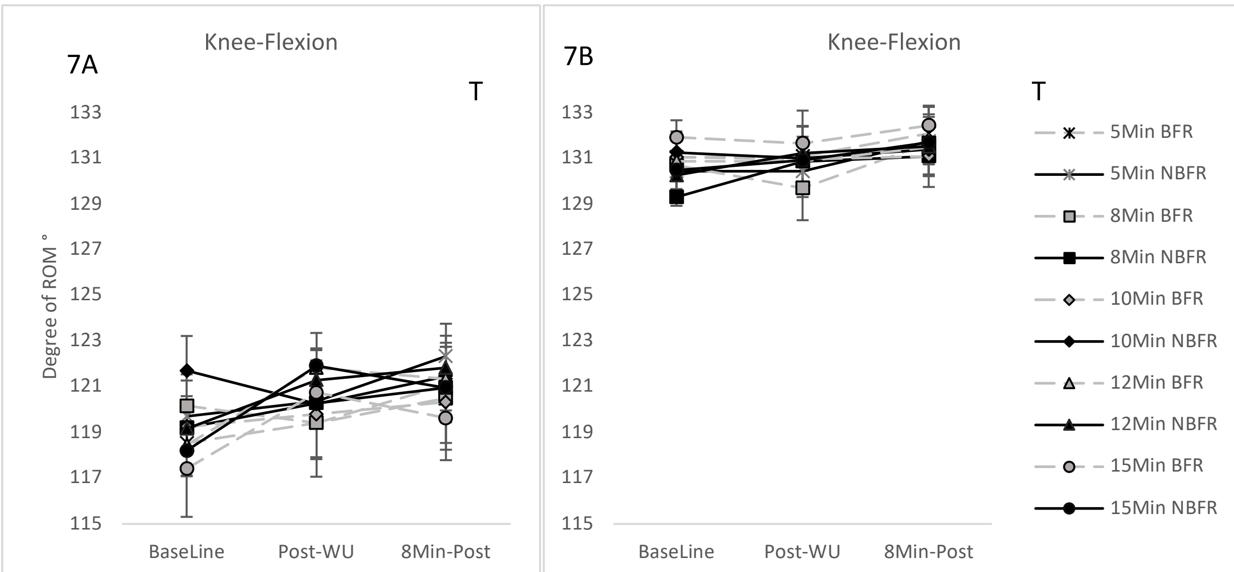
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T ($p<0.01$). Values reported as mean ±SE.

Knee-Flexion

Figure 7A & 7B show the changes in knee-flexion ROM during different conditions and durations for males and females, respectively. One-way ANOVA allowed the researcher to determine significant baseline difference ($p<0.01$) in knee-flexion range of motion (ROM) between genders. Males had significantly lower baseline ROM. Repeated measures ANOVA yielded a significant time main effect ($p<0.01$) but did not detect significant condition or duration main effects ($p>0.05$) for ROM. ROM responded to WU by increasing from baseline to post-WU and from post-WU to post-8min. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 7A. Knee-Flexion for Male & Figure 7B. Knee Flexion Hamstring for Female



Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

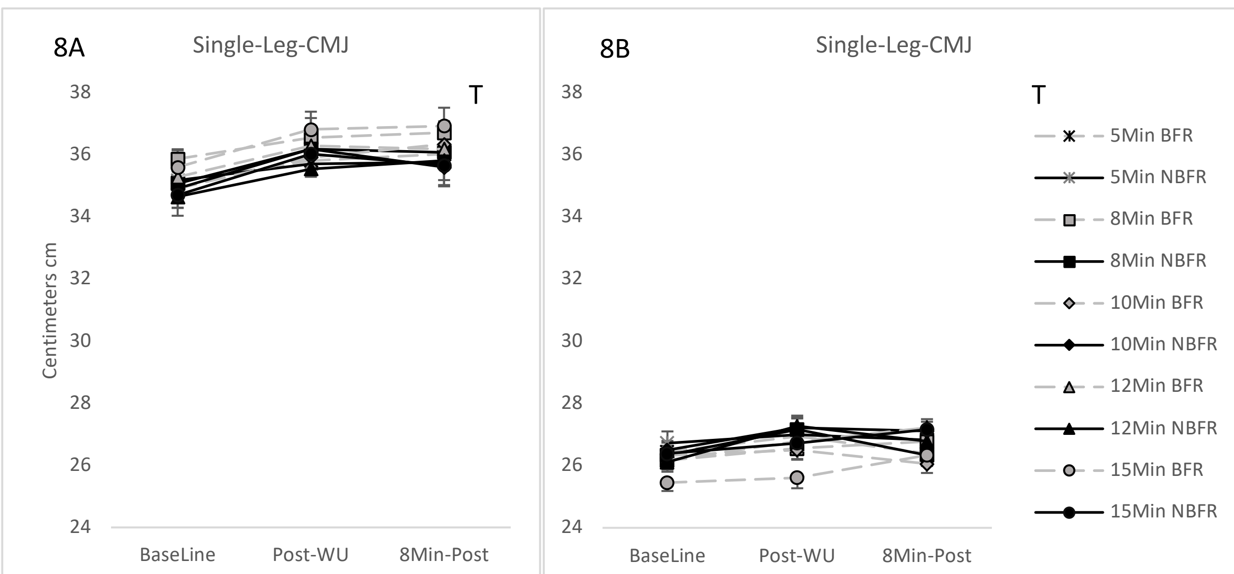
Significant time main effect T (p<0.01). Values reported as mean ±SE.

Vertical Jump Response

Vertical jump height

Figure 8A & 8B show the changes in vertical jump (VJ) height during different conditions and durations for males and females, respectively. Repeated measures ANOVA yielded a significant time main effect (p<0.01) but did not detect significant condition or duration main effects (p>0.05) for VJ height. VJ height responded to WU by increasing from baseline to post-WU and decreasing from post-WU to post-8min. Repeated measures ANOVA yielded a time*sex (p=0.064) trend. Males had a greater percent increase in VJ height post-WU and maintained increasing from post-WU to post-8min, while female VJ height decreased. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 8A. Jump Height for Male & Figure 8B. Jump Height for Female



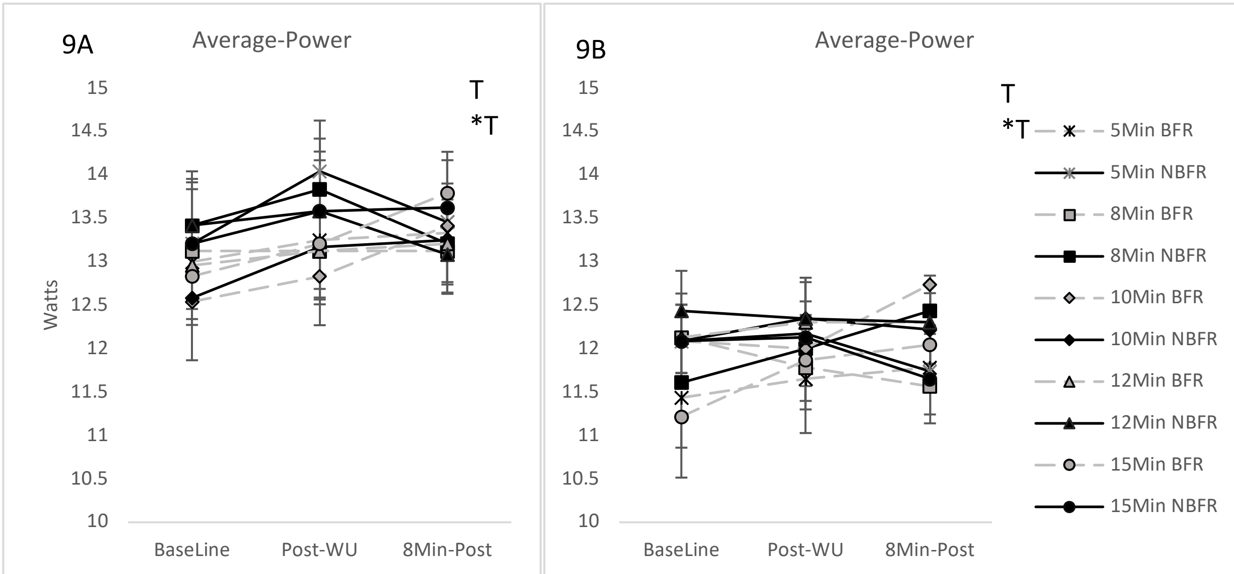
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T (p<0.01). Values reported as mean ±SE.

Average-Power

Figure 9A & 9B show the changes in average-power (AP) during different conditions and durations for males and females, respectively. Repeated measures ANOVA yielded a significant time main effect ($p<0.01$) but did not detect significant condition or duration main effects ($p>0.05$) for AP. AP responded to WU by increasing from baseline to post-WU and decreasing from post-WU to post-8min. Repeated measures ANOVA yielded a significant conditions*time interaction ($p<0.05$). While both conditions increased AP in response to WU, the NBFR conditions had the greatest percent increase and decrease from baseline to post-WU and from post-WU to post-8min, respectively. Furthermore, the BFR conditioned reacted inversely from post-WU to post-8min and increased while NBFR decreased. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions ($p>0.05$).

Figure 9A. Average-Power for Male & Figure 9B. Average-Power for Female



Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

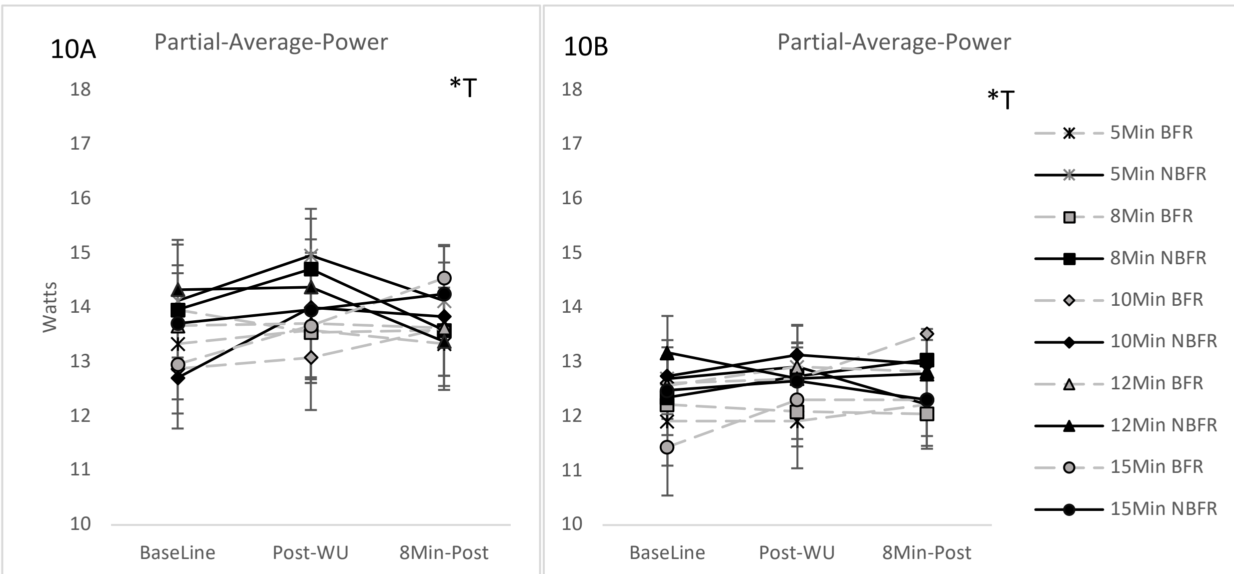
Significant time main effect T ($p<0.05$), significant condition*time interaction *T ($p<0.05$).

Values reported as mean ±SE.

