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The acute effects of aerobic exercise with blood flow restriction cuffs on arterial compliance in males and females

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THE ACUTE EFFECTS OF AEROBIC EXERCISE WITH BLOOD FLOW RESTRICTION CUFFS ON ARTERIAL COMPLIANCE IN MALES AND FEMALES

A Thesis

by

Maria M. Gonzalez

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THE ACUTE EFFECTS OF AEROBIC EXERCISE WITH BLOOD FLOW RESTRICTION CUFFS ON ARTERIAL COMPLIANCE IN MALES AND FEMALES

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by
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ABSTRACT

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RESULTS: Significant condition*gender interactions found in in SBP ($p<.05$), PR ($p<.01$), SVR ($p<.01$), SpO2 ($p<.05$), PWV carotid to femoral ($p<.03$), and PWV femoral to distal ($p<.02$). Significant condition*time interactions were found in SBP ($p<.01$), DBP ($p<.01$), MAP ($p<.01$), SV ($p<.01$), CO ($p<.01$), SVR ($p<.01$), TVI ($p<.01$), HR ($p<.01$), and SAE ($p<.01$). Significant condition main effects were found in SBP ($p<.02$), DBP ($p<.03$), PR ($p<.03$), SV ($p<.01$), CO ($p=.01$), SVR ($p<.01$), TVI ($p<.01$), HR ($p<.01$), and SAE ($p<.03$) as well as a condition trend in PWV femoral to distal ($p=.06$). Significant time main effects were found in SBP ($p<.01$), MAP ($p<.04$), PP ($p<.01$), PR ($p<.01$), CO ($p<.01$), SVR ($p<.01$), TVI ($p<.01$), HR ($p<.01$), SpO2 ($p<.01$), LAE ($p<.03$), and PWV femoral to distal ($p<.01$).

CONCLUSION: The 60-minute session, at a moderate aerobic intensity, might have the potential to improve arterial elasticity more than a 20-minute BFR session.

KEYWORDS: Blood flow restriction, arterial elasticity, pulse wave velocity, endurance

DEDICATION

This thesis is dedicated to my family, specifically my mother, Margarita Gonzalez, who devoted most of her spare time drilling my school lessons. To my two older siblings, Rebecca and Luis Edmundo, thank you for being loud, odd, brilliant, and setting an example of what a person should be. To my younger sister, Vanessa, thank you for expressing a different form of independence to adhere to.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Cardiovascular disease (CVD) is currently the leading cause of death worldwide (Branca, Nikogosian, & Lobstein, 2007) and is responsible for one in every five deaths (Lloyd-Jones et al., 2009). CVD is preventable through various lifestyle behaviors, such as increased physical activity and a balanced diet. CVD has been found to correlate with the elasticity of arteries, in which a reduced arterial compliance is linked to increased odds of future CVD events (Grey et al., 2003; Laurent et al., 2001). Arterial elasticity is the ability of an artery to expand and return to its baseline shape (Arnett, Evans, & Riley, 1994) and arterial compliance is the relationship between transmural volume and pressure on an arterial segment (Wiinberg, 2000). Large and small arteries continue to increase in elasticity until the age of 30 and steadily decrease in elasticity afterwards (Arnett et al., 1994; Avolio et al., 1985; Gardner & Parker, 2010; Tanaka, DeSouza, & Seals, 1998). The stiffening of the arterial system contributes to numerous CVDs such as hypertension, stroke, atrial fibrillation, heart failure, and coronary artery disease (Shirwany & Zou, 2010).

Multiple studies have been conducted to investigate the effects of exercise programs on arterial stiffness (Kakiyama et al., 2005; Yoshizawa et al., 2010). Arterial stiffness can be assessed through the use of pulse wave velocity (PWV), a non-invasive superficial measurement that measures the time taken for an arterial pulse to propagate from one site to the another (Millasseau, Stewart, Patel, Redwood, & Chowienczyk, 2005; Mitchell et al., 2010). Aerobic exercise has been found to reduce the stiffening rate of arteries (Edwards, Schofield, Magyari, Nichols, & Braith, 2004; Madden, Lockhart, Cuff, Potter, & Meneilly, 2009; Tanaka et al., 1998; Vaitkevicius et al., 1993). Additionally, a decrease on arterial compliance due to age and lifestyle factors can be reversed with regular aerobic exercise (Tanaka et al., 2000) thus lowering the risk of CVD. Aerobic training has been found to decrease resting PWV in as little as 8-weeks, however, after 4 weeks of detraining, PWV returns to baseline levels (Kakiyama et al., 2005). A study conducted by Cameron and Dart (1994) explored arterial compliance in a sample of sedentary individuals over a span of four weeks of aerobic exercise at a moderate intensity. The study concluded there was an increase of arterial compliance over four weeks, which was found to be significant after one week of training. Therefore, it appears that aerobic exercise is effective at improving arterial compliance and may lower the risk of CVD. This is congruent with the recommendations made by the American College of Sports Medicine; aerobic exercise, three to five days a week, for at least 30 minutes (Ferguson, 2014).

A new form of training, blood flow restriction (BFR), decreases blood flow to an active muscle during exercise. BFR is implemented in training with low intensity causing similar adaptations to those seen in high intensity training (Takarada, Takazawa, et al., 2000). This new form of exercise has been proven safe and effective for improving muscle mass, strength, and function (M. A. Mattar et al., 2014). BFR training has been found to increase stroke volume (S. Park et al., 2010); microvascular filtration capacity (Evans, Vance, & Brown, 2010); glycogen content (Burgomaster et al., 2003; Sundberg, 1994); capillary density, increased type 1 to type 2 fiber ratio (Esbjornsson et al., 1993); and higher citrate synthase activity in an aerobic environment. BFR aerobic exercise has also been found to increase arterial elasticity more than high intensity training in an elderly population (Ozaki, Miyachi, Nakajima, & Abe, 2011; S. Y.

Park, Kwak, Harveson, Weavil, & Seo, 2015). Additionally, a study conducted by Abe et al. (2010), demonstrated a low intensity (40% VO2max) aerobic exercise with BFR cuffs can cause an increase in muscle volume in healthy young men. BFR research studies have found significant findings in arterial compliance and hemodynamics in an aerobic setting (Iida et al., 2011; Ozaki et al., 2011; Renzi, Tanaka, & Sugawara, 2010). However, these BFR studies have not compared BFR, at a low intensity and short duration, to a recommended exercise intensity and duration.

Problem and Purpose Statement

CVD is the number one cause of death worldwide and can be detected through PWV and arterial compliance. The purpose of this study was to investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without BFR on arterial elasticity and PWV when compared to a 60-minute walk/ run at 65% VO2 without BFR.

Study Purposes

The purposes of this study were to 1) investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without blood flow restriction (BFR) cuffs on large and small arterial elasticity and pulse wave velocity (PWV) when compared to a 60-minute walk/ run at 65% VO2 without BFR, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in males and females.

Significance of the Study

Arterial stiffness is an independent risk marker and predictor of CVD (Blacher, Asmar, Djane, London, & Safar, 1999; Weber et al., 2004). A large portion of CVD is preventable through various lifestyle behaviors, such as an active lifestyle and a healthy diet. Short aerobic bouts of exercise can reduce arterial stiffness in individuals of high CVD risk (Madden et al., 2009). In recent literature, BFR has been combined with low intensity exercise to mimic the benefits of a high intensity exercise protocol (Abe, Kearns, & Sato, 2006; Cook, Brown, Deruisseau, Kanaley, & Ploutz-Snyder, 2010; Melina Andrade Mattar et al., 2014).

In recent studies, low intensity BFR walking and resistance protocols have provided compelling evidence that BFR improves muscle strength and hypertrophy (Abe et al., 2006; Moore et al., 2004; Takarada, Takazawa, et al., 2000). Similar adaptions have been found with high intensity protocols (Takarada, Sato, & Ishii, 2002). Findings from this study aim to determine if BFR applied to a short aerobic exercise could increase arterial elasticity at the same extent as a long duration aerobic exercise.

Assumptions

1. All participants would complete the study in a timely manner.
2. Participants provided accurate information on Health Status Questionnaire.
3. All equipment provided accurate results following proper calibration.
4. All participants performed the VO2max test at the best of their ability.
5. All participants arrived 8-hours fasted, hydrated, and rested on testing days.
6. All participants would complete the study.

Limitations

1. The study might not be representative of the population due to all participants being volunteers and not being randomly sampled.
2. Health history and medical information were gathered though self-report.
3. Participants were asked to refrain from changes on their current physical activity; however, physical activity performed outside of the study was not monitored.

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 40 were excluded from this study, due to the effects age has on arterial elasticity.
3. Individuals suffering from diseases or disabilities that prevent the individual from undergoing maximal testing were excluded. These included metabolic and cardiovascular diseases, hypertension, joint injuries, and chronic pain.
4. Individuals were required to be 8-hours fasted and adequately hydrated before testing.

Research Questions

In order to test the hypotheses, the following research questions were addressed:

1) Would there be a change in small and large arterial elasticity and PWV following a 20-minute walk/run at 40% VO2 with and without BFR when compared to a 60-minute walk/ run at 65% VO2 without BFR?

2) Would there be a change in SpO2, HR, SBP, DBP, MAP, CO, SV, SVR and TVI in males and females following a 20-minute walk/run at 40% VO2 with and without BFR when compared to a 60-minute walk/ run at 65% VO2 without BFR?

Hypotheses

1) The 20-minute run/walk BFR session would have values in PWV and arterial elasticity similar to the values seen following the 60-minute session.
2) The 20-minute run/walk BFR session would have values of SpO2, HR, SBP, DBP, MAP, CO, SV, SVR and TVI similar to the values seen following the 60-minute session.

Operational Definitions

To aid the reader, the following terms are defined as used in this study:

1) **PAR-Q:** PAR-Q (Physical activity readiness questionnaire) is a screening tool that is designed to determine whether a subject may perform the exercise in a safe and risk free manner.
2) **Blood Flow Restriction (BFR):** BFR is a technique that restricts venous blood return during exercise. This process involves cuffs placed over the inguinal crease, to which they are then inflated to a specific pressure. The cuffs are 5 centimeters wide and contain an inflatable bladder.
3) **Arterial compliance:** the measurement of the elastic properties of the arteries, which has an inverse relationship with arterial stiffness.
4) **Hemodynamics:** Analysis of physical aspects of blood circulation and blood flow.
5) **Pulse Wave Velocity:** Noninvasive assessment of arterial compliance in which velocity of blood pressure wave forms traveling between two different sites are measured.
6) **Hydration:** Hydration status was deemed adequate when urine specific gravity measured 1.010 and lower as determined by a clinical urine refractometer.

Summary

Cardiovascular disease (CVD) is the leading cause of death (Branca et al., 2007) and is linked to poor diet, inactive lifestyle, hypertension, diabetes, and smoking (Ortega et al., 2011). Arterial elasticity has been found to correlate with CVD occurrence, in which a reduced compliance would be associated with increased arterial stiffness and risk of CVD events (Grey et al., 2003; Laurent et al., 2001). Aerobic exercise has been found to reduce the stiffening rate of arteries (Edwards et al., 2004; Madden et al., 2009; Tanaka et al., 1998; Vaitkevicius et al., 1993).

Blood flow restriction (BFR) is an exercise technique that decreases blood flow to the active muscle, during a low intensity protocol, which can result in the adaptions seen in high intensity training (Takarada, Takazawa, et al., 2000). When using BFR with a low intensity exercise protocol, training has been proven safe and effective to improve muscle function, strength, and muscle mass (M. A. Mattar et al., 2014). Varying exercise protocols, with BFR, differ in arterial elasticity, in which greater elasticity has been found in aerobic exercise when compared to resistance training (Ozaki et al., 2011; S. Y. Park et al., 2015).

Currently in the literature, there is insufficient research regarding the acute effects of aerobic exercise with BFR on arterial stiffness. The purposes of this study were to 1) investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without blood flow restriction (BFR) cuffs on large and small arterial elasticity and pulse wave velocity (PWV) when compared to a 60-minute walk/ run at 65% VO2 without BFR, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP),

mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in males and females.

Chapter 2 includes a review of selected literature related to arterial stiffness and BFR. Chapter 3 includes the methodology used in the present study. Chapter 4 includes the results of the present study. Chapter 5 includes a summary of the present study, conclusions drawn from the results, and recommendations for future research related to arterial stiffness with BFR.

CHAPTER II

REVIEW OF THE LITERATURE

The purposes of this study were to 1) investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without blood flow restriction (BFR) cuffs on large and small arterial elasticity and pulse wave velocity (PWV) when compared to a 60-minute walk/ run at 65% VO2 without BFR, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in males and females.

Arterial Compliance

Arterial elasticity is the ability of arteries to expand during ventricular contraction and recoil during ventricular relaxation (Arnett et al., 1994) and arterial compliance is the relationship between transmural volume and pressure on an arterial segment (Wiinberg, 2000). Arterial compliance can be measured noninvasively through the use of pulse wave velocity (PWV), which measures arterial stiffness by determining the time taken for an arterial pulse to propagate from one site to another with the use of a tonometer (Millasseau et al., 2005). A reduction in arterial compliance has been identified as a marker for future cardiovascular disease (CVD) (Arnett et al., 1994). CVD is currently the leading cause of death worldwide (Branca et al., 2007) which accounts for one of every five deaths (Lloyd-Jones et al., 2009); which includes coronary heart disease, heart failure, hypertension, congenital heart disease, heart infections, conduction disorders, atherosclerosis, disorders of the heart valves, cardiomyopathy, and heart arrhythmia. A large portion of CVD is preventable through various lifestyle behaviors, such as an active lifestyle and a healthy diet. Early detection of CVD has been found to correlate with the elasticity of arteries, in which a reduced compliance would link to an increased arterial stiffness and predict future CVD events (Grey et al., 2003; Laurent et al., 2001). Although the death rate due to CVD has fallen through the years, the prevalence of risk factors is rising at an alarming level (Kones, 2011). Regular aerobic exercise is associated with the enhancement of arterial compliance, in which the American College of Sports Medicine recommends physical activity, three to five days a week, for at least 30 minutes (Ferguson, 2014).

There is currently no study that compares a 60-minute bout of aerobic exercise to a 20-minute bout with BFR exercise and its effects on arterial compliance. Therefore, the purpose of this review is to provide detailed information and findings from previous studies that investigated the effects of aerobic exercise with and without BFR on arterial compliance.

Arterial Compliance Relation to Cardiovascular Disease

A reduction in arterial compliance has been identified as a marker for future cardiovascular diseases (Arnett et al., 1994), which increases mortality by increasing the risk of events such as hypertension, stroke, atrial fibrillation, heart failure, and coronary artery disease (Shirwany & Zou, 2010). Arterial stiffness can be enhanced by diabetes mellitus (Lehmann, Gosling, & Sonksen, 1992), renal disease (London et al., 1990), smoking (McVeigh, Morgan, Finkelstein, Lemay, & Cohn, 1997), hypertension (Valappil et al., 2008), increased cholesterol and triglycerides (Bhuiyan et al., 2005), and atherosclerosis (Wada et al., 1994). Arterial elasticity has been found to increase throughout the lifespan until individuals reach a plateau around the age of 30, to which it steadily declines (Arnett et al., 1994; Avolio et al., 1985; Gardner & Parker, 2010; Tanaka et al., 1998). Poor arterial elasticity has been found to correlate with obstructive sleep apnea in obese individuals (Seetho et al., 2014), cognitive decline and impairment in elderly individuals (Zeki Al Hazzouri et al., 2013; Zeki Al Hazzouri & Yaffe, 2014), and tooth loss (Asai et al., 2015).

Type 2 diabetes mellitus (DM2) is known to increase the risk of acquiring CVD qualities, which includes a reduced arterial compliance (Agnoletti et al., 2013; Grundy et al., 1999). Diabetes mellitus is a metabolic disease that results from a defect of insulin action, secretion, or both (Gerich, 1998). It is estimated that 20.8 million people, in the United States, have diabetes; in which about 14.6 million were diagnosed and 6.2 million are undiagnosed (Deshpande, Harris-Hayes, & Schootman, 2008). Long-term complications of DM2 include loss of vision, renal failure, foot ulcers, and amputations (Cade, 2008). Most individuals with DM2 are obese, with fat distribution predominantly in the abdominal region. Excess weight gain, in the abdominal region, is associated with dyslipidemia, blood pressure, atherosclerosis, diabetes (Purnell, Zinman, & Brunzell, 2013), and an increased risk of death caused by cardiovascular disease (Berrington de Gonzalez et al., 2010).

Several studies propose that detection of arterial stiffness may predict cerebrovascular events (Boutouyrie et al., 1999; Salonen & Salonen, 1991). An increase in arterial stiffness leads to an increase in systolic blood pressure that demands a greater left ventricular workload (Westerhof & O'Rourke, 1995) following a hypertrophic response and a decrease in diastolic blood pressure that leads to impaired coronary perfusion (Watanabe, Ohtsuka, Kakihana, & Sugishita, 1993). The rate arterial stiffness occurs is associated with an increased risk of inflammatory processes, presence of endothelial dysfunction, and oxidative stress (Tuttolomondo et al., 2010). After a stroke has occurred, arterial stiffness remains elevated and the risk for reoccurrence is high; which is 26% at 5 years and 40% at 10 years (Mohan et al., 2011). Additional risk factors occur after a stroke if it is poorly managed (Kopunek et al., 2007), which can lead to acquiring hypertension and heart disease (Roth, 1993). Limitations may occur with an incidence of a stroke that often leads to long-term levels of an inactive lifestyle.

Several studies have shown that habitual aerobic exercise can decrease arterial stiffness (Sugawara et al., 2006; Tanaka et al., 2000), which could partly be caused by an improvement in endothelial function, inflammation, and oxidative stress (Maeda et al., 2009; Tanabe et al., 2003). There are multiple forms of exercise that can lead to improved fitness, preventing the occurrence of acquiring a disease or improving current status of the disease, and prolonging life expectancy. Exercise helps improve arterial stiffness and reduces the incidence of developing a cardiovascular occurrence.

The Relationship Between Aerobic Exercise and Arterial Elasticity

Multiple studies have established that physically active individuals have a lower incidence of CVD when compared to their sedentary counterparts (Blair et al., 1989; Powell, Thompson, Caspersen, & Kendrick, 1987). Physically active individuals have a reduced arterial compliance that may be connected to the positive effect exercise has on blood pressure, the glucose-insulin metabolism, lipoproteins and plasma lipids (Shephard & Balady, 1999). Aerobic capacity, determined by the maximal oxygen consumption, is strongly associated with cardiovascular risk (Talbot, Morrell, Metter, & Fleg, 2002; P. T. Williams, 2001) and has an inverse relationship between PWV and VO2 (Vaitkevicius et al., 1993).