Partial-Average-Power

Figure 10A & 10B show changes in partial-average-power (PAP) during different conditions and durations for males and females, respectively. Repeated measures ANOVA did not detect significant condition ($p=0.06$), time, or duration main effects ($p>0.05$) for PAP. Repeated measures ANOVA yielded a significant conditions*time interaction ($p<0.05$). While both conditions increased PAP in response to WU, the NBFR conditions had the greatest percent increase and decrease from baseline to post-WU and from post-WU to post-8min, respectively. Furthermore, the BFR condition reacted inversely from post-WU to post-8min and increased while NBFR decreased. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 10A. Partial-Average-Power for Male & Figure 10B. Partial-Average-Power for Female



Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

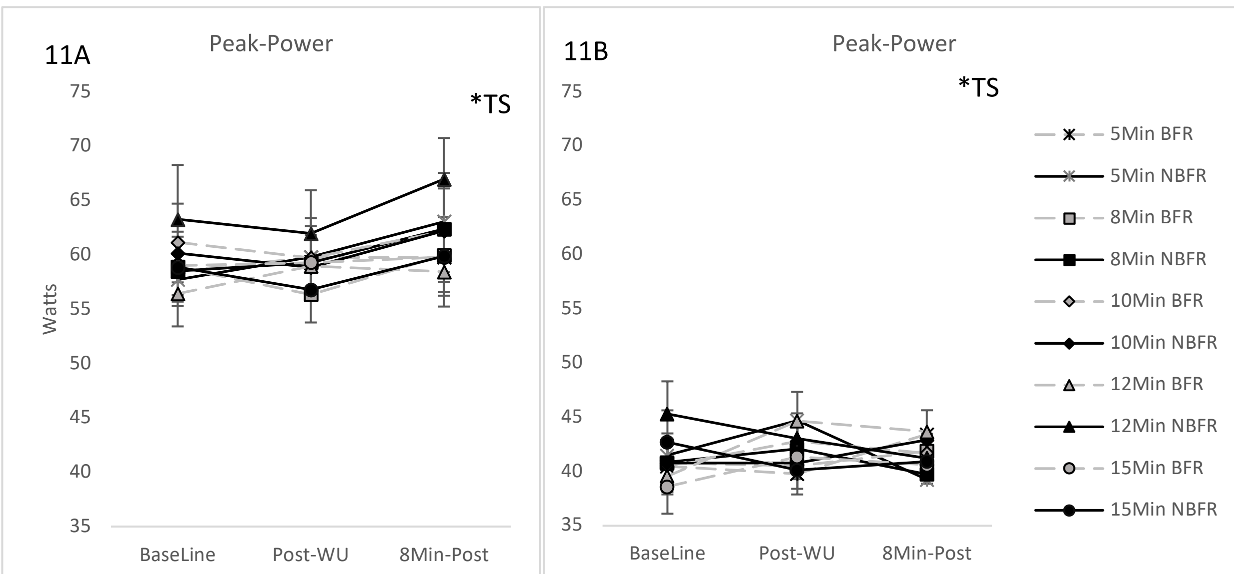
Significant condition*time interaction *T (p<0.05). Values reported as mean ±SE.

Peak-Power

Figure 11A & 11B show the changes in peak-power (PP) during different conditions and durations for males and females, respectively. Repeated measures ANOVA did not detect a significant condition, time, or duration main effects (p>0.05) for PP. Repeated measures ANOVA yielded significant conditions*time*sex interactions (p<0.05). While both genders steadily increased PP in response to WU by BFR, only males increased PP in response to a

NBFR-WU while females steadily lost PP in response to a NBFR-WU. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, durations*conditions*time, or duration*conditions*time*sex interactions ($p>0.05$).

Figure 11A. Peak-Power for Male & Figure 11B. Peak-Power for Female



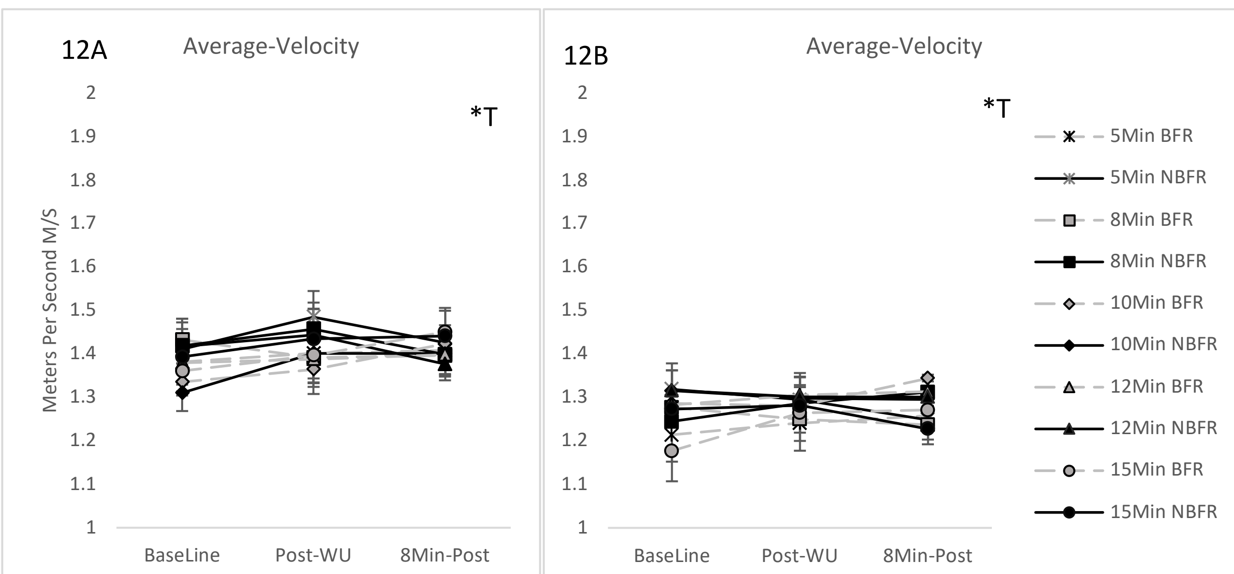
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant condition*time*sex interaction *TS ($p<0.05$). Values reported as mean ±SE.

Average-Velocity

Figure 12A & 12B show the changes in average-velocity (AV) during different conditions and durations for males and females, respectively. Repeated measures ANOVA did not detect significant time ($p=0.07$), condition, or duration main effects ($p>0.05$) for AV. Repeated measures ANOVA yielded a significant conditions*time interaction ($p<0.05$). While both conditions increased AV in response to WU, the NBFR conditions had the greatest percent increase and decrease from baseline to post-WU and from post-WU to post-8min, respectively. Furthermore, the BFR conditioned reacted inversely from post-WU to post-8min and increased while NBFR decreased. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 12A. Average-Velocity for Male & Figure 12B. Average-Velocity for Female



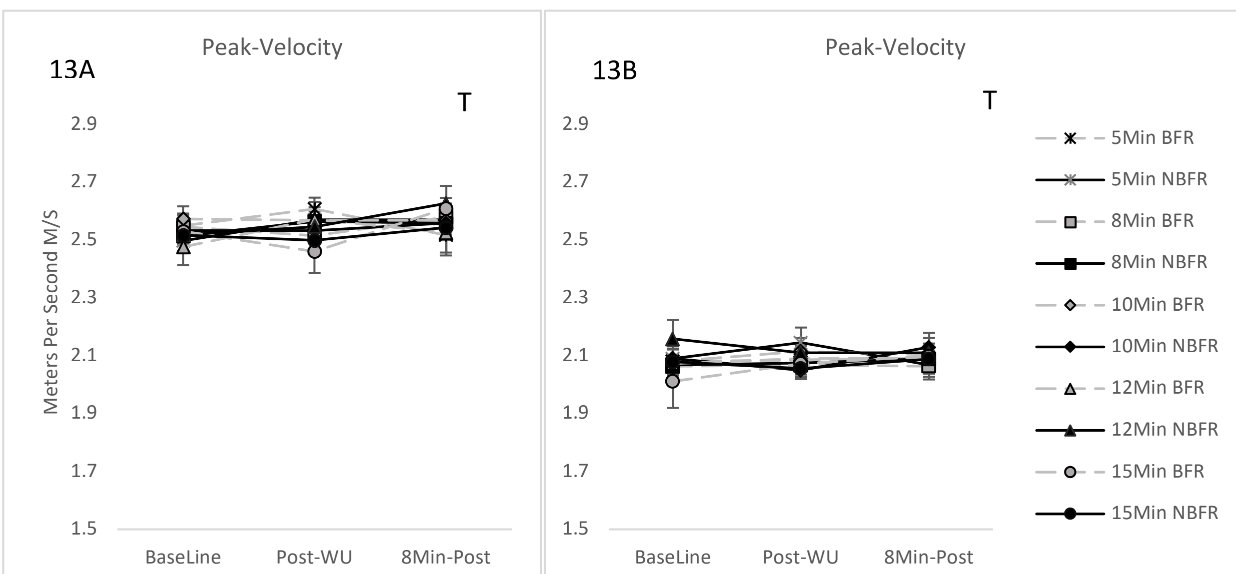
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant condition*time interaction *T (p<0.05). Values reported as mean ±SE.

Peak-Velocity

Figure 13A & 13B show the changes in peak-velocity (PV) during different conditions and durations for males and females, respectively. Repeated measures ANOVA yielded a significant time main effect ($p<0.05$) but did not detect significant condition or duration main effects ($p>0.05$) for PV. PV responded to WU by increasing from baseline to post-WU and from post-WU to post-8min. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions ($p>0.05$).

Figure 13A. Peak-Velocity for Male & Figure 13B. Peak-Velocity for Female



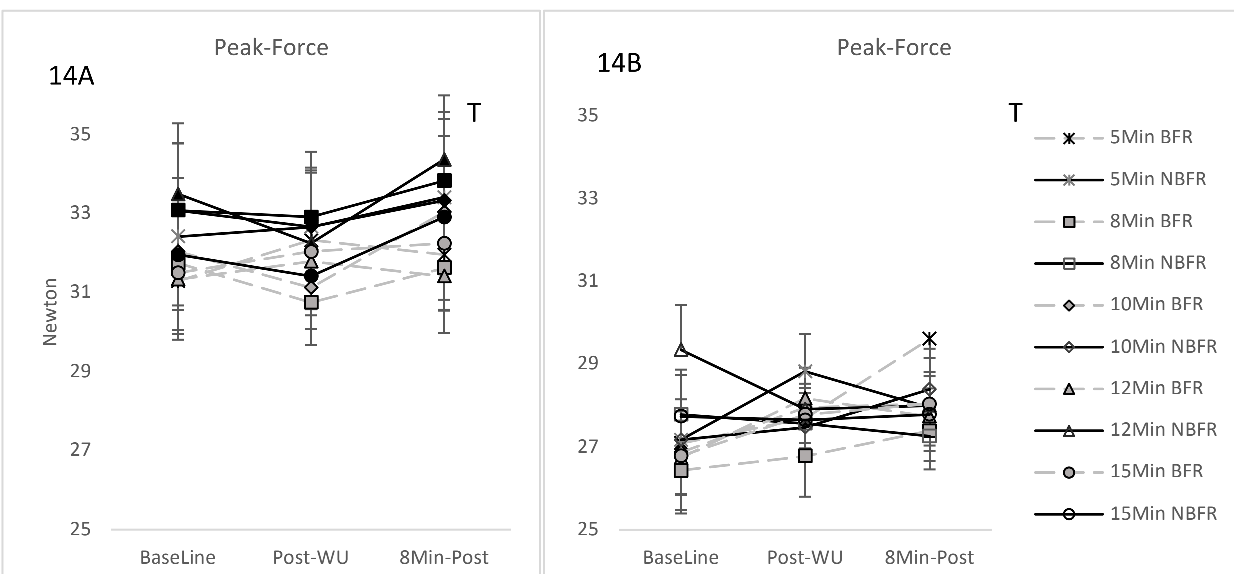
Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T ($p<0.05$). Values reported as mean ±SE.

Peak-Force

Figure 14A & 14B show the changes in peak-force (PF) during different conditions and durations for males and females, respectively. Repeated measures ANOVA yielded a significant time main effect (p<0.05) but did not detect significant condition or duration main effects (p>0.05) for PF. PF responded to WU by increasing from baseline to post-WU and from post-WU to post-8min. Repeated measures ANOVA did not detect significant duration*sex, conditions*sex, time*sex, duration*conditions, duration*conditions*sex, durations*time, duration*time*sex, conditions*time, conditions*time*sex, durations*conditions*time, or duration*conditions*time*sex interactions (p>0.05).

Figure 14A. Peak-Force for Male & Figure 14B. Peak-Force for Female



Male BFR (N=24) NBFR (N=24), Female BFR (N=23) NBFR (N=23)

Significant time main effect T (p<0.05). Values reported as mean ±SE.

CHAPTER V

DISCUSSION

Temperature Response

A significant time main effect was detected for all skin-temperature (ST) sites (Quad, Hamstring, and Calf) saw a significant time main effect ($p<0.01$). ST decreased from baseline to post warm-up (WU) and generally increased from post-WU to post-8min in both conditions for all sites. These findings are in agreement with multiple studies (Bishop, 2003b; Formenti et al., 2013; Fröhlich et al., 2015; Johnson et al., 1979; Journeay et al., 2006; Kidston, 2013; Kiens et al., 1989 Quesada et al., 2016).

During rest, skeletal muscle temperature is typically lower than core temperature, and ~70% of blood is in the veins (Bishop, 2003b; Farrell et al., 2012). With the onset of exercise, rhythmic contractions of the exercised muscle create fluctuating pressures against local vasculature (Kiens et al., 1989; Korthuis, 2011; Rowell, 2004). During the contraction phase of movement, the vasculatures of the exercised muscles are compressed. This compression causes the deep veins surrounding the muscle to be emptied and restricts the flow of blood through the muscle (Kidston, 2013; Stewart et al., 1998). During the relaxation phase, the deep veins surrounding the exercised muscle are pulled open after being emptied (Rowell, 2004). In response to sustained rhythmic contractions, reflexive sympathetic activity acts to vasoconstrict the vasculature of the periphery to return blood to the central veins and heart (Farrell et al., 2012; Kidston, 2013; Stewart et al., 1998). The increase in venous return is then redistributed to the working muscles (~2.2L*min^{-1}) that are undergoing vasodilation in response to mechanical stimulation (Bishop, 2003a; Farrell et al., 2012; Kidston, 2013; Kiens et al., 1989; Stewart et al., 1998; Rowell, 2004). As exercise continues, heat is stored in the exercised muscle, causing the intramuscular temperature to surpass core temperature (Bishop, 2003a; Farrell et al., 2012; Journeay et al., 2006; Kidston, 2013). The heat produced by the muscle is then transferred to the blood of its surrounding vasculature and pumped back to the central veins, resulting in the elevation of core temperature (Bishop, 2003a, Kidston, 2013). Baroreceptors sense the elevated central temperature in the vasculature of the core results in a reversal (vasodilation) of the initial vasoconstrictive response at the onset of exercise (Johnson et al., 1979; Journeay et al., 2006; Kidston, 2013; Sheriff, 2010). Skin blood flow (SKBF) and ST are then raised during post-exercise rest or prolonged exercise to dissipate accumulated heat (Bishop, 2003a). This explains the increase in temperature from post-WU to post-8min, in the current study. Bishop (2003a) illustrates that ST can continue to decrease for up to 30 minutes of exercise. As muscle temperature rises, skin temperature typically drops and begins to rise during the recovery phase post-WU (Bishop, 2003a; Fröhlich et al., 2015; Kidston, 2013;). Kidston., (2013) stated that a decrease in skin temperature is normal, due to the onset of vasodilation from the mechanoreceptors in the muscle and vasoconstriction to the skin. In agreement with the findings of the current study, Kidston (2013) showed that ST remained above post-WU values after resting for 5 and 10 mins.

The displacement of blood flow from the skin to the exercising muscles is normal. SKBF & ST decrease within the first few minutes of exercise to provide blood to the strained muscles

(Fröhlich et al., 2015; Trecroci et al., 2018). Following a WU or during prolonged exercise, SKBF & ST begin elevating to dissipate accumulated heat. However, the cardiovascular response to exercise varies between populations (Formenti et al., 2013). The male ST average was significantly greater at baseline for QST ($p<0.01$), HST ($p<0.01$), and CST ($p<0.05$), when compared to the female's ST average. A significant time*sex interaction showed that although both genders saw a significant ST response, males had a significantly greater average percent drop from baseline to post-WU in Q&CST ($p<0.05$) but not in HST ($p=0.06$).

A significant duration*time*sex interaction ($p<0.05$) showed that as the durations continued, the temperature responses for different length of WU throughout time was different for genders. This is due to an inverse response to increases in durations; where males steadily continued to reach lower ST's and females began to reach greater ST's for post-WU and post-8min recordings. The male ST percent change from baseline to post-WU and from post-WU to post-8min increased while female ST percent change decreased as duration increased. A significant duration*condition*sex revealed that males had the greatest percent difference between conditions on the 15-min session while females had their smallest percent difference between conditions on the 15-min session. A significant QST conditions*time*sex interaction ($p<0.05$) showed that males had a greater percent drop from baseline to post-WU and increases from post-WU to post-8min when compared to females, in response to WU with BFR.

These findings are in agreement with multiple studies (Formenti et al., 2013; Kaciuba-Uscilko et al., 2001; Karabulut et al., 2013a; Sampaio et al., 2016; Savastano et al., 2009; Trecroci et al., 2018). The difference in WU response can be explained by the physiological differences between males and females such as body surface area to body mass, subcutaneous fat content, and lower exercise capacity (Formenti et al., 2013; Kaciuba-Uscilko et al., 2001;

Karabulut et al., 2013a; Sampaio et al., 2016; Savastano et al., 2009; Trecroci et al., 2018). It has also been shown that subcutaneous fat thickness significantly alters the magnitude stimulus of the BFR cuffs during exercise (Karabulut et al., 2013a) Another possible explanation is that greater intensities of exercise are shown to cause greater shifts in SKBF (Weigert et al., 2018). Force is a significant factor in the ejection speed of blood out of the muscle (Järvholm et al., 1988). If males exercised at intensities that required more force (1.5kg for males vs. 1kg for females), their force could explain why they saw greater SKBF differences.

In response to varying durations, only the HST saw a significant duration*main effect and duration*time interaction ($p<0.05$). As durations increased, the population average HST from baseline to post-WU significantly decreased in both conditions. One small explanation to this is that the hamstrings were most strained by increases in duration. Hamstrings have been reported to have a high amount of type II muscle fibers (Garret, Califf, and Basset., 1984). Type II fibers are more forceful than type I fibers and the force of each contraction significantly affects the blood flow through the contracting muscle (Bottinelli et al., 1994; Järvholm et al., 1988; Weigert et al., 2018). Additionally, it has been shown that the greatest ST drops are seen in areas of the greatest muscular activity (Fröhlich et al., 2015; Trecroci et al., 2018).

The QST ($p<0.01$) and HST ($p<0.05$) saw significant condition*time interactions**.** The BFR condition ST response was lower post-WU and post-8min. From baseline to post-WU and from post-WU to post-8min, Q&HST had a greater percent decreases and increases, respectively, in the BFR condition when compared to the NBFR condition. The findings are in agreement with one other study that observed ST during exercise with and without BFR (Barros et al., 2017). Barros et al., (2017) showed that the ST of the quad had a significantly different responses between BFR and NBFR, with no significant difference for the hamstrings (Barros et al., 2017).

In contrast to the current study, Sampaio et al., (2016) reported no significant differences in ST of the quad, post-exercise. However, both studies used relatively low restriction pressures (130% of systolic blood pressure and 150mmHg, respectively). Furthermore, these studies differed from each other and the current study in exercise protocols and exercise mode. Barros et al., (2017) used 4 sets of 8-12 reps, and Sampaio et al., (2016) used 4 sets of concentric failure. This could explain the differences in significance between the studies. A significant duration*condition interaction was found for QST, which revealed that greater percent differences between conditions were observed as the duration of WU increased.

A proposed explanation for the results is the restriction of venous outflow by the KAATSU cuff. Rhythmic flow out of the muscle has been shown to significantly affect the SKBF response to exercise (Kiens et al., 1989; Korthuis, 2011; Rowell, 2004). Studies that observed thermoregulation suggests that heat convection transfer from the muscle to the core through the blood is essential for heat dissipation (Kenny et al., 2003; Raccuglia et al., 2016). Furthermore, BFR is shown to cause lateral expansion and blood pooling in the affected limb (Loenneke et al., 2012; Visser et al., 2006; Wilson et al., 1993; Yasuda et al., 2009). This lateral expansion could compress peripheral skin blood vessels, while the vessels of the muscles are continuously pumped and filled with blood during BFR exercise. This would cause the skin temperature to decrease significantly more in the BFR condition and explain why ST continuously decreased as the BFR-WU duration length increased.

In support of the significance of the difference in temperature, Marins et al., (2013) states that asymmetries in ST ≤0.4°C are normal, anything from 0.5-0.7 should be monitored, and anything from 0.8-1 should be prevented. For QST, the 5-8min session asymmetries between conditions remained slightly below 0.4°C, at 0.3°C. While the 10-min session asymmetries reached 0.8℃ and the 12-15 min sessions reached 0.6℃ post-WU. At post-8min, asymmetries were considered normal at ≤0.4℃ and only reached 0.4℃ on the 15min session.

Range of Motion Response

All ROM's tested in the current study increased in response to WU. Increased ROM post-WU is to be expected and has been demonstrated (Bishop, 2003a; Ericson et al., 1988; Wiktorsson-Moller et a., 1983; Zakas et al., 2006). Previous research has noted that increases in ROM from WU can be attributed to the breaking of actin-myosin bonds created during rest and the increase in tissue temperature (Bishop, 2003a; Wiktorsson-Moller et a., 1983; Zakas et al., 2006). In the current study, ROM increased from baseline to post-WU and from post-WU to post-8min. While increases were seen for both times, baseline to post-WU recordings increased to a greater percent than post-WU to post-8min recordings. In support, Mizuno et al., (2013) showed that the greatest percent increase in ROM was seen immediately after the exercise intervention. One novel finding is that several WU studies have reported that knee-flexion did not increase in response, while the current findings revealed that knee-flexion significantly increased in response to WU in both conditions (Stewart et al., 1998; Wiktorsson-Moller et a., 1983; Zakas et al., 2006).

A possible explanation to this is that different ROM's were used between the current and conflicting study. The current study proposes that the degree of motion of each joint during exercise should be recorded to verify the differences in pre to post-WU ROM responses. The findings of the current study can only be applied to cycling, active ROM, and for up to 8 minutes post-WU. One possible explanation as to why active ROM differences were not seen is that longer rest durations were not used. Future research should determine if differences in active

ROM are seen after longer wait periods. Another possible reason that differences were not seen is that only active ROM was taken. Future research should determine the effects of BFR exercise on passive ROM..

Vertical Jump Response

All VJ variables failed to yield a significant condition or duration main effect ($p>0.05$). The variables single-leg vertical-jump (VJ) height, average-power (AP), peak velocity (PV) ($p<0.01$), and peak-force (PF) ($p<0.05$) yielded a significant time main effect**.** These variables generally increased in response to WU and continued to improve post-8min. The current findings are in agreement with (multiple) studies (Asmussen et al., 1976; Kidston, 2013; Walshe et al., 1996). Improvements in factors of VJ performance with a cycle-ergometer WU is usual and can be attributed to the decreased viscous resistance, increased muscle temperature, musculotendon compliance, myoelectric response, and psychological preparedness (Asmussen et al., 1976; Binkhorst et al., 1977; Bishop, 2003a; Kidston, 2013; Kubo et al., 1999; Racinais et al., 2010; Walshe et al., 1996; Wilson et al., 1994).

During cycle-ergometer WU's it is shown that the knee and hip go through the greatest ROM during work and have been shown to significantly contribute to the VJ (Ericson et al., 1988; Fukashiro et al., 1987; Hubley et al., 1983; Wozniak, 1991; Zebis et al., 2011). Kubo et al., (1999) stated that 21% of the variance in CMJ could be attributed to the elastic properties on the vastus lateralis and in-part by the knee extensors and 85% of the increases in CMJ height could be accounted for by the myoelectric responses post-WU. The ability to utilize the SSC is enhanced with increased temperatures that allow for reduced viscous resistance and increased musculotendon compliance (Anderson et al., 1993; Bishop, 2003a; Walshe et al., 1996; Wilson et al., 1994).