Following a 12-minute bout of cycling, PWV was not found to be significantly different between cycling and non-cycling days (Munir et al., 2008). Participants cycled at increasing workloads of 25 to 150 W; in which PWV and radial waveforms were measured via SphygmoCor tonometer, hemodynamics were measured via automated oscillometric method, arterial waveform was measured via servo-controlled finger pressure cuff, and stroke volume and brachial/femoral artery dimensions were measured via transthoracic echocardiography and duplex ultrasound. Results concluded that exercise dilates muscle arteries and reduces arterial pressure augmentation, but had no significance in PWV due to a lack of reduction in smooth muscle relaxation.

Another study investigated the effects of a 6-day endurance exercise training has on arterial compliance (Currie, Thomas, & Goodman, 2009). Participants cycled at 65% VO2peak for 2 hours a day; in which PWV was measured via SphygmoCor tonometer, microhematocrit determinations taken by resting and post blood samples, heart rate was measured via Polar watch and chest strap, and blood flow was measured via venous occlusion strain-gauge plethysmography. Results concluded that central and peripheral PWV was reduced; in which the authors speculated this might have been caused by structural changes to the artery independent of composition.

Blood Flow Restriction

Training stimulates skeletal muscle to adapt to the stimulus, which is specific to the intensity. For instance, the intensity for endurance is below 67%, hypertrophy is between 67% and 85%, and strength is above 85% of a one repetition maximum (1RM) (Baechle, 2000). Atrophy is a loss of muscle size and strength due to inactivity that creates a variety of negative outcomes, as it needed for daily and immune function (Matthews D., 1999). Increasing resistance exercise slows down muscle atrophy, but unfortunately the intensity a person needs to receive these benefits is not suitable for some individuals, such as the elderly, and could lead to injury. A new form of training has surfaced, blood flow restriction (BFR), which decreases blood flow to the active muscle in a low intensity and mimics the training effect of a high intensity protocol (Karabulut, Abe, Sato, & Bemben, 2010; Takarada, Takazawa, et al., 2000). The use of BFR can be used for individuals who cannot withstand the high intensity of an exercise by exercising at a low intensity with all benefits of a higher intensity.

Blood Flow Restriction on Arterial Compliance

BFR can elicit an increase in muscle strength and mass, but it may also be able to produce a response to reduce arterial compliance. During BFR exercise, the pressure the cuffs induce on the limbs occlude venous return and cause blood pooling that results in increasing metabolic stress and fast-twitch fiber recruitment (Suga et al., 2009). After the exercise has been completed, the deflation of the cuff results in shear stress that is followed by and enhanced blood flow and/or increased vasodilation (Patterson & Ferguson, 2010). The increase in shear stress elicits a hyperemic blood flow that may be resulted from an increased release of nitric oxide (Pyke & Tschakovsky, 2005; Thijssen et al., 2011) during the ischemic exercise.

In an acute knee extension and flexion with BFR, improvements in arterial compliance were found while using a low-intensity (Fahs et al., 2011) that might be attributed to the regional vasoactive substance augmentation (Fahs et al., 2011; Wilkinson et al., 2002) and decreased tone in sympathetic vasoconstriction (Boutouyrie et al., 1994). In opposition, several studies have indicated that BFR does not influence arterial compliance (Clark et al., 2011; Fahs et al., 2011) while high intensity resistive exercise, without BFR, can decrease arterial compliance (Ozaki et al., 2013).

Blood Flow Restriction on Aerobic Exercise

This new form of exercise has been proven safe and effective in improving muscle mass, strength, and function (M. A. Mattar et al., 2014). BFR training has been found to increase stroke volume (S. Park et al., 2010); microvascular filtration capacity (Evans et al., 2010); glycogen content (Burgomaster et al., 2003; Sundberg, 1994); capillary density, increased type 1 to type 2 fiber ratio (Esbjornsson et al., 1993); and higher citrate synthase activity in an aerobic environment. BFR aerobic exercise has been found to increase arterial elasticity more than high intensity training (Ozaki et al., 2011; S. Y. Park et al., 2015). A study conducted by Abe et al. (2010), demonstrated that a low intensity (40% VO2max) aerobic exercise with BFR cuffs can cause an increase in muscle volume in healthy young men.

Renzi et al. (2010) reported a decrease in arterial compliance and endothelial function when using BFR cuffs, at a low intensity, following five two-minute bouts of aerobic exercise. Participants walked at 2 mph with and without BFR during two randomized sessions. The popliteal arterial structure was measured with a duplex ultrasound machine, flow mediated vasodilation was measured with a brachial analyzer, and hemodynamics was measured with photoplethysmography. Results concluded that BFR cuffs, while walking, elicited an elevation in blood pressure and a decrease in stroke volume and flow-mediated vasodilation. The authors speculated that BFR caused a reduced arterial compliance because the cuffs augment the left ventricle afterload during exercise.

A 6-week BFR endurance training study found an improvement in limb venous compliance in elderly female participants (Iida et al., 2011). Participants walked for 20-minutes at 2.5 mph five times a week with and without BFR cuffs and had venous compliance measured with a multiple proximal occlusion pressure. Results concluded that BFR cuffs, during a walking training study, elicited an increased maximal venous outflow. The authors speculated that BFR caused an improvement in venous compliance due to a change in hydrostatic force in the leg through venous pooling that would lead to affecting the cardiovascular reflex responses. Another speculation is that muscle compartment, which the cuffs compress the veins and prevent the usual expansion of the veins, may affect the structural factors that influence venous compliance.

Following a 10-week training study, arterial compliance and muscular strength were found to increase with a single type of training in elderly participants (Ozaki et al., 2011). Participants walked for 20-minutes at 45% of their heart rate reserve for 4 days a week, with or without BFR cuffs, and had arterial compliance measured by a semiautomated osillometric device. The control and BFR group had no condition differences in arterial compliance, but were both significantly different between pre and post values. Results also concluded that BFR cuffs in a 10-week walking training study elicited increased muscle size and strength. The authors speculated that the 10-week training study with and without BFR elicited equivalent increases in arterial compliance was due to similar blood pressure responses in the two conditions.

Conclusion

This review highlighted the lack of endurance protocols with BFR on arterial compliance. The study conducted by Renzi et al. (2010) is a major supporting factor in the acute effects that BFR has on arterial compliance while walking and it is clear in the literature that none of the sessions were compared to an exercise session that had an optimal response on arterial compliance, but rather only compares them to the same exercise with and without cuffs. However, inconsistent instrumentation for arterial compliance while walking with BFR cuffs makes cross-referencing difficult and can lead to inconsistent reports between studies. Because of the lack of endurance protocols being reported in the literature, it is necessary to evaluate and compare BFR walking sessions at a low and short duration to a longer duration for greater insight on the arterial compliance response.

CHAPTER III

METHODS

The purposes of this study were to 1) investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without blood flow restriction (BFR) cuffs on large and small arterial elasticity and pulse wave velocity (PWV) when compared to a 60-minute walk/ run at 65% VO2 without BFR, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in males and females.

Participants

Thirty-four healthy male (17) and female (17) participants between the ages of 18 and 40 years were recruited for this research study. Every participant was part of a within subject design. The University of Texas Rio Grande Valley Institutional Review Board approved the study procedure for Human Subjects. Female participants came in during any day of their menstrual cycle, as arterial stiffness does not differ between the phases of the menstrual cycle (Hayashi et al., 2006; Ounis-Skali, Mitchell, Solomon, Solomon, & Seely, 2006; Willekes, Hoogland, Keizer, Hoeks, & Reneman, 1997; M. R. Williams et al., 2001). The length of testing for each subject was one 60-minute introduction session and three experimental sessions, which had two sessions lasting approximately 90 minutes and one 120-minute session for a total of 6 hours.

Inclusion Criteria

1. Participants who were within the 18 to 40 year age range.
2. Participants who had no medical history of hypertension, cardiovascular disease, respiratory disease, joint or muscle problems, any metabolic disease, chronic pain, or currently ingesting medication that might interfere with vascular function.

Exclusion Criteria

1. Participants ingesting medication for hypertension, cardiovascular disease, or chronic pain.
2. Participants ingesting medication that may interfere with vascular function.
3. Participants who had joint or muscle problems.
4. Participants whom had a medical history of hypertension, cardiovascular disease, respiratory disease, joint or muscle problems, or any metabolic disease.
5. Participants who were suffering from chronic back pain and joint injuries in the lower back extremities.

Recruitment

Participants were recruited from The University of Texas Rio Grande Valley through classroom recruitment; in which a professor permission script was used as a well as an in-person script (see appendix for forms). Participants were also recruited by means of fliers and word of mouth at UTRGV (see appendix for flier). Participation in this study was voluntary and participants were allowed to withdraw at any time.

Experimental Protocol

On the first day, the participants filled out and signed an informed consent form and questionnaires (see appendix for forms). Subjects were then familiarized with the study procedures before starting the exercise sessions. Following initial screening (PAR-Q and health questionnaire) and familiarization, anthropometric measures were taken; which included height, weight, body composition, and thigh circumference. Height was measured via stadiometer and weight and body fat percentages were measured using the Tanita Body Composition Analyzer (sends a low frequency signal from one foot to the other to determine the body composition based on the level of conductance). Thigh circumference was taken at the mid-point of the greater trochanter and at the lateral epicondyle. Inflation of the BFR cuffs (elastic cuffs that are tightened and filled with air to restrict blood flow) (5 cm wide; KAATSU-Master System, Sato Sports Plaza, Tokyo Japan) was based on thigh circumference: <45–50 cm = 120 mmHg; 51–55 cm = 150 mmHg; 56–59 cm = 180 mmHg; and ≥60 cm = 210 mmHg. Once anthropometric and body composition measurements were taken, each subject preformed the Bruce Protocol on a treadmill. Testing consisted of running on a treadmill, with increasing speeds and incline, until exhaustion. Participants were fitted with a mask for the metabolic cart (the mask was connected to the metabolic cart via breathing tube to measure inspired oxygen and expired carbon dioxide that analyzed and calculated to measure maximum oxygen consumption). Gas exchange and heart rate (via Polar chest strap and watch) were monitored continuosly by the metabolic cart machine while performing VO2 Max testing and endurance exercise on a treadmill. This first session lasted approximately 60-minutes.