The results from the current study indicate that a cycle-ergometer WU's with or without BFR for 5-15mins at 50 RPMs with 1-1.5kg of resistance for females and males, respectively, are a well-tolerated method, duration-range, and intensity of improving factors of VJ performance. Although neither condition was significantly superior, a significant condition*time interaction ($p<0.05$) showed that AP, PAP, and AV decreased from post-WU to post-8min in the NBFR condition and increased in the BFR condition.

A similar study showed that immediately after bouts of BFR, the average squat-jump height was positively affected while the CMJ was negatively affected for the BFR leg when compared to the control leg (Beaven et al., 2012). This study also revealed a positive impact on jump power and acceleration 24 hours post exercise intervention. The steady improvements seen in the current study and delayed improvements seen in Beaven et al., 2012, suggest that BFR may be suitable for explosive events when they have long wait times between the WU and event while NBFR may be suitable for events that immediately follow the WU.

In agreement with an overview by Karabulut et al., (2007), these responses may be explained by multiple physiological factors. Some possible explanations to the slower but steady increases observed in the BFR condition include metabolic accumulation, muscular, and neural activity (Brandner et al., 2015; Karabulut et al., 2007; Karabulut et al., 2013a; Yasuda et al., 2006; Yasuda et al., 2009). This may suggest the need for longer wait times between BFR-WU and event to allow the outflow of metabolites created during BFR use. Under these conditions, more powerful type 2 fibers are shown to be activated to a significantly greater extent when compared to the NBFR conditions (Karabulut et al. 2007; Yasuda et al., 2009). Another possible explanation to the response seen in the BFR condition immediately post-WU is that blood pooling and lateral expansion may reduce musculotendon compliance, SSC use, and subsequently, the ability to transition from eccentric to concentric during the CMJ. Muscular compliance has been shown to increase the rate of contraction due to the linear stretching of the muscles involved (Wilson et al., 1994). Blood pooling and lateral expansion from BFR use may cause lateral force transmissions that acutely reduce compliance, and linear stretching (Loenneke et al., 2012; Visser et al., 2006; Wilson et al., 1993; Yasuda et al., 2009).

Furthermore, the PAP recording from the TENDO Power Analyzer V- 316 is used to quantify the rate of force development (RFD). The RFD is defined as the slope of the force-time curve (Gruber et al., 2004). This is the rate at which force is developed, from the onset of the motion to the peak force. Tendo states that PAP is a better representation of RFD because it is factored from the first 50% of the motion. This quality is said to be more important to athletic performance than VJ height alone (Patterson et al., 2004). Further supporting the previous statement that BFR may be suitable only when they have long wait times between WU's and events such as cyclists who warm up 30 minutes before their race (Faulkner, Ferfuson, Hupperets, Hodders, and Havenith., 2012). Due to the current findings, this study would propose that regardless of the contributing factors involved in attenuating CMJ performance immediately post-WU, they may fade in ~8mins, and a benefit may be seen. In support, it is said that the benefits of restriction pre-event may only be seen in an optimal zone that has not been elucidated yet (Gibson et al., 2013). One small and novel finding was that PP saw a significant conditions*time*sex interaction ($p<0.05$). This revealed that males had increases in their PP in response to both WU conditions. While females only had increases in their PP in response to the BFR-WU condition. In response to the NBFR, females decreased in their PP. Suggesting that females responded better to the BFR-WU when compared to the NBFR-WU when there is a need for PP. Finally, the findings of the current study elucidate the need for future research in the restriction of blood flow for use in WU's.

Conclusion

The purposes of this study were to 1.) Elucidate ranges of optimal ranges for BFR-WU's 2.) Determine if blood flow restriction warm-ups (BFR-WU) are appropriate for enhancing a desired response.

The research questions asked were:

1. Was the length of BFR-WU important to optimizing performance?
2. Would there be differences between the BFR and NBFR conditions?
3. Will differences dissipate over time?

Research Hypothesis 1. There will be an optimal length of BFR-WU, where performance is optimized.

The results of the present study did not support this hypothesis. The length of BFR-WU did not produce significantly different vertical jumps (VJ) or range of motions (ROM). However, as BFR-WU duration increased, hamstring skin-temperature (ST) significantly decreased. This may affect other events and should be investigated in future research.

Research Hypothesis 2. There will be differences between conditions.

The results of the present study did support this hypothesis for quad skin temperature, hamstring skin temperature, average power, partial average power, and average velocity. The majority of the variables mentioned, generally had greater average scores for the post-WU time and the NBFR condition. However, the NBFR generally decreased in average power, partial average power, and average velocity from post-WU to post-8min, while the BFR condition steadily increased. If enhancing a single effort event is the goal, NBFR may be recommended for events that take place immediately after the WU and BFR is recommended for events with wait times between the WU and event.

Research Hypothesis 3. Differences will dissipate over time.

The results of the present study did support this hypothesis for quad skin temperature, hamstring skin temperature, average power, partial average power, and average velocity. The majority of the variables mentioned, generally had greater average scores for the post-WU time and the NBFR condition. Differences between conditions generally decreased from post-WU to post-8min. While the NBFR condition had increases from baseline to post-WU and decreases from post-WU to post-8min for vertical jump performance, the BFR condition steadily continued to increase.

This study is the first to search for optimal durations and wait times for BFR-WU's that enhance performance. The current findings reveal that BFR-WU's were successful in maintaining increases in vertical-jump (VJ) performance compared to a NBFR-WU. The BFR-WU condition usually caused increases from baseline to post-WU and from post-WU to post-8min, while the NBFR-WU condition mostly caused decreases from post-WU to post-8min.

This study also revealed that quad and hamstring skin-temperature (ST) is significantly affected by BFR use. As BFR-WU duration increased, hamstring ST generally decreased. Suggesting that lateral expansion of the muscles further reduces skin blood flow during BFR-

WU. Genders mostly reacted differently between times and condition for quad and hamstring ST. Males had significantly greater drops in ST when compared to females as durations increased.

Finally, it was revealed that BFR-WU’s yielded insignificant effects on active ROM. The results support the need for future research in BFR-WU’s. Findings indicate that greater rest durations between WU and event, passive ROM, depth jumps, and the upper limbs could be suggested. To conclude, both BFR and NBFR WU’s are appropriate to increase VJ height and ROM.

REFERENCES

Albert, M. (1991). *Eccentric muscle training in sports and orthopaedics* (pp. 1-157). New York: Churchill Livingstone.

Alter, M. J. (2004). *Science of flexibility*. Human Kinetics.

Amaral, B., Arias, J., & Karabulut, M. (2016). The Effect of Warm-up with Different Blood Flow Restriction Settings on Strength and Vertical Power: 3273 Board# 338 June 3, 330 PM-500 PM. *Medicine & Science in Sports & Exercise*, *48*(5S), 938.

Anderson, F. C., & Pandy, M. G. (1993). Storage and utilization of elastic strain energy during jumping. *Journal of biomechanics*, *26*(12), 1413-1427.

Anrep, G. V., & Von Saalfeld, E. (1935). The blood flow through the skeletal muscle in relation to its contraction. *The Journal of Physiology*, *85*(3), 375-399.

Asmussen, E., & Bonde-Petersen, F. (1974). Storage of elastic energy in skeletal muscles in man. *Acta Physiologica Scandinavica*, *91*(3), 385-392.

Asmussen, E., Bonde-Petersen, F., & Jørgensen, K. (1976). Mechano-elastic properties of human muscles at different temperatures. *Acta Physiologica Scandinavica*, *96*(1), 83-93.

Böning, D., Hollnagel, C., Boecker, A., & Göke, S. (1991). Bohr shift by lactic acid and the supply of O2 to skeletal muscle. *Respiration physiology*, *85*(2), 231-243.

Baker, D. (1996). Improving vertical jump performance through general, special, and specific strength training. *Journal of strength and Conditioning Research*, *10*, 131-136.

Barcroft, J., & King, W. O. R. (1909). The effect of temperature on the dissociation curve of blood. *The Journal of Physiology*, *39*(5), 374.

Barros, N., Aidar, F. J., Gama, D., Oliveira, L. M. C., & Aparecido, E. (2017). Comparison of Traditional strength training and Kaatsu strength training on thermal asymmetry, fatigue rate, and peak torque. *Journal of Exercise Physiology Online*, *20*(1), 1-13.

Beaven, C. M., Cook, C. J., Kilduff, L., Drawer, S., & Gill, N. (2012). Intermittent lower-limb occlusion enhances recovery after strenuous exercise. *Applied Physiology, Nutrition, and Metabolism*, *37*(6), 1132-1139.

Behm, D. G., & Sale, D. G. (1993). Velocity specificity of resistance training. *Sports medicine*, *15*(6), 374-388.

Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2015). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied physiology, nutrition, and metabolism*, *41*(1), 1-11.

Binkhorst, R. A., Hoofd, L., & Vissers, A. C. (1977). Temperature and force-velocity relationship of human muscles. *Journal of Applied Physiology*, *42*(4), 471-475.

Bishop, D. (2003). Warm up I. *Sports medicine*, *33*(6), 439-454.

Bishop, D. (2003). Warm up II. *Sports medicine*, *33*(7), 483-498.

Blazevich, A. J., Cannavan, D., Waugh, C. M., Fath, F., Miller, S. C., & Kay, A. D. (2012). Neuromuscular factors influencing the maximum stretch limit of the human plantar flexors. *Journal of Applied Physiology*, *113*(9), 1446-1455.

Boone, D. C., & Azen, S. P. (1979). Normal range of motion of joints in male subjects. *JBJS*, *61*(5), 756-759.

BOSCO, C., Viitasalo, J. T., Komi, P. V., & Luhtanen, P. (1982). Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. *Acta Physiologica Scandinavica*, *114*(4), 557-565.

Bottinelli, R., Betto, R., Schiaffino, S., & Reggiani, C. (1994). Unloaded shortening velocity and myosin heavy chain and alkali light chain isoform composition in rat skeletal muscle fibres. *The Journal of physiology*, *478*(2), 341-349.

Bradley, P. S., Olsen, P. D., & Portas, M. D. (2007). The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *The Journal of Strength & Conditioning Research*, *21*(1), 223-226.

Brandner, C. R., Warmington, S. A., & Kidgell, D. J. (2015). Corticomotor excitability is increased following an acute bout of blood flow restriction resistance exercise. *Frontiers in human neuroscience*, *9*, 652.

Buekers, M. J., Magill, R. A., & Hall, K. G. (1992). The effect of erroneous knowledge of results on skill acquisition when augmented information is redundant. *The Quarterly Journal of Experimental Psychology Section A*, *44*(1), 105-117.

Cavagna, G. A. (1977). Storage and utilization of elastic energy in skeletal muscle. *Exercise and sport sciences reviews*, *5*(1), 89-130.

Chiu, L. Z., FRY, A. C., WEISS, L. W., SCHILLING, B. K., BROWN, L. E., & SMITH, S. L. (2003). Postactivation potentiation response in athletic and recreationally trained individuals. *The Journal of Strength & Conditioning Research*, *17*(4), 671-677.

Cho, S., Irianto, J., & Discher, D. E. (2017). Mechanosensing by the nucleus: From pathways to scaling relationships. *J Cell Biol*, *216*(2), 305-315.

Clarkson, H. M. (2000). *Musculoskeletal assessment: joint range of motion and manual muscle strength*. Lippincott Williams & Wilkins.

Colomer-Poveda, D., Romero-Arenas, S., Vera-Ibáñez, A., Viñuela-García, M., & Márquez, G. (2017). Effects of 4 weeks of low-load unilateral resistance training, with and without blood flow restriction, on strength, thickness, V wave, and H reflex of the soleus muscle in men. *European journal of applied physiology*, *117*(7), 1339-1347.

Cook, S. B., Clark, B. C., & Ploutz-Snyder, L. L. (2007). Effects of exercise load and blood-flow restriction on skeletal muscle function. *Medicine and science in sports and exercise*, *39*(10), 1708-1713.

Crenshaw, A. G., Hargens, A. R., Gershuni, D. H., & Rydevik, B. (1988). Wide tourniquet cuffs more effective at lower inflation pressures. *Acta Orthopaedica Scandinavica*, *59*(4), 447-451.

Crisafulli, A., Tangianu, F., Tocco, F., Concu, A., Mameli, O., Mulliri, G., & Caria, M. A. (2011). Ischemic preconditioning of the muscle improves maximal exercise performance but not maximal oxygen uptake in humans. *Journal of applied physiology*, *111*(2), 530-536.

Crisóstomo, R. S. S., Candeias, M. S., & Armada-da-Siva, P. A. S. (2014). The use of ultrasound in the evaluation of the efficacy of calf muscle pump function in primary chronic venous disease. *Phlebology*, *29*(4), 247-256.

Cunha, A. C. V., Burke, T. N., França, F. J. R., & Marques, A. P. (2008). Effect of global posture reeducation and of static stretching on pain, range of motion, and quality of life in women with chronic neck pain: a randomized clinical trial. *Clinics*, *63*(6), 763-770.

de Freitas, M. C., Gerosa-Neto, J., Zanchi, N. E., Lira, F. S., & Rossi, F. E. (2017). Role of metabolic stress for enhancing muscle adaptations: Practical applications. *World journal of methodology*, *7*(2), 46.

DeVries, H. A. (1974). Physiology of exercise for physical education and athletics.

Ellis, C. G., Mathieu-Costello, O., Potter, R. F., MacDonald, I. C., & Groom, A. C. (1990). Effect of sarcomere length on total capillary length in skeletal muscle: in vivo evidence for longitudinal stretching of capillaries. *Microvascular research*, *40*(1), 63-72.

Ericson, M. O., Nisell, R., & Németh, G. (1988). Joint motions of the lower limb during ergometer cycling. *Journal of Orthopaedic & Sports Physical Therapy*, *9*(8), 273-278.

Evans, C., Vance, S., & Brown, M. (2010). Short-term resistance training with blood flow restriction enhances microvascular filtration capacity of human calf muscles. *Journal of sports sciences*, *28*(9), 999-1007.

Fahs, C. A., Rossow, L. M., Loenneke, J. P., Thiebaud, R. S., Kim, D., Bemben, D. A., & Bemben, M. G. (2012). Effect of different types of lower body resistance training on arterial compliance and calf blood flow. *Clinical physiology and functional imaging*, *32*(1), 45-51.

Farrell, P. A., Joyner, M., & Caiozzo, V. (2011). *ACSM's advanced exercise physiology*. Wolters Kluwer Health Adis (ESP).

Faulkner, S. H., Ferguson, R. A., Gerrett, N., Hupperets, M., Hodder, S. G., & Havenith, G. 2012). Reducing muscle temperature drop post warm-up improves sprint cycling performance.

Fink, W. J., Costill, D. L., & Van Handel, P. J. (1975). Leg muscle metabolism during exercise in the heat and cold. *European journal of applied physiology and occupational physiology*, *34*(1), 183-190.

Fleck, S. J., & Kraemer, W. J. (1982). The overtraining syndrome. *Strength & Conditioning Journal*, *4*(4), 50-51.

Formenti, D., Ludwig, N., Gargano, M., Gondola, M., Dellerma, N., Caumo, A., & Alberti, G. (2013). Thermal imaging of exercise-associated skin temperature changes in trained and untrained female subjects. *Annals of biomedical engineering*, *41*(4), 863-871.

Fröhlich, M., Ludwig, O., Zeller, P., & Felder, H. (2015). Changes in skin surface temperature after a 10-minute warm-up on a bike ergometer. *International Journal of Kinesiology and Sports Science*, *3*(3), 13-17.

Fry, C. S., Glynn, E. L., Drummond, M. J., Timmerman, K. L., Fujita, S., Abe, T., ... & Rasmussen, B. B. (2010). Blood flow restriction exercise stimulates mTORC1 signaling and muscle protein synthesis in older men. *Journal of applied physiology*, *108*(5), 1199-1209.

Fukashiro, S., & Komi, P. V. (1987). Joint moment and mechanical power flow of the lower limb during vertical jump. *International Journal of Sports Medicine*, *8*(S 1), S15-S21.

Garhammer, J., & Gregor, R. (1992). Propulsion forces as a function of intensity for weightlifting and vertical jumping. *Journal of Applied Sport Science Research*, *6*(3), 129-134.

Garrett Jr, W. E., Califf, J. C., & Bassett, F. H. (1984). Histochemical correlates of hamstring injuries. *The American journal of sports medicine*, *12*(2), 98-103.

Ghosh, S., Standen, N. B., & Galiñanes, M. (2000). Preconditioning the human myocardium by simulated ischemia: studies on the early and delayed protection. *Cardiovascular research*, *45*(2), 339-350.

Gibson, N., White, J., Neish, M., & Murray, A. (2013). Effect of ischemic preconditioning on land-based sprinting in team-sport athletes. *International Journal of Sports Physiology & Performance*, *8*(6).

Gruber, M., & Gollhofer, A. (2004). Impact of sensorimotor training on the rate of force development and neural activation. *European journal of applied physiology*, *92*(1-2), 98-105.

Haff, G. G., & Triplett, N. T. (Eds.). (2015). *Essentials of strength training and conditioning 4th edition*. Human kinetics.

Hertogh, C., Chamari, K., Damiani, M., Martin, R., Hachana, Y., Blonc, S., & Hue, O. (2005). Effects of adding a preceding run-up on performance, blood lactate concentration and heart rate during maximal intermittent vertical jumping. *Journal of sports sciences*, *23*(9), 937-942.

Hubley, C. L., & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 247-254.

Hunt, J. E., Galea, D., Tufft, G., Bunce, D., & Ferguson, R. A. (2013). Time course of regional vascular adaptations to low load resistance training with blood flow restriction. *Journal of applied physiology*, *115*(3), 403-411.

Iversen, E., & Røstad, V. (2010). Low-load ischemic exercise-induced rhabdomyolysis. *Clinical Journal of Sport Medicine*, *20*(3), 218-219.

Järvholm, U., Styf, J., Suurkula, M., & Herberts, P. (1988). Intramuscular pressure and muscle blood flow in supraspinatus. *European journal of applied physiology and occupational physiology*, *58*(3), 219-224.

Jean-St-Michel, E., Manlhiot, C., Li, J., Tropak, M., Michelsen, M. M., Schmidt, M. R., ... & Redington, A. N. (2011). Remote preconditioning improves maximal performance in highly trained athletes. *Med Sci Sports Exerc*, *43*(7), 1280-6.

Johnson, J. M., & Park, M. K. (1979). Reflex control of skin blood flow by skin temperature: role of core temperature. *Journal of Applied Physiology*, *47*(6), 1188-1193.

Journeay, W. S., Carter, R., & Kenny, G. P. (2006). Thermoregulatory control following dynamic exercise. *Aviation, space, and environmental medicine*, *77*(11), 1174-1182.

KAATSU GLOBAL, I. (2017). *KAATSU_User_Manual*. Retrieved from https://www.kaatsu-global.com/: https://www.kaatsu-global.com/Assets/Files/Presentations/KAATSU_User_Manual.pdf

KAATSU GLOBAL, I. D. (2019). *Article.cfm?cms_ArticleID=290*. Retrieved from https://www.kaatsuperformance.com/: https://www.kaatsuperformance.com/Article.cfm?cms_ArticleID=290

Kaciuba-Uscilko, H., & Grucza, R. (2001). Gender differences in thermoregulation. *Current Opinion in Clinical Nutrition & Metabolic Care*, *4*(6), 533-536.

Karabulut, M., Abe, T., Sato, Y., & Bemben, M. (2007). Overview of neuromuscular adaptations of skeletal muscle to KAATSU Training. *International Journal of KAATSU Training Research*, *3*(1), 1-9.

Karabulut, M., Cramer, J. T., Abe, T., Sato, Y., & Bemben, M. G. (2010). Neuromuscular fatigue following low-intensity dynamic exercise with externally applied vascular restriction. *Journal of Electromyography and Kinesiology*, *20*(3), 440-447.

Karabulut, M., & Perez, G. (2013a). Neuromuscular response to varying pressures created by tightness of restriction cuff. *Journal of Electromyography and Kinesiology*, *23*(6), 1494-1498.

Karabulut, M., Sherk, V. D., Bemben, D. A., & Bemben, M. G. (2013b). Inflammation marker, damage marker and anabolic hormone responses to resistance training with vascular restriction in older males. *Clinical physiology and functional imaging*, *33*(5), 393-399.

Karabulut, M., Leal Jr, J. A., Garcia, S. D., Cavazos, C., & Bemben, M. (2014). Tissue oxygenation, strength and lactate response to different blood flow restrictive pressures. *Clinical physiology and functional imaging*, *34*(4), 263-269.

Karabulut, M., & Garcia, S. D. (2017). Hemodynamic responses and energy expenditure during blood flow restriction exercise in obese population. *Clinical physiology and functional imaging*, *37*(1), 1-7.

Karvonen, J. (1992). Importance of warm-up and cool down on exercise performance. In *Medicine in Sports Training and Coaching* (Vol. 35, pp. 189-214). Karger Publishers.

Katayama, K., Yamashita, S., Ishida, K., Saito, M., Koike, T., & Ogoh, S. (2014). Sympathetic Outflow during Leg Cycling is Suppressed by Muscle Pump-Induced Increase in Central Blood Volume: 1280 Board# 20 May 29, 800 AM-930 AM. *Medicine & Science in Sports & Exercise*, *46*(5S), 328.

Kenny, G. P., Reardon, F. D., Zaleski, W., Reardon, M. L., Haman, F., & Ducharme, M. B. (2003). Muscle temperature transients before, during, and after exercise measured using an intramuscular multisensor probe. *Journal of applied physiology*, *94*(6), 2350-2357.

Kidston, M. (2013). *Time Course Changes in Muscle Temperature and Performance Following Active Warm Up in Cool Environments* (Doctoral dissertation).

Kiens, B., Saltin, B., WALLØSE, L., & Wesche, J. (1989). Temporal relationship between blood flow changes and release of ions and metabolites from muscles upon single weak contractions. *Acta physiologica scandinavica*, *136*(4), 551-559.

Klavora, P. (2000). Vertical-jump tests: A critical review. *Strength and Conditioning Journal*, *22*(5), 70-75.

Knudson, D., Bennett, K., Corn, R. O. D., Leick, D., & Smith, C. (2001). Acute effects of stretching are not evident in the kinematics of the vertical jump. *The Journal of Strength & Conditioning Research*, *15*(1), 98-101.

Koga, S., Shiojiri, T., Kondo, N., & Barstow, T. J. (1997). Effect of increased muscle temperature on oxygen uptake kinetics during exercise. *Journal of Applied Physiology*, *83*(4), 1333-1338.

Korthuis, R. J. (2011, June). Skeletal muscle circulation. In *Colloquium Series on Integrated Systems Physiology: From Molecule to Function* (Vol. 3, No. 4, pp. 1-144). Morgan & Claypool Life Sciences.

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *Journal of applied physiology*, *87*(6), 2090-2096.

Kubota, A., Sakuraba, K., Sawaki, K., Sumide, T., & Tamura, Y. (2008). Prevention of disuse muscular weakness by restriction of blood flow. *Medicine and science in sports and exercise*, *40*(3), 529-534.

Larsson, S. E., Bengtsson, A., Bodegård, L., Henriksson, K. G., & Larsson, J. (1988). Muscle changes in work-related chronic myalgia. *Acta Orthopaedica Scandinavica*, *59*(5), 552-556.

Larsson, R., Öberg, P. Å., & Larsson, S. E. (1999). Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia. *Pain*, *79*(1), 45-50.

Loenneke, J., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2012). The anabolic benefits of venous blood flow restriction training may be induced by muscle cell swelling. *Medical hypotheses*, *78*(1), 151-154.

Loenneke, Jeremy P., Christopher A. Fahs, Lindy M. Rossow, Robert S. Thiebaud, Kevin T. Mattocks, Takashi Abe, and Michael G. Bemben. "Blood flow restriction pressure recommendations: a tale of two cuffs." *Frontiers in physiology* 4 (2013): 249.

Loenneke, J. P., Thiebaud, R. S., Abe, T., & Bemben, M. G. (2014). Blood flow restriction pressure recommendations: the hormesis hypothesis. *Medical hypotheses*, *82*(5), 623-626.