Participants were required to show up hydrated [in which participants were required to provide a urine sample at the beginning of each session that was measured by a Clinical Urine

Refractometer 300005 (SPER Scientific, Scottsdale, AZ, USA), and needed a hydration status at or below 1.010] and with at least 8-hour fasted during the three separate randomized sessions. If the participants were inadequately hydrated, they were instructed to drink water to reach proper hydration. Urine samples were continuously collected every 20 minutes until participants were deemed hydrated according to preset standards. After reaching hydration status, the participants lied down in the supine position for a minimum of 10 minutes and baseline arterial elasticity and hemodynamics were measured using HDI/PulseWave CR-2000TM Research Cardio Vascular Profiling System (Hypertension Diagnostic, Inc., Eagan, Minnesota, USA) and measurement of pulse wave velocity using SphygmoCor® CPV Pulse Wave Analyzer (AtCor Medical, Itasca, IL, USA). Testing sessions consisted of running on a treadmill at moderate speeds (65% or 40% VO_2max). Conditions were randomized into three sessions, a 60-minute walk/run without BFR cuffs at 65% VO2 intensity, 20-minute walk/run at 40% VO2 intensity with the BFR cuffs inflated, and 20-minute walk/run at 40% VO2 intensity with the BFR cuffs un-inflated. Participants wore the BFR elastic cuffs on the 20-minute walk/run at 40% VO2 intensity with the BFR cuffs inflated and 20-minute walk/run at 40% VO2 intensity without the BFR cuffs inflated, in which the cuffs were placed on the most proximal portion of both legs while seated. The cuffs were tightened to an initial pressure rage of 50-55 mmHg for males and 55-60 mmHg for females on the 20-minute walk/run at 40% VO2 intensity with the BFR cuffs inflated and 40-45 mmHg for both sexes on the 20-minute walk/run at 40% VO2 intensity without the BFR cuffs inflated. If the subject was doing the 20-minute walk/run at 40% VO2 intensity with the BFR cuffs inflated session, the BFR cuffs were inflated at 120mmHg for 30 seconds and air pressure was released for 10 seconds. The air pressure was increased by increments of 20mmHg, which was held for 30 seconds and released for 10 seconds until final pressure was reached; which was dependent on their thigh circumference. HR and SpO2 were measured in 5-minute intervals during the length of the 20- or 60-minute sessions. Upon completion of exercise, participants lied on a bed in the supine position and post exercise arterial compliance and hemodynamics were assessed at 10, 20, and 40 minutes and PWV was assessed at immediately, 15, 25, and 45 minutes. The total time required to complete each of these sessions was approximately 120, 90, and 90 minutes that were separated with at least 48 hours between each session. Calibration of all the equipment was performed regularly according to instructions provided by the manufacturer.

Moxus VO_2 Metabolic Cart

Participants were required to wear a breathing mask that was connected to the MOXUS Modular VO2 System (AEI Technologies, Inc., Pittsburgh, PA, USA) through mask and breathing tubes. The metabolic cart computer collected inspired oxygen and expired carbon dioxide and the software recorded analysis and calculations of energy expenditure and oxygen consumption. Heart Rate was assessed continuously by wearing a Polar Heart Rate Monitor FT7 series (Polar Electro Inc., Lake Success, NY, USA).

Bruce Protocol

The Bruce Protocol (Bruce, Kusumi, & Hosmer, 1973) consisted of multiple stages of increasing speeds and inclines until maximal exertion was reached. The metabolic cart (MOXUS Modular VO2 System) continuously recorded oxygen consumption and carbon dioxide production during the test.

Table 1. Bruce Protocol

Stage	Minutes	% Grade	Km/Hr	MPH
1	3	10	2.7	1.7
2	6	12	4	2.5
3	9	14	5.4	3.4
4	12	16	6.7	4.2
5	15	18	8	5
6	18	20	8.8	5.5
7	21	22	9.6	6

Clinical Urine Refractometer

Participants are required to provide a urine sample at the beginning of each session. Hydration was be measured by using 1-3 drops of the urine sample on to the lens of the urine refractometer (Refractometer 300005; SPER Scientific, Scottsdale, AZ, USA). The device was then pointed at a light source and the level of refraction, caused by the sample, was recorded. The device was then cleaned and the rest of the urine was discarded into the biohazard waste.

HDL/PulseWave CR-2000TM Research Cardio Vascular Profiling System

Participants were instructed to lie in the supine position with their arms held comfortably abducted from their bodies by roughly 15 degrees and legs separated comfortably, have an appropriate-sized blood pressure cuff placed above the left antecubital space, and a plastic wrist stabilizer on the right wrist to minimize movement while the measurements were taken place. The pulse wave analysis sensor was placed proximal to the crease between the wrist and hand with the sensor lined over the radial artery at a point of a strong pulse. The sensor was adjusted to signal strength of 18-22 before each recording. When recording, the subject would be required to stay as still as possible for a duration of about a minute, in which blood pressure would be taken before a 30 s time recording took place. The device measured blood pressure, heart rate, stroke volume, left ventricular ejection time, systemic vascular resistance, total vascular impedance, and small and large arterial elasticity.

Pulse Wave Velocity

Analysis of pulse wave velocity was conducted noninvasively using a pulse wave velocity analyzer; SphygmoCor® Pulse Wave Analyzer (AtCor Medical Pty. Ltd., Sydney Australia). Subject required three electrodes to be attached to monitor the heart's electrical activity, which were placed at the top and bottom of the sternum and at the bottom of the rib cage near the mid-axillary line. The subject lied down and had segmental measures take at the carotid (neck), radial (wrist), femoral artery (groin), and the posterior tibial (foot). Measurements were taken to determine the time that it takes to propagate a pulse from one site to another; which used four sites to acquire 3 different measurements: carotid to radial (upper peripheral), carotid to femoral (central), and femoral to posterior tibial (lower peripheral).

Pulse Oximeter

Analysis of blood oxygen level (SpO2) was measured via red and infrared light using the Finger Pulse Oximeter (Invacare, Elyria, Ohio, USA). The participants were required to insert their index finger in the device, which detected the percentage of oxygen in the blood and pulse rate.

Tanita Body Composition Analyzer

Analysis of body weight and body fat percentage was measured by means of bioelectrical impedance on a Body Composition Analyzer TBF-310 (Tanita, Arlington Heights, Illinois, USA). The subject were required to take off unnecessary clothing, jewelry, shoes, and socks before stepping on the scale portion of the device. Once instructed, the subject stepped onto the scale and had their body fat percentage and weight taken.

BFR (blood flow restriction) Cuff

The elastic cuffs are 50 mm in width and were filled with air to create pressure to restrict blood flow. The cuffs are to be connected to an electronic air pressure control system that monitors the restrictive pressures. Thigh circumference was taken at the mid-point of the greater trochanter and at the lateral epicondyle. The cuffs were then inflated to reach an individual's final pressure depending on thigh circumference: <45–50 cm = 120 mmHg; 51–55 cm = 150 mmHg; 56–59 cm = 180 mmHg; and ≥60 cm = 210 mmHg. The BFR cuffs were placed on the uppermost portion of the thigh and tightened to the initial pressure. The cuffs were tightened to an initial pressure rage of 50-55 mmHg for males and 55-60 mmHg for females on the 20-minute walk/run at 40% VO2 intensity with the BFR cuffs inflated and 40-45 mmHg for both sexes on the 20-minute walk/run at 40% VO2 intensity without the BFR cuffs inflated. Inflation began at 120 mmHg and was slowly inflated to a maximal inflation. The pressure was slowly increased, by 20 mmHg, by holding the pressure for 30 s and releasing for 10 s between increments until maximal inflation was reached.

Statistical Analysis

A 2-way analysis of variance (ANOVA) with repeated measures was used to see if significant differences exist in large and small arterial elasticity, central and peripheral pulse wave velocity, blood oxygen level, heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, cardiac output, stroke volume, systemic vascular resistance, and total vascular impedance. Using Pearson Correlation Coefficient, the relationships between the variables was assessed. An alpha of 0.05 was used to determine statistical significance and data were analyzed using SPSS 23.0 for Windows (IBM Corporation, New York, USA).

CHAPTER IV

RESULTS

The purposes of this study were to 1) investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without blood flow restriction (BFR) cuffs on large and small arterial elasticity and pulse wave velocity (PWV) when compared to a 60-minute walk/ run at 65% VO2 without BFR, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in males and females.

Subject Characteristics

Thirty-four participants were recruited for the study, including 17 male and 17 female participants. Table 1 shows descriptive statistics that were taken from the study population. Participants were recruited from the University of Texas Rio Grande Valley at the Brownsville campus.

Table 2. Descriptive Statistics

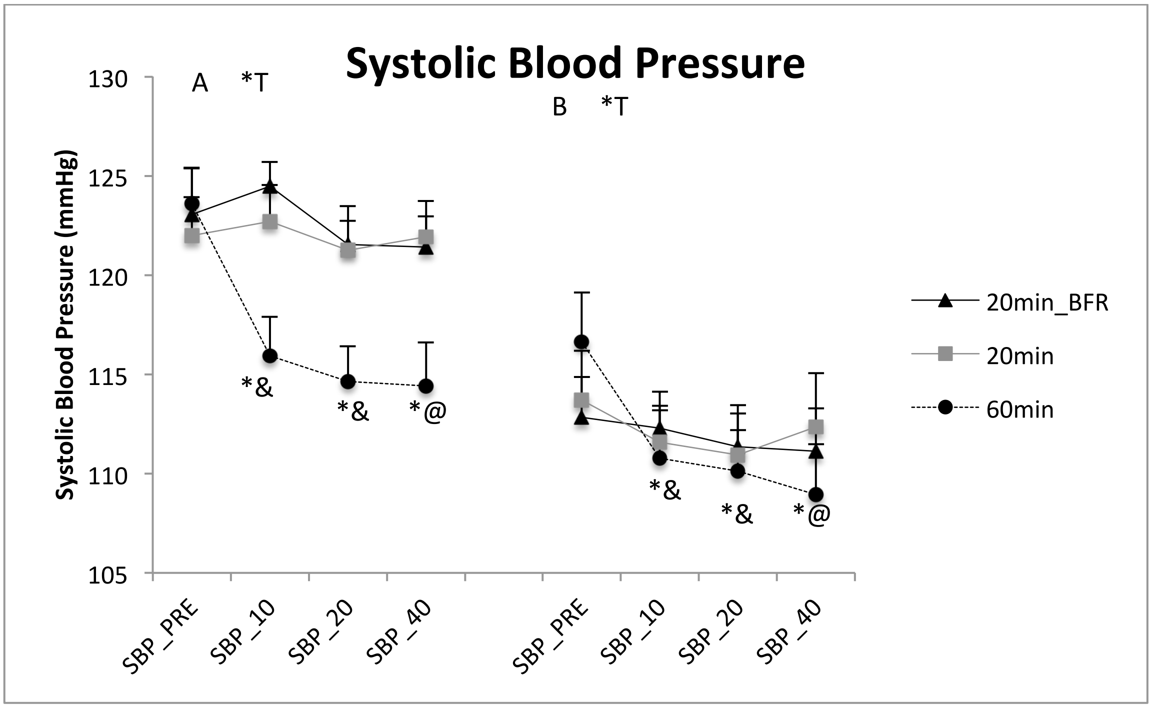
Variables	Male (n=17)	Female (n=17)	Combined Cohort (n=34)
Age (yr)	23.12 (±2.8)	22.88 (±4.2)	23 (±3.5)
Height (cm)	174.45 (±6.7)	158.51 (±3.4)	166.48 (±9.6)
Weight (kg)	80.53 (±10.2)	62.78 (±13)	71.66 (±14.6)
Body Fat Percentage (%)	20.17 (±6.7)	28.36 (±8.7)	24.26 (±8.7)
VO_{2MAX} (ml/kg/min)	47.66 (±8.7)	37.36 (±4.3)	42.51 (±8.6)

Values are reported as means (SD).

Hemodynamic Responses

Figure 1 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on systolic blood pressure (SBP) in males and females. Except for condition main effect, categories (males vs. females) were statistically similar ($p > .05$) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*gender ($p < .05$) and condition*time ($p < .01$) interaction and condition ($p < .02$) and time ($p < .01$) main effects. In condition main effects, significantly higher SBP was found at 10 ($p < .01$), 20 ($p < .01$), and 40 ($p < .01$) minutes following the 20min and 20min_BFR sessions when compared to the 60min session and the 60min session was significantly lower than 20min and 20min_BFR at 40 minute time point. In condition main effects, SBP was significantly higher following 20min_BFR than 60min ($p < .03$). In time main effects, SBP was significantly higher at the 20 ($p < .01$) and 40 ($p < .01$) minutes following 20min and 20min_BFR when compared to the 60min session.

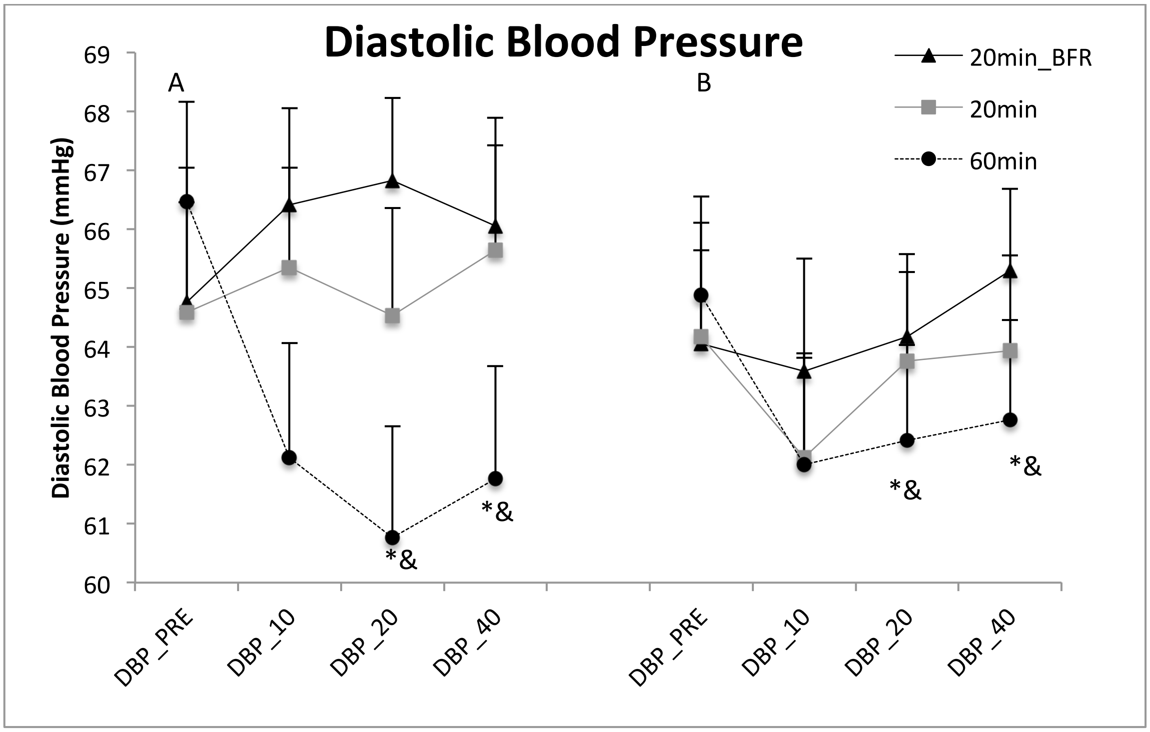
Figure 1. Systolic Blood Pressure



A= Males (N=17), B= Females (N=17)
*@ Significant condition difference between the 60min and both BFR sessions (p<.02).; *& Significant condition difference between 60min and 20min_BFR (p<.02). *T Significant time difference (*p*<.01). Values reported as mean ±SE.

Figure 2 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on diastolic blood pressure (DBP) in males and females. Except for condition main effect, categories were statistically similar (*p*>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time (p<.01) interaction and condition (p<.03) main effects. In condition main effects, significantly higher DBP was found at 20 (p<.01) and 40 (p<.01) minutes following the 20min_BFR session when compared to the 60min session.

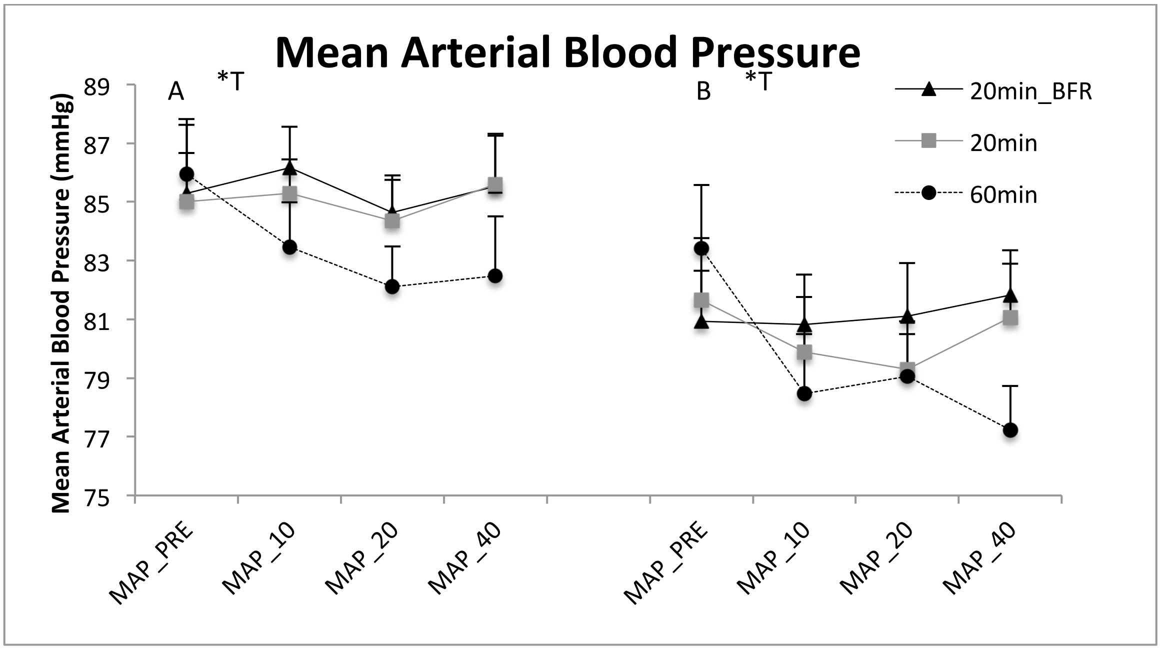
Figure 2. Diastolic Blood Pressure



A= Males (N=17), B= Females (N=17)
*& Significant condition difference between 60min and 20min_BFR (p<.03). Values reported as mean ±SE.