Loenneke, J. P., Kim, D., Fahs, C. A., Thiebaud, R. S., Abe, T., Larson, R. D., ... & Bemben, M. G. (2015). Effects of exercise with and without different degrees of blood flow restriction on torque and muscle activation. *Muscle & nerve*, *51*(5), 713-721.

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Boesen, J., Johannsen, F., & Kjaer, M. (1997). Determinants of musculoskeletal flexibility: viscoelastic properties, cross-sectional area, EMG and stretch tolerance. *Scandinavian journal of medicine & science in sports*, *7*(4), 195-202.

Marins, J., Fernández-Cuevas, I., Arnaiz Lastras, J., Fernandes, A. A., & Sillero Quintana, M. (2013). Applications of infrared thermography in sports. A review. *International Journal of Medicine and Science of Physical Activity and Sport, in press*, *15*(60), 805-824.

Markovic, G. (2007). Does plyometric training improve vertical jump height? A meta-analytical review. *British journal of sports medicine*, *41*(6), 349-355.

Matchanov, A. T., Levtov, V. A., & Orlov, V. V. (1983). Changes in blood flow after longitudinal stretching of the cat m. gastrocnemius. *Fiziologicheskii zhurnal SSSR imeni IM Sechenova*, *69*(1), 74-83.

McCutcheon, L. J., Geor, R. J., & Hinchcliff, K. W. (1999). Effects of prior exercise on muscle metabolism during sprint exercise in horses. *Journal of Applied Physiology*, *87*(5), 1914-1922.

McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-up strategies for sport and exercise: mechanisms and applications. *Sports medicine*, *45*(11), 1523-1546.

Mendonca, G. V., Vaz, J. R., Pezarat-Correia, P., & Fernhall, B. (2015). Effects of walking with blood flow restriction on excess post-exercise oxygen consumption. *International journal of sports medicine*, *36*(03), e11-e18.

Mizuno, T., Matsumoto, M., & Umemura, Y. (2013). Viscoelasticity of the muscle–tendon unit is returned more rapidly than range of motion after stretching. *Scandinavian journal of medicine & science in sports*, *23*(1), 23-30.

Nardone, A., Romano, C., & Schieppati, M. (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *The Journal of physiology*, *409*(1), 451-471.

Nesser, T. W., & Demchak, T. J. (2007). VARIATIONS OF PRESEASON CONDITIONING ON VOLLEYBALL PERFORMANCE. *Journal of Exercise Physiology Online*, *10*(5).

Nielsen, J. L., Aagaard, P., Bech, R. D., Nygaard, T., Hvid, L. G., Wernbom, M., ... & Frandsen, U. (2012). Proliferation of myogenic stem cells in human skeletal muscle in response to low-load resistance training with blood flow restriction. *The Journal of physiology*, *590*(17), 4351-4361.

Patterson, D. D., & Peterson, D. F. (2004). Vertical jump and leg power norms for young adults. *Measurement in Physical Education and Exercise Science*, *8*(1), 33-41.

Pope, Z. K., Willardson, J. M., & Schoenfeld, B. J. (2013). Exercise and blood flow restriction. *The Journal of Strength & Conditioning Research*, *27*(10), 2914-2926.

Quesada, J. I. P., Martínez, N., Palmer, R. S., Psikuta, A., Annaheim, S., Rossi, R. M., ... & Pérez-Soriano, P. (2016). Effects of the cycling workload on core and local skin temperatures. *Experimental Thermal and Fluid Science*, *77*, 91-99.

Raccuglia, M., Lloyd, A., Filingeri, D., Faulkner, S. H., Hodder, S., & Havenith, G. (2016). Post-warm-up muscle temperature maintenance: blood flow contribution and external heating optimisation. *European journal of applied physiology*, *116*(2), 395-404.

Racinais, S., & Oksa, J. (2010). Temperature and neuromuscular function. *Scandinavian journal of medicine & science in sports*, *20*, 1-18.

Reeser, J. C., Verhagen, E. A. L. M., Briner, W. W., Askeland, T. I., & Bahr, R. (2006). Strategies for the prevention of volleyball related injuries. *British journal of sports medicine*, *40*(7), 594-600.

Rowell, L. B. (2004). Ideas about control of skeletal and cardiac muscle blood flow (1876–2003): cycles of revision and new vision. *Journal of applied physiology*, *97*(1), 384-392.

Sampaio, L., Bezerra, E., Paladino, K., dos Santos, J. O. L., Quesada, J. I. P., & Rossato, M. (2016). Effect of training level and blood flow restriction on thermal parameters: preliminary study. *Infrared Physics & Technology*, *79*, 25-31.

Sata, S. (2005). Kaatsu training for patella tendinitis patient. *International Journal of KAATSU Training Research*, *1*(1), 29-32.

Sato, Y. (2005). The history and future of KAATSU training. *International Journal of KAATSU Training Research*, *1*(1), 1-5.

Savastano, D. M., Gorbach, A. M., Eden, H. S., Brady, S. M., Reynolds, J. C., & Yanovski, J. A. (2009). Adiposity and human regional body temperature. *The American journal of clinical nutrition*, *90*(5), 1124-1131.

Schleip, R., Naylor, I. L., Ursu, D., Melzer, W., Zorn, A., Wilke, H. J., ... & Klingler, W. (2006). Passive muscle stiffness may be influenced by active contractility of intramuscular connective tissue. *Medical hypotheses*, *66*(1), 66-71.

Sheppard, J. M., McGuigan, M., & Newton, R. U. (2007). The effect of accentuated eccentric load on vertical jump kinetics kinematics in elite male athletes. *Int J Sports Sci Coaching*, *2*(3), 267-73.

Sheriff, D. D. (2010). Role of mechanical factors in governing muscle blood flow. *Acta physiologica (Oxford, England)*, *199*(4), 385-391.

Stewart, I. B., & Sleivert, G. G. (1998). The effect of warm-up intensity on range of motion and anaerobic performance. *Journal of Orthopaedic & Sports Physical Therapy*, *27*(2), 154-161.

Tabata, S., Suzuki, Y., Azuma, K., & Matsumoto, H. (2016). Rhabdomyolysis after performing blood flow restriction training: a case report. *Journal of strength and conditioning research*, *30*(7), 2064-2068.

Takarada, Y., Takazawa, H., & Ishii, N. (2000a). Applications of vascular occlusions diminish disuse atrophy of knee extensor muscles. *Medicine and science in sports and exercise*, *32*(12), 2035-2039.

Takarada, Y., Takazawa, H., Sato, Y., Takebayashi, S., Tanaka, Y., & Ishii, N. (2000b). Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *Journal of applied physiology*, *88*(6), 2097-2106.

Takarada, Y., Sato, Y., & Ishii, N. (2002). Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *European journal of applied physiology*, *86*(4), 308-314.

Trecroci, A., Formenti, D., Ludwig, N., Gargano, M., Bosio, A., Rampinini, E., & Alberti, G. (2018). Bilateral asymmetry of skin temperature is not related to bilateral asymmetry of crank torque during an incremental cycling exercise to exhaustion. *PeerJ*, *6*, e4438.

Tucker, C. R. (1978). Cross-sectional myofibre and myofibril growth in immobilized developing skeletal muscle. *Journal of cell science*, *29*(1), 297-312.

Visnes, H., Aandahl, H. Å., & Bahr, R. (2013). Jumper's knee paradox—jumping ability is a risk factor for developing jumper's knee: a 5-year prospective study. *Br J Sports Med*, *47*(8), 503-507.

Visser, B., & van Dieën, J. H. (2006). Pathophysiology of upper extremity muscle disorders. *Journal of electromyography and kinesiology*, *16*(1), 1-16.

Walshe, A. D., Wilson, G. J., & Murphy, A. J. (1996). The validity and reliability of a test of lower body musculotendinous stiffness. *European journal of applied physiology and occupational physiology*, *73*(3-4), 332.

Watsford, M. L., Murphy, A. J., McLachlan, K. A., Bryant, A. L., Cameron, M. L., Crossley, K. M., & Makdissi, M. (2010). A prospective study of the relationship between lower body stiffness and hamstring injury in professional Australian rules footballers. *The American journal of sports medicine*, *38*(10), 2058-2064.

Weigert, M., Nitzsche, N., Kunert, F., Lösch, C., Baumgärtel, L., & Schulz, H. (2018). Acute exercise-associated skin surface temperature changes after resistance training with different exercise intensities. *International Journal of Kinesiology and Sports Science*, *6*(1), 12-18.

Wernbom, M., Paulsen, G., Nilsen, T. S., Hisdal, J., & Raastad, T. (2012). Contractile function and sarcolemmal permeability after acute low-load resistance exercise with blood flow restriction. *European journal of applied physiology*, *112*(6), 2051-2063.

Wiktorsson-Moller, M., Öberg, B., Ekstrand, J., & Gillquist, J. (1983). Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. *The American journal of sports medicine*, *11*(4), 249-252.

Wilk, K. E., Voight, M. L., Keirns, M. A., Gambetta, V., Andrews, J. R., & Dillman, C. J. (1993). Stretch-shortening drills for the upper extremities: theory and clinical application. *Journal of Orthopaedic & Sports Physical Therapy*, *17*(5), 225-239.

Wilson, G. J., Newton, R. U., Murphy, A. J., & Humphries, B. J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine and science in sports and exercise*, *25*(11), 1279-1286.

Wilson, G. J., Murphy, A. J., & Pryor, J. F. (1994). Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. *Journal of applied physiology*, *76*(6), 2714-2719.

Witvrouw, E., Danneels, L., Asselman, P., D'Have, T., & Cambier, D. (2003). Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players: a prospective study. *The American journal of sports medicine*, *31*(1), 41-46.

Wozniak Timmer, C. A. (1991). Cycling biomechanics: a literature review. *Journal of Orthopaedic & Sports Physical Therapy*, *14*(3), 106-113.

Wright, V., & Johns, R. J. (1961). Quantitative and qualitative analysis of joint stiffness in normal subjects and in patients with connective tissue diseases. *Annals of the rheumatic diseases*, *20*(1), 36.

Yasuda, T., Fujita, T., Miyagi, Y., Kubota, Y., Sato, Y., Nakajima, T., ... & Abe, T. (2006). Electromyographic responses of arm and chest muscle during bench press exercise with and without KAATSU. *International Journal of KAATSU Training Research*, *2*(1), 15-18.

Yasuda, T., Brechue, W. F., Fujita, T., Shirakawa, J., Sato, Y., & Abe, T. (2009). Muscle activation during low-intensity muscle contractions with restricted blood flow. *Journal of sports sciences*, *27*(5), 479-489.

Yasuda, T., Abe, T., Brechue, W. F., Iida, H., Takano, H., Meguro, K., ... & Nakajima, T. (2010). Venous blood gas and metabolite response to low-intensity muscle contractions with external limb compression. *Metabolism*, *59*(10), 1510-1519.

Yasuda, T., Loenneke, J. P., Thiebaud, R. S., & Abe, T. (2012). Effects of blood flow restricted low-intensity concentric or eccentric training on muscle size and strength. *Plos one*, *7*(12), e52843.

Zakas, A., Doganis, G., Zakas, N., & Vergou, A. (2006). Acute effects of active warm-up and stretching on the flexibility of elderly women. *Journal of sports medicine and physical fitness*, *46*(4), 617.

Zebis, M. K., Andersen, L. L., Ellingsgaard, H., & Aagaard, P. (2011). Rapid hamstring/quadriceps force capacity in male vs. female elite soccer players. *The Journal of Strength & Conditioning Research*, *25*(7), 1989-1993.

Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: a review of observational and experimental studies. *Scandinavian journal of medicine & science in sports*, *20*(4), 556-567.