Figure 3 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on mean arterial pressure (MAP) in males and females. Except for condition main effect, categories were statistically similar ($p>.05$) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time ($p<.01$) interaction and time ($p<.04$) main effects. A follow-up on time main effects found no significance in MAP.

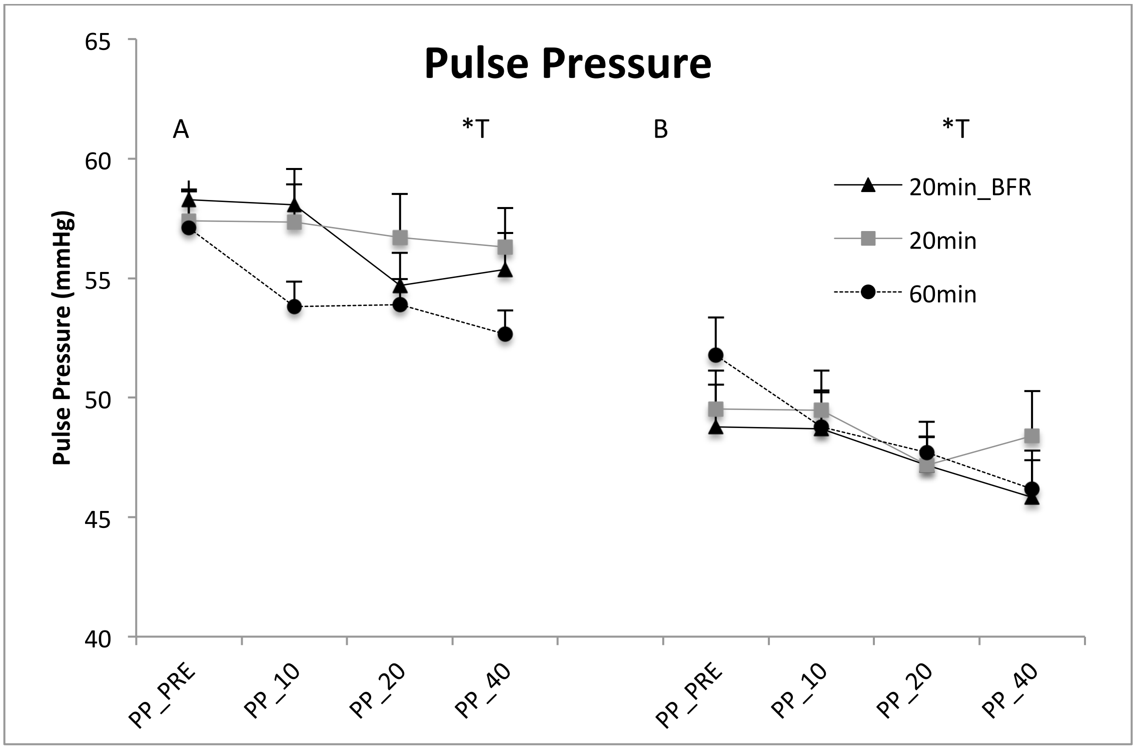
Figure 3. Mean Arterial Pressure



A= Males (N=17), B= Females (N=17)
*T Significant time difference (p<.04). Values reported as mean ±SE.

Figure 4 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on pulse pressure (PP) in males and females. Except for condition main effect, categories were statistically similar (p>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant time (p<.01) main effects. In time main effects, PP pre values were significantly higher than 20 and 40 minute time points (p≤.01) and the 40 minutes was significantly lower than pre and 10 time points (p<.05).

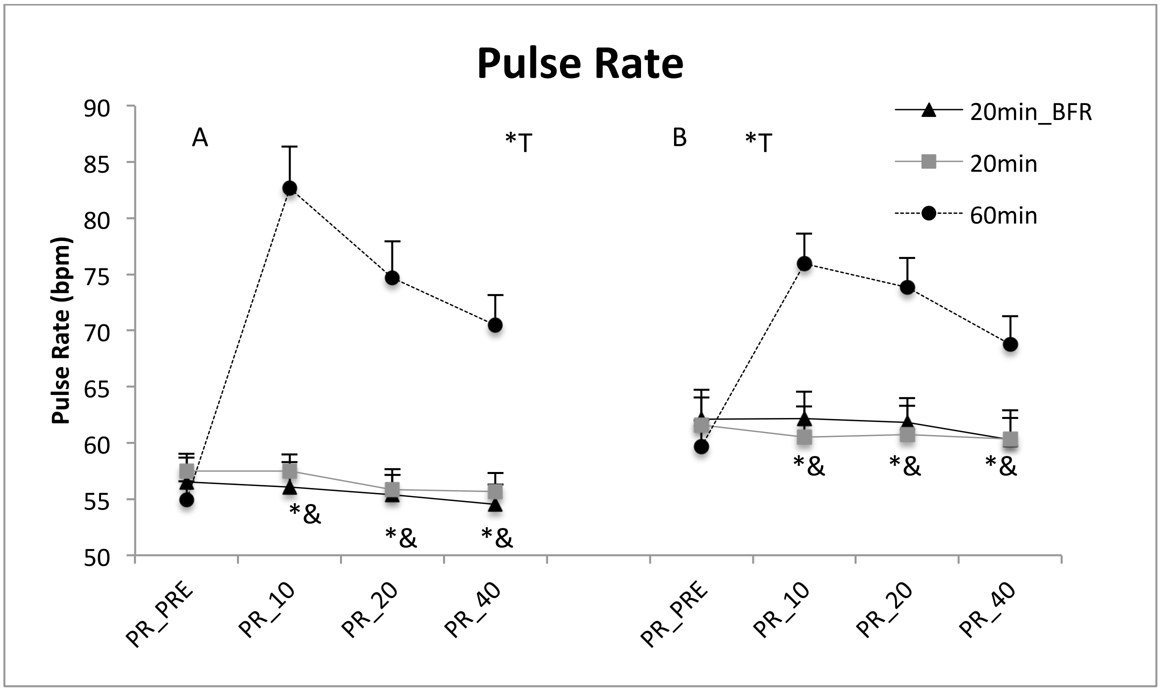
Figure 4. Pulse Pressure



A= Males (N=17), B= Females (N=17)
*T Significant time difference ($p<.01$). Values reported as mean ±SE.

Figure 5 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on pulse rate (PR) in males and females. Except for condition main effect, categories were statistically similar ($p>.05$) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*gender (p<.03), condition*time (p<.01), and time*gender (p<.05) interactions; and condition (p<.01) and time (p<.01) main effects. In time main effects, all time points were significant of each other in PR (p<.01). For condition, paired *t*-test analysis showed PR significance originated in the 60min, which was higher than 20min and 20min_BFR at 10 (p<.01), 20 (p<.01), and 40 (p<.01) minutes.

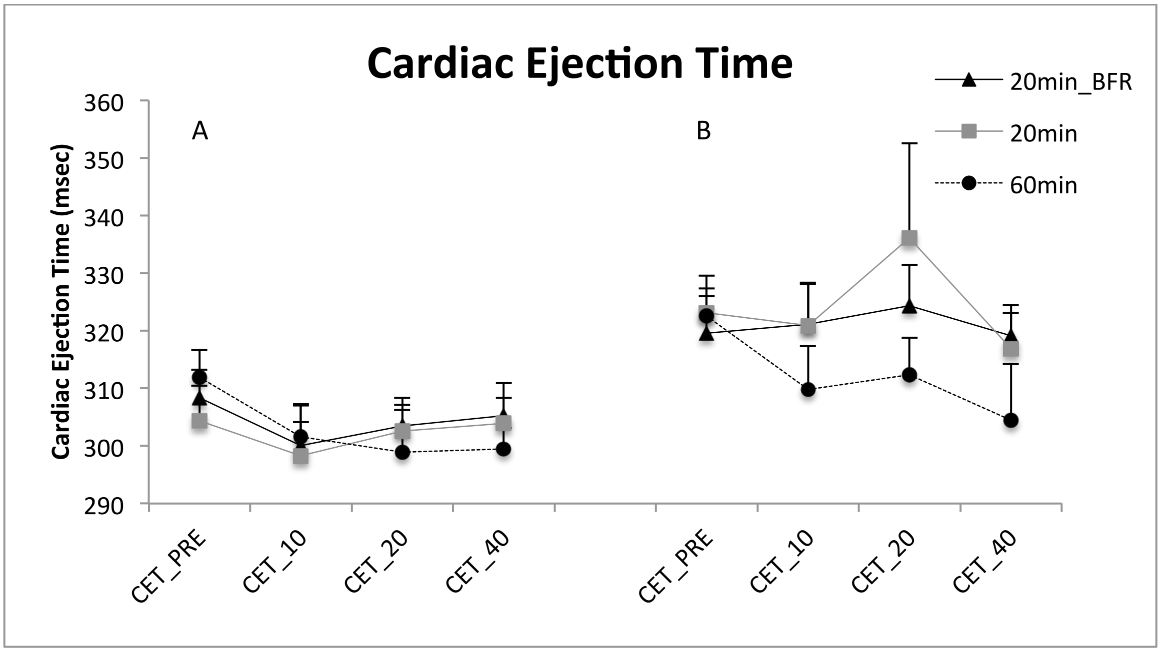
Figure 5. Pulse Rate



A= Males (N=17), B= Females (N=17)
*& Significant condition difference between 60min and 20min_BFR ($p<.01$). *T Significant time difference ($p<.01$). Values reported as mean ±SE.

Figure 6 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on cardiac ejection time (CET) in males and females. Except for condition main effect, categories were statistically similar ($p>.05$) for all effects and interactions and were reported together. There was no significant condition or time effect found in CET.

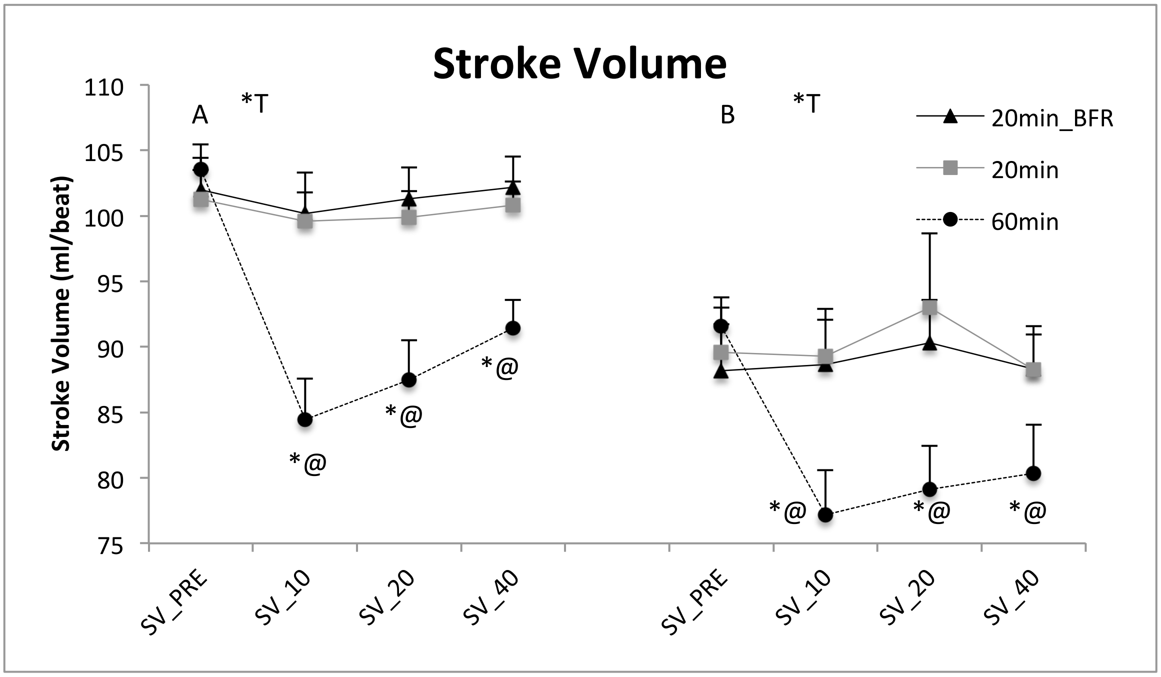
Figure 6. Cardiac Ejection Time



A= Males (N=17), B= Females (N=17)
Values reported as mean ±SE.

Figure 7 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on stroke volume (SV) in males and females. Except for condition main effect, categories were statistically similar (p>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time (p<.01) interaction and condition (p<.01) and time (p<.01) main effects. In condition main effects, significantly lower SV was found following the 60min session than the 20min and 20min_BFR sessions (p<.01). In time main effects, SV pre values were significantly different from the other time points (p≤.01), 10 min was significant different from pre and 10 minute time points (p<.03), and 40 min was significantly different from pre and 10 minute time points (p<.03). For condition, paired *t*-test analysis showed SV significance originated in the 60min, which was lower than 20min and 20min_BFR at 10 (p<.01), 20 (p<.01), and 40 (p<.01) minutes.

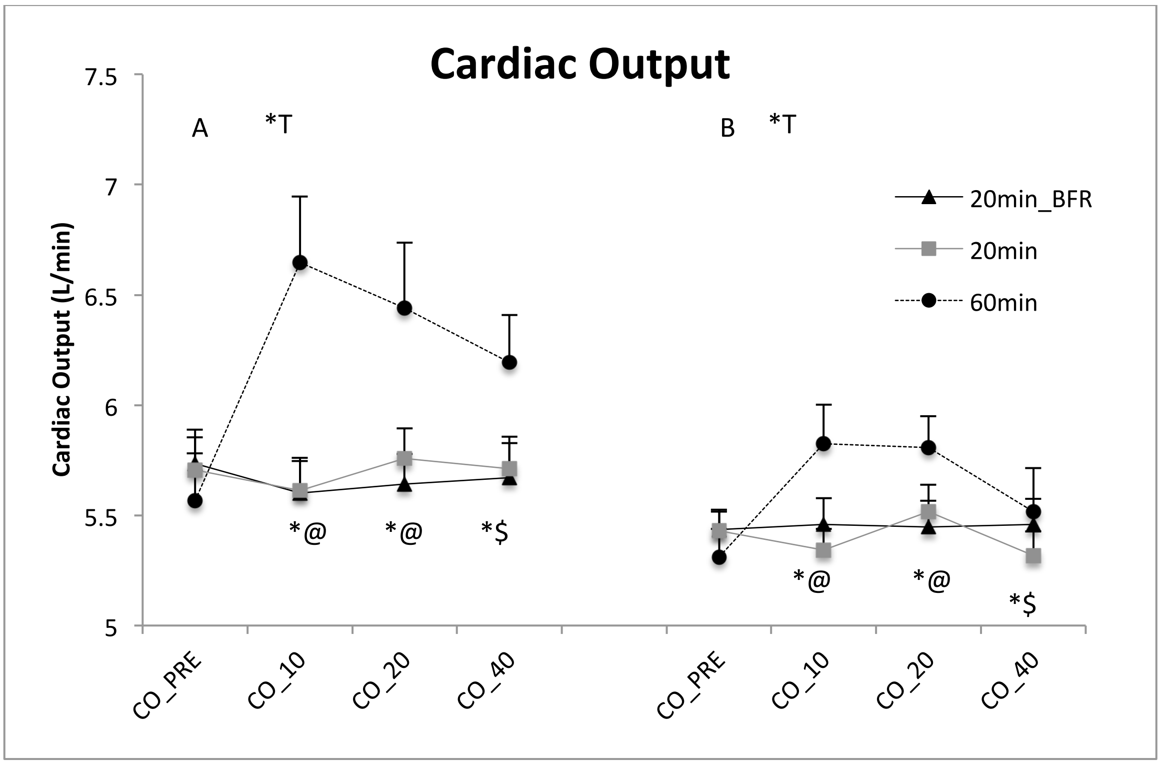
Figure 7. Stroke Volume



A= Males (N=17), B= Females (N=17)
*@ Significant condition difference between the 60min and both BFR sessions (p<.01). *T Significant time difference (*p*<.01). Values reported as mean ±SE.

Figure 8 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on cardiac output (CO) in males and females. Except for condition main effect, categories were statistically similar (*p*>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time (p<.01) interaction and condition (p=.01) and time (p<.01) main effects. In condition main effects, significantly lower cardiac output was found following the 20min than 60min session (p<.02). In time main effects, CO pre values were lower than the 10 and 20 minute time points (p<.01), 10 min is significantly different than pre and 40 minute time points (p<.02), 20 min is significantly different than pre and 40 minute time points (p<.01), and 40 min is significantly different than 10 and 20 minute time points (p<.02). For condition, paired *t*-test analysis showed CO significance originated in the 60min, which was higher than 20min and 20min_BFR at 10 (p<.01) and 20 (p<.01) minutes and higher than 20min at 40 min (p<.01).