APPENDIX A

Definitions

1. Blood flow restriction **(BFR)**: The use of external compression to restrict blood flow in and out of the applied limb.
2. Non-Blood flow restriction **(NBFR)**: The control in a BFR study. This refers to a limb or group that is not affected by BFR.
3. KAATSU: elastic bands with a pressure sensor that restrict blood flow while performing low intensity exercise (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan).
4. Initial restrictive pressure **(IRP)**: the first and lowest pressure of the BFR cuffs when it is only tightened and deflated.
5. Final restrictive pressure **(FRP)**: the final and highest pressure of the BFR cuffs, which is used during cycle ergometer sessions. Measured by capillary refill time of ≤2 seconds in this study.
6. Physical activity readiness questionnaire **(PAR-Q)**: A questionnaire designed to measure the participant's physical activity status.
7. Systolic blood pressure **(SBP)**: The pressure against the walls of the arteries during systole (the contraction of the ventricles).
8. Diastolic blood pressure **(DBP):** The pressure against the walls of the arteries during diastole (the relaxation of the ventricles).
9. 90:90 Hamstring test: used to measure maximal knee extension while the hip is at a 90-degree angle.
10. Prone Knee Flexion test: Used to measure maximal knee flexion while lying prone (face down).

11. Dorsiflexion test: used to measure range of motion of ankle dorsiflexion, taken while the participant is seated upright on the floor with extended knees and instructed to completely flex the foot towards the body.
12. Vertec: Instrument used to measure a participant's maximal vertical jump. Participants mark their maximum vertical by pushing pre-measured veins over. (Sport Imports, Vertec Vertical Jump Trainer, Vertec2).
13. Tendo: Instrument attached to a participant by a provided belt that is used to measure maximum power output. (TENDO Power Analyzer V- 316).
14. Random counterbalanced method **(RCM)**: a method used to reduce the learning curve or false responses that may alter results.
15. Countermovement **(CMJ)**: A technique used to utilize the stretch shortening cycle in a maximal vertical jump test. The arms swing down with the quick flexing of the hips, knees, and downward motion of the trunk before jumping and reaching upward with the arms.
16. Warm-up **(WU):** An exercise technique used to prepare the body for physical activity.
17. Passive Warm-up: A technique used to increase muscle temperature through external means (i.e. heating pads or sauna).
18. Active Warm-up: Short (5-15 min) submaximal intensity (40-60% Vo2) bouts of exercise that are designed to prepare the body for more intense bouts of exercise.
19. Capillary Refill Time **(CRT)**: The time it takes for the capillaries of the skin to refill after outside compression. Observed through skin color change.

List of ABBREVIATIONS

1. 1RM- One rep maximum
2. AP- Average power
3. AV- Average velocity
4. BFR- KAATSU blood flow restriction
5. CC- contractile component
6. CMJ- Counter movement jump
7. CRT- Capillary refill time
8. DBP- Diastolic blood pressure
9. FRP- Final resting pressure
10. WU- Warm up
11. iEMG- Electromyography
12. IP- Ischemic pre-conditioning
13. IRP- Initial resting pressure
14. NBFR- Non-blood flow restriction
15. VJ- Vertical jump
16. PAP- Partial average power
17. PAR-Q- Physical activity readiness questionnaire
18. PEC- Parallel elastic component
19. PF- Peak force
20. PP- Peak power
21. PV- Peak velocity
22. QOL- Quality of life

23. RCM- Random counter balanced method

24. RT- Resistance training

25. SKBF- Skin blood flow

26. SBP- Systolic blood pressure

27. SEC- Series elastic component

28. SSC- Stretch shortening cycle

29. ST- Skin temperature

APPENDIX–FORMS

1.) **Recruitment Flyer**

The department of Health and Human Performance from the University of Texas Rio Grande Valley (Brownsville), invite you to participate in one of our health research studies.

The purposes of this study are to 1) investigate the optimal warm up time for blood flow restriction cuff use and without, 2) to examine the acute effects of a warm up with and without blood flow restriction on lower body single leg flexibility, vertical jump power, and temperature

Total Time Required for Study: 6 Sessions Approximately 1 hour each

First day

- The subject will undergo an initial screening and will complete a PAR Q questionnaire. Participants will be familiarized with the study procedure.

Subsequent days

- Warm-up on a cycle ergometer at 1Kp (females) and 1.5Kp (males) of resistance at 50 rotations per minute (RPM)
- Three scores will be taken pre and post warm-up: temperature, flexibility tests, and single leg vertical power output
- Tests will be administered pre, post, and post-8min for a total of 3 times.

Your Help Is Needed!

Subjects needed:

- **24 males and 24 females**
- **Ages 18-50**

If you are interested please tear off a tab with our information and contact us!

Murat.Karabulut@utrgv.edu
Phillipe.lopez01@utrgv.edu

956-698-9611 Phillipe Lopez
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2.) **Informed Consent**

University of Texas Rio Grande Valley
Informed Consent Form to Participate in Research

Project Title: The acute effects of warm-up with and without blood flow restriction cuffs on lower body's temperature, flexibility, and vertical jump power

Principal Investigator: Dr. Murat Karabulut
Co-Investigators: Phillipe Lopez

Faculty Advisor: Dr. Murat Karabulut
Department: Health and Human Performance

You are being asked to volunteer as a participant for this research study. The study will be conducted in the research laboratory of the Health and Human Performance Department at the University of Texas Rio Grande Valley at the Brownsville campus (M-1 Building, room 216). You have been selected as a participant due to your inquiry or recruitment. After analyzing the health questionnaires you are to fill out, you will be informed whether or not you are qualified to participate in this study.

Please read this form carefully and ask any questions you have before agreeing to participate in this study.

Purpose

The purposes of this study are to:

1) Investigate the optimal cycle ergometer warm-up time for blood flow restriction cuff use for lower body flexibility and single leg vertical jump performance.
2) Observe the acute effects of a cycle ergometer warm-up with blood flow restriction on lower body skin temperature.
3) Observe lower body flexibility, single leg vertical jump performance, and skin temperature post BFR cycle ergometer warm-up.

Procedures

If you agree to be in this study, you will be asked to do the following:

On the first day, you will be evaluated to determine if you qualify for the study. You will be asked to fill out questionnaires and will be familiarized with the study procedures before starting the exercise sessions. Following the initial screening, PAR-Q and health questionnaire (both of which will be provided for you), your cardiovascular and anthropometric measurements including: blood pressure (BP), resting heart rate (HR), height, weight, and body composition Participants that answer yes to any PAR-Q question, or have blood pressure at or higher than 140/90 mmHg will be excluded from this study. Those who pass screening will be familiarized with procedures including: Blood flow restriction cuff placement and inflation, cycle ergometer seat placement and warm-up intensity, vertical jumps required for the study, skin temperature (ST) recordings, and range of motion (ROM) tests. Inflation of the blood flow restriction cuffs (elastic cuffs that are tightened and filled with air to restrict blood flow) will be determined by following a set protocol. Bike adjustments will also take place; the bike seat height will be placed at the location of the greater trochanter of your femur. The cycle ergometer warm-up will be practiced for 5-minutes at 1Kp (females) and 1.5Kp (males) of resistance at 50 rotations per minute (RPM). Maximal counter movement jump (CMJ) and maximal single leg CMJ will be practiced and scores will be recorded. Finally, ST recordings and the four lower body ROM tests will be practiced. This session will last approximately 1 hour each.

This study will consist of 5 different warm-up duration sessions: Approximately 1 hour each

Cycle ergometer warm-ups will be 5, 8, 10, 12, or 15 minutes. All times will be required, chosen at random, and separated by at least 48 hours from each other and lower body training. For each session the participant (you) will come fasted for at least 8 hours, hydrated, and asked to maintain similar eating habits 24 hours before each exercise session.

At the start of each session: hydration status, as well as baseline ST and ROM of the body will be taken. Hydration status will be checked via urine refractometer and must be <1.010 before taking baseline lower body ST and ROM. There will be a 3-minute warm-up before recording baseline maximal single leg CMJ. Post 3-minute warm-up and pre maximal single leg CMJ testing, differences from baseline lower body temperature and ROM will be taken. A blood flow restriction cuff (BFR) will be then be placed on your dominant or non-dominant leg at random. ST, ROM, and maximal single leg CMJ will be taken immediately after each warm-up with BFR. These procedures will be repeated 10 and 20 minutes post warm-ups. Data on the lower body will be collected a total of 5 times. Each session will last approximately 1 hour.

ST sites will be located at your mid anterior thigh at the rectus femoris, mid posterior thigh at the bicep femoris, and at the belly of the calf muscle. ST will be recorded using a non-contact infrared thermometer (IRT207 Heat Seeker™ Infrared Thermometer). After ST data is collected, you will perform the 90:90 hamstring flexibility, leg lift, seated dorsiflexion, and prone knee flexion ROM. Maximal ROM will be taken via goniometer. Post ST and ROM score collection, left and right leg CMJ performance will be taken via Tendo sports machine and vertec height.

Length of Participation

You will be required to visit the research labs in the Department of Health and Human Performance on 6 separate days for a total time commitment of approximately 6 hours.

University of Texas Rio Grande Valley
Informed Consent Form to Participate in Research

Risks

There are minimal risks to healthy individuals performing any of the requirements for this study. These standard protocols have been approved at numerous other institutions and will be performed by qualified and trained personnel. However, you may experience discomfort when BFR cuff is inflated and when performing warm up protocols.

Benefits

You can receive information about your anthropometric measures such as height, weight, body composition, resting BP and HR. Also, you will obtain information about increasing your flexibility as well as warm up training options.

Injury

In case of injury or illness resulting from this study, emergency medical services will be contacted ((956)882-3896 or 911). Otherwise first aid will be administered appropriately if medical assistance is needed the service will provided through your personal health insurance. However, you or your insurance company may be expected to pay the usual charge for this treatment. The University of Texas at Rio Grande Valley has set no funds to compensate you in the event of an injury.

Confidentiality

In published reports, all data will remain confidential. Research records will be stored in locked cabinets and on encrypted computers. Only the named researchers will have access to the data.

Costs

There is no cost for participation.

Compensation

You will receive no financial compensation for your time and participation in this study.

Voluntary Nature of the Study

Participation in this study is voluntary. If you decline to participate, you will not be penalized or lose benefits or services unrelated to the study. If you decide to participate, you may decline to answer any question and may choose to withdraw at any time.

Waivers of Elements of Confidentiality

The University of Texas Rio Grande Valley
IRB APPROVED
IRB# 2017-024-02
Expires:08/28/2019

IRB APPROVED UTRGV

<u>University of Texas Rio Grande Valley</u>

Informed Consent Form to Participate in Research

Your name will not be linked with your responses unless you specifically agree to be identified. Please select one of the following options

_____ I consent to being quoted directly.

_____ I do not consent to being quoted directly.

Contacts and Questions

If you have any concerns, complaints, or questions about the research and/or the researcher(s) conducting this study you are encouraged to contact the Department of Health and Human Performance. You may speak with the principal investigator (also faculty advisor) Dr. Murat Karabulut, Ph.D., at (956) 882-7236, Murat.Karabulut@utrgv.edu or e-mail co-Investigator phillipe.lopez01@utrgv.edu.

<u>Who to Contact Regarding Your Rights as a Participant</u>: This research has been reviewed and approved by the Institutional Review Board for Human Subjects Protection (IRB). If you have any questions about your rights as a participant, or if you feel that your rights as a participant were not adequately met by the researcher, please contact the IRB at (956) 665-2889 or irb@utrgv.edu.

You are voluntarily making a decision whether or not to participate. Your signature indicates that, having read and understood the information provided above, you have decided to participate. You will be given a copy of this information to keep for your records. If you are not given a copy of this consent form, please request one.

Statement of Consent

I have read the above information as well as asked questions and have received satisfactory answers. I consent to participate in the study.

____

Signature Date

The University of Texas Rio Grande Valley
IRB APPROVED
IRB# 2017-024-02
Expires:08/28/2019

IRB APPROVED UTRGV

3.) **PAR-Q**

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

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

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

If you answered

YES to one or more questions

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

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

NO to all questions

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

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

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

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

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

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

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

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT
or GUARDIAN (for participants under the age of majority) ______________________________ WITNESS ______________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

4.) **Health Status Questionnaire**

HEALTH STATUS QUESTIONNAIRE

SECTION ONE - GENERAL INFORMATION

1. Date____________________
2. Name____
3. Mailing Address_____________________________________ Phone (H)_______________
   _____________________________________ Phone (W)_______________
   Email _____________________________________
4. *EI* Personal Physician__________________________________ Phone__________________
   Physician Address__________________________________ Fax____________________
   ____
5. *EI* Person to contact in case of emergency___________________ Phone__________________
6. Gender (circle one): Female ◯ Male *RF* ◯
7. *RF* Date of birth___________/__________/____________
8. Height ____________________ Weight ________________________
9. Number of hours worked per week: Less than 20 ◯ 20-40 ◯ 41-60over 60 ◯
10. *SLA* More than 25% of the time at your job is spent (circle all that apply)
    ◯ Sitting at desk ◯ Lifting loads ◯ Standing ◯ Walking ◯ Driving

SECTION TWO - CURRENT MEDICAL INFORMATION

11. Date of last medical physical exam:______________
12. Circle all medicine taken of prescribed in last 6 months:
    - ☐ Blood thinner *MC*
    - ☐ Diabetic *MC*
    - ☐ Digitalis *MC*
    - ☐ Diuretic *MC*
    - ☐ Epilepsy medication *SEP*
    - ☐ Heart rhythm medication *MC*
    - ☐ High blood pressure medication *MC*
    - ☐ Insulin *MC*
    - ☐ Nitroglycerin *MC*
    - Other___________________
13. Please list any orthopedic conditions. Include any injuries in the last six months
    ____

14. Any of these health symptoms that occur frequently (two or more times/month) requires medical attention. Please check any that apply.

- a. ☐ Cough up blood *MC*
- b. ☐ Abdominal pain *MC*
- c. ☐ Low-back pain *MC*
- d. ☐ Leg Pain *MC*
- e. ☐ Arm or shoulder pain *MC*
- f. ☐ Chest pain *RF MC*
- g. ☐ Swollen joints *MC*
- h. ☐ Feel faint *MC*
- i. ☐ Dizziness *MC*
- j. ☐ Breathlessness with slight exertion *MC*
- k. ☐ Palpitation or fast heart beat *MC*
- l. ☐ Unusual fatigue with normal activity *MC*

Other____

SECTION THREE - MEDICAL HISTORY

15. Please circle any of the following for which you have been diagnosed or treated by a physician or health professional:

- ☐ Alcoholism *SEP*
- ☐ Anemia, sickle cell *SEP*
- ☐ Anemia, other *SEP*
- ☐ Asthma *SEP*
- ☐ Back strain *SLA*
- ☐ Bleeding trait *SEP*
- ☐ Bronchitis, chronic *SEP*
- ☐ Stroke *MC*
- ☐ Thyroid problem *SEP*
- ☐ Ulcer *SEP*
- ☐ Congenital defect *SEP*
- ☐ Diabetes *SEP*
- ☐ Emphysema *SEP*
- ☐ Epilepsy *SEP*
- ☐ Eye problems *SLA*
- ☐ Gout *SLA*
- ☐ Hearing loss *SLA*
- ☐ Heart problems *MC*
- ☐ Cancer *SEP*
- ☐ Cirrhosis *MC*
- ☐ Concussion *MC*
- ☐ Hyperlipidemia *RF*
- ☐ Kidney problem *MC*
- ☐ Mental illness *SEP*
- ☐ Neck strain *SLA*
- ☐ Obesity *RF*
- ☐ Phlebitis *MC*
- ☐ Rheumatoid arthritis *SLA*
- ☐ Stress *RF*
- ☐ High blood pressure *MC*
- ☐ HIV *SEP*
- ☐ Hypoglycemia *SEP*

Other_________________

16. Circle any operations that you have had:

☐ Back *SLA* ☐ Heart *MC* ☐ Kidney *SLA* ☐ Eyes *SLA* ☐ Joint *SLA* ☐ Neck *SLA*

☐ Ears *SLA* ☐ Hernia *SLA* ☐ Lung *SLA* Other___________________________

17. *RF* Circle any who died of heart attack before age 55:

☐ Father ☐ Brother ☐ Son

18. *RF* Circle any who died of heart attack before age 65:

☐ Mother ☐ Sister ☐ Daughter

SECTION FOUR - HEALTH-RELATED BEHAVIORS

19. Have you ever smoked? Yes ◯ No ◯

20. *RF* Do you now smoke? Yes ◯ No ◯

21 .*RF* If you are a smoker, indicate the number smoked per day:

Cigarettes: 40 or more ◯ 20-39 10-19 ◯ 1-9 ◯

Cigars or pipes only: 5 or more or any inhaled less than 5

22. *RF* Do you exercise regularly? Yes ◯ No ◯

23.. Last physical fitness test:__________________

24. How many days a week do you accumulate 30 minutes of moderate activity?

0 1 2 3 4 5 6 7 days per week

25. How many days per week do you normally spend at least 20 minutes in vigorous exercise?

0 1 2 3 4 5 6 7 days per week

26. What activities do you engage in a least 1x per week?

____

27. Weight now:__________lb. One year ago:_________ Age 21:_________

SECTION FIVE - HEALTH-RELATED ATTITUDES

28. These are traits that have been associated with coronary-prone behavior. Circle the number that corresponds to how you feel towards the following statement:

I am an impatient , time-conscious, hard-driving individual.

Circle the number that best describes how you feel:

◯ 6= Strongly agree
◯ 5= Moderately agree
◯ 4= Slightly agree
◯ 3= Slightly disagree
◯ 2= Moderately disagree
◯ 1= Strongly disagree

29. How often do you experience "negative" stress from each of the following:

	Always	Usually	Frequently	Rarely	Never
Work:	☐	☐	☐	☐	☐
Home or family :	☐	☐	☐	☐	☐
Financial pressure:	☐	☐	☐	☐	☐
Social pressure:	☐	☐	☐	☐	☐
Personal health	☐	☐	☐	☐	☐

30. List everything not included on this questionnaire that may cause you problems in a fitness test or fitness program:

____

____

____

____

Action Codes

EI = Emergency Information- must be readily available
MC= Medical Clearance needed-do not allow exercise without physician's permission.
SEP= Special Emergency Procedures needed- do not let participant exercise alone; make sure the person's exercise partner knows what to do in case of an emergency
RF= Risk Factor of CHD (educational materials and workshops needed).
SLA= Special or Limited Activities may be needed- you may need to include or exclude specific exercises.
Other (not marked) = Personal information that may be helpful for files or research.

5.) **Data Collection Sheet**

Participant # ____

Session # ____

Bike Height	Vertec Height	Bed Height	Dominant Leg	BFR Warmup Time	Leg with BFR

	Baseline														
Temperature (Celsius)						**Range of Motion (degrees)**									
Quad		Hamstring		Calf Belly		90:90		Leg Lift		Dorsiflexsion		Knee Flexsion			
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right		

Pressure	Initial		Final	

	Pre-BFR														
Temperature (Celsius)						**Range of Motion (degrees)**									
Quad		Hamstring		Calf Belly		90:90		Leg Lift		Dorsiflexsion		Knee Flexsion			
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right		

Vertec (in)		**Tendo**											
Height Increase		Average Power		Partial Average		Peak Power (W)		Average		Peak Velocity		Peak Force (N)	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

	___ Minutes After BFR												
Temperature (Celsius)						**Range of Motion (degrees)**							
Quad		Hamstring		Calf Belly		90:90		Leg Lift		Dorsiflexion		Knee Flexsion	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

Vertec (in)		**Tendo**											
Height Increase		Average Power		Partial Average		Peak Power (W)		Average		Peak Velocity		Peak Force (N)	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

	___ Minutes After BFR												
Temperature (Celsius)						**Range of Motion (degrees)**							
Quad		Hamstring		Calf Belly		90:90		Leg Lift		Dorsiflexion		Knee Flexsion	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

Vertec (in)		**Tendo**											
Height Increase		Average Power		Partial Average		Peak Power (W)		Average		Peak Velocity		Peak Force (N)	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

	___ Minutes After BFR												
Temperature (Celsius)						**Range of Motion (degrees)**							
Quad		Hamstring		Calf Belly		90:90		Leg Lift		Dorsiflexion		Knee Flexsion	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

Vertec (in)		**Tendo**											
Height Increase		Average Power		Partial Average		Peak Power (W)		Average		Peak Velocity		Peak Force (N)	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

6.) **Professor Permission Script**

The University of Texas Rio Grande Valley
Professor Permission Script

My name is Phillipe Lopez; I am a graduate student from the Department of Health and Human Performance at the University of Texas Rio Grande Valley (UTRGV). I would like to ask permission to enter your classroom to invite your students to participate in my research study. My study is about the acute effects of warm up with and without blood flow restriction cuffs on lower body's temperature, flexibility, and vertical jump power.

As a participant, students will be asked to perform 6 sessions, which will include: A preliminary session in which the student will be asked to come in hydrated (which will be tested via urine sample) and fasted. This session will include anthropometric measuring and cycle ergometer seat height measurements. Students will then come to the lab for 5 cycle ergometer warm-up sessions with blood flow restriction placed on one leg. Each of these sessions will last approximately 1 HOUR. The total time commitment is approximately 6 hours. Participation in this research is completely voluntary; they may choose not to participate without penalty. All data will be confidential by being collected by Phillipe Lopez and Murat Karabulut, and later stored in a locked file cabinet for 3 years.

If allowed, I would like to come in at the beginning of the class time. I will ask you to please exit the classroom to reduce any possible feeling of coercion to participate in the study. I will also ask you to not mention the study further and redirect students to my email or cellphone number, if any questions arise.

You could potentially offer extra credit for participation in the study I will conducting or by means of writing a report that is relevant to the material in the course if you choose to offer the extra credit.

This research study has been reviewed and approved by the UTRGV Institutional Review Board for the Protection of Human Subjects (IRB).

If you have questions about the research, please feel free to contact either Phillipe Lopez at phillipe.lopez01@utrgv.edu ; and/ or the principal investigator Murat Karabulut murat.karabulut@utrgv.edu. Or, if you have any questions regarding your students' rights as participants in the study, please call the IRB at (956) 665-2889 or email at irb@utrgv.edu.

Do I have your permission to recruit students from your classroom(s) Dr. Murat Karabulut?
Do I have your permission to recruit students from your classroom(s) Dr. Ulka Karabulut?
Do I have your permission to recruit students from your classroom(s) Dr. Merill Funk?
Do I have your permission to recruit students from your classroom(s) Ms. Margarita Gonzalez?

7.) **In Person Permission Script**

<u>The University of Texas Rio Grande Valley</u>
Recruitment Script

My name is Phillipe Lopez; I am a graduate student from the Department of Health and Human Performance at the University of Texas Rio Grande Valley (UTRGV). I would like to invite you to participate in my research study: **The Acute Effects of a warm-up with and without Blood Flow Restriction Cuffs on lower body temperature, flexibility, and vertical jump power.**

This research study has been reviewed and approved by the UTRGV Institutional Review Board for the Protection of Human Subjects (IRB).

To qualify for this study, you must be between the ages of 18 and 50, not have a blood pressure greater than 140/90mmHg, and dependent on answers selected on Physical Activity Readiness-Questionnaire and Health Status Questionnaire.

Participation in this research is completely voluntary; you may choose not to participate without penalty.

As a participant, you will be asked to perform 6 sessions, which will include: A preliminary session in which you will be asked to come in hydrated (which will be tested via urine sample) and fasted. This session will include anthropometric measuring and cycle ergometer seat height measurements. You will then come to the lab for 5 cycle ergometer warm-up sessions with blood flow restriction placed on one leg. Each of these sessions will last approximately 1 hour. The total time commitment is approximately 6 hours. Participation in this research is completely voluntary; you may choose not to participate without penalty. All data will be collected by Phillipe Lopez and Murat Karabulut, and later stored in a locked file cabinet for 3 years. Participation is confidential and your name will not be reported in the published study.

If you would like to participate in this research study, please e-mail principal investigator Murat Karabulut at murat.karabulut@utrgv.edu, or research assistant phillipe.lopez01@utrgv.edu

Do you have any questions now? If you have questions later, please contact me by email at phillipe.lopez01@utrgv.edu

"You may also contact principal investigator/my faculty advisor Dr. Murat Karabulut, at murat.karabulut@utrgv.edu."

BIOGRAPHICAL SKETCH

Phillipe Thomas Lopez, Bachelor's degree in Exercise Science December 2015 acquired from The University of Texas at Rio Grande Valley, Master's degree in Exercise Science December 2019 acquired from the University of Texas Rio Grande Valley, philopez5286@gmail.com.