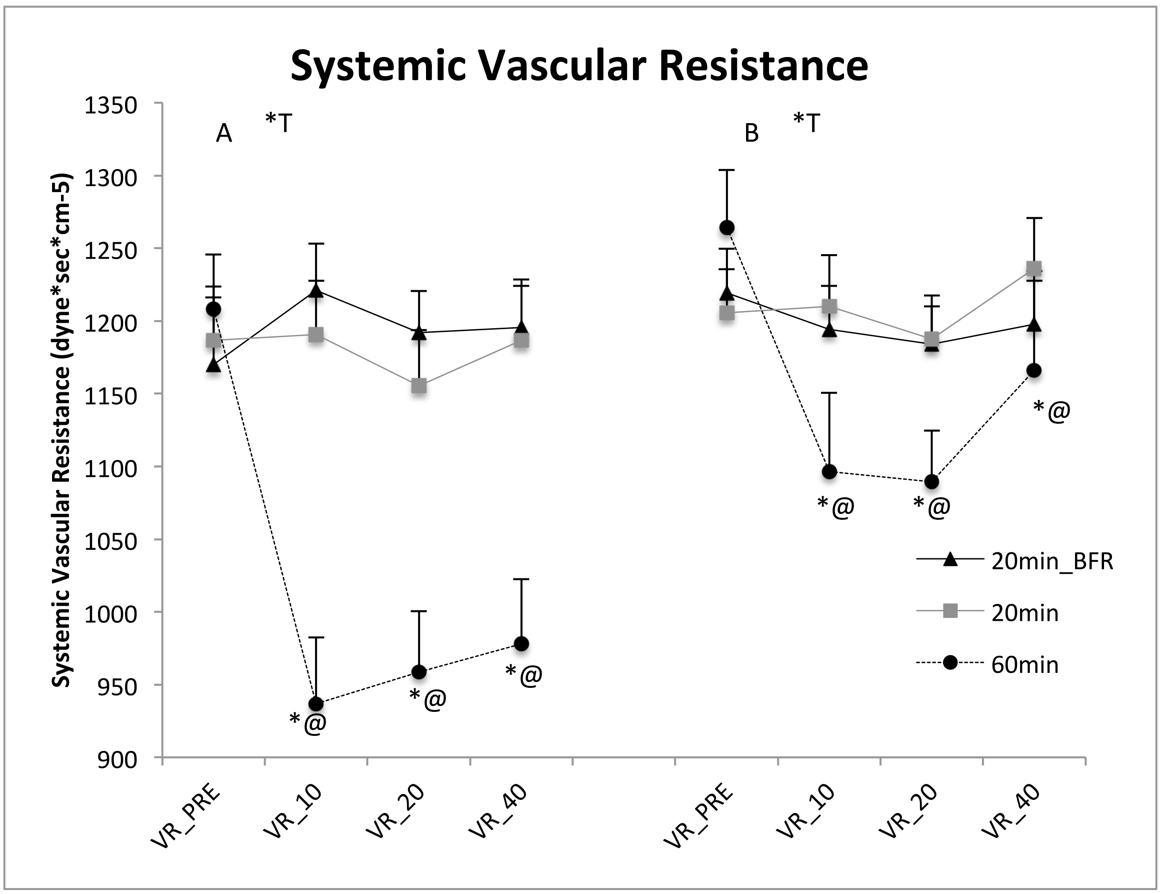
Figure 8. Cardiac Output



A= Males (N=17), B= Females (N=17)
*@ Significant condition difference between the 60min and both BFR sessions (p<.01).; *$ Significant condition difference between 60min and 20min (p<.01). *T Significant time difference (*p*<.01). Values reported as mean ±SE.

Figure 9 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on systemic vascular resistance (SVR) in males and females. Except for condition main effect, categories were statistically similar (*p*>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*gender (p<.01) and condition*time (p<.01) interactions and condition (p<.01) and time (p<.01) main effects. In condition main effects, SVR at 60min was significantly lower than 20min and 20min_BFR sessions (p<.01). In time main effects, SVR pre values were significantly different than 20 and 40 minute time points (p<.05). For condition, paired *t*-test analysis showed SVR significance originated in the 60min, which is lower than 20min and 20min_BFR at 10 (p<.01), 20 (p<.01), and 40 (p<.02) minutes.

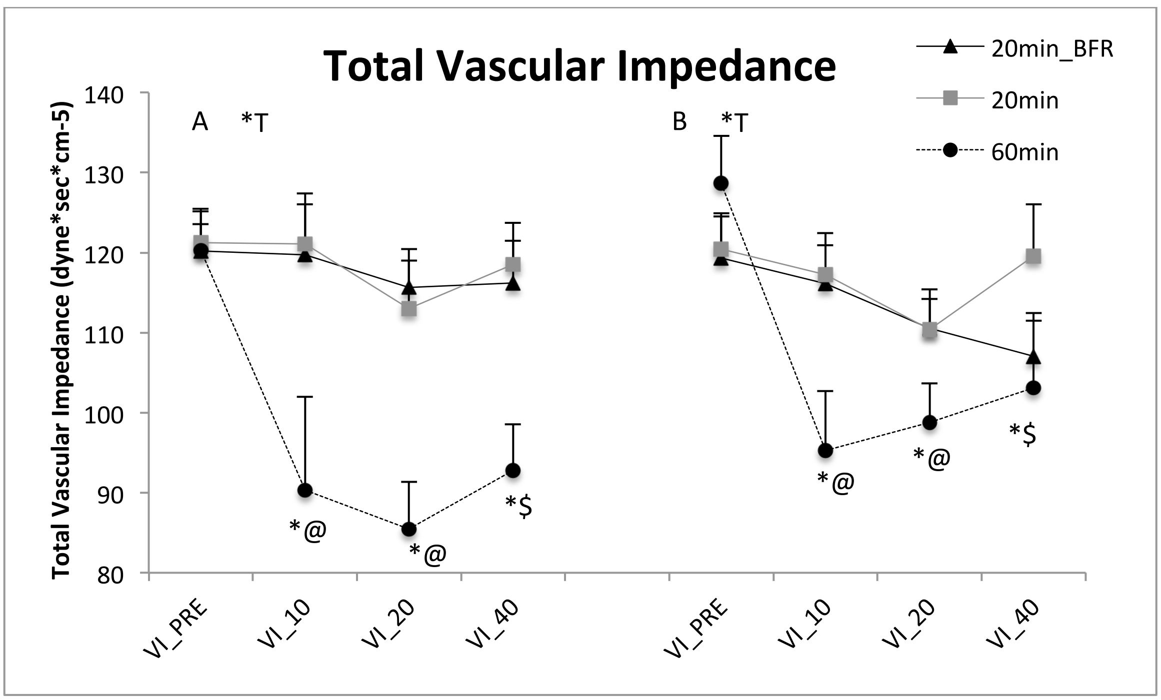
Figure 9. Systemic Vascular Resistance



A= Males (N=17), B= Females (N=17)
*@ Significant condition difference between the 60min and both BFR sessions (p<.01). *T Significant time difference (*p*<.01). Values reported as mean ±SE.

Figure 10 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on total vascular impedance (TVI) in males and females. Except for condition main effect, categories were statistically similar ($p>.05$) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time ($p<.01$) interaction and condition ($p<.01$) and time ($p<.01$) main effects. In condition main effects, TVI in 60min is lower than 20min and 20min_BFR ($p<.01$). In time main effects, TVI pre values were significantly different from all other time points ($p<.02$). For condition, paired *t*-test analysis showed TVI significance originated in the 60min, which was lower than 20min and 20min BFR at 10 ($p<.01$) and 20 ($p<.01$) minutes and 20min at 40 ($p<.01$) minutes.

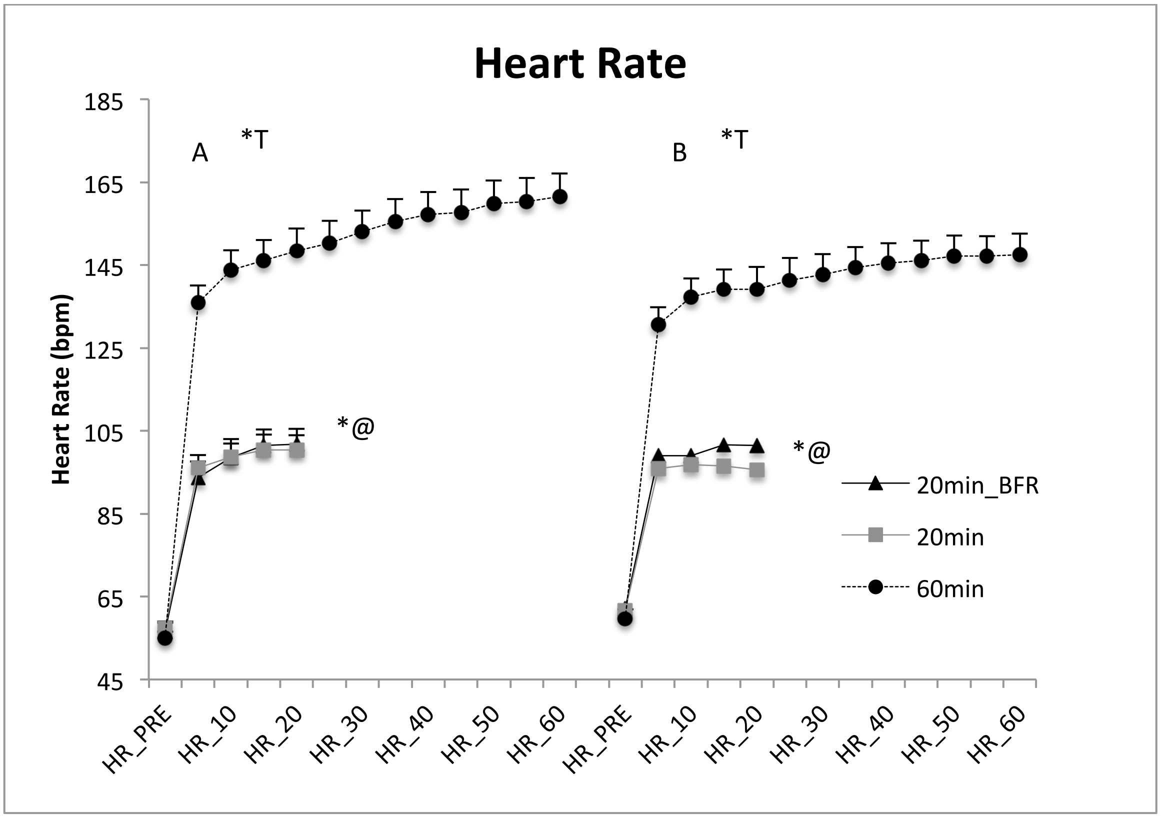
Figure 10. Total Vascular Impedance



A= Males (N=17), B= Females (N=17)
*@ Significant condition difference between the 60min and both BFR sessions ($p<.01$).; *$ Significant condition difference between 60min and 20min ($p<.01$). *T Significant time difference ($p<.01$). Values reported as mean ±SE.

Figure 11 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on heart rate (HR) in males and females. Except for condition main effect, categories were statistically similar ($p > .05$) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time (P<.01) interaction and condition (P<.01) and time (p<.01) main effects. In condition main effects, HR in 60min was significantly higher than 20min and 20min_BFR sessions (p<.01). In time main effects, HR in pre, 5, and10 minutes are significantly different than all other time points (p<.01); 10, 15, and 20 minutes are significantly different from pre and 5 minutes (p<.01). For condition, paired *t*-test analysis showed HR significance originated in the 60min, which was higher than 20min and 20min_BFR at 5 (p<.01), 10 (p<.01), 15 (p<.01), and 20 (p<.01) minutes.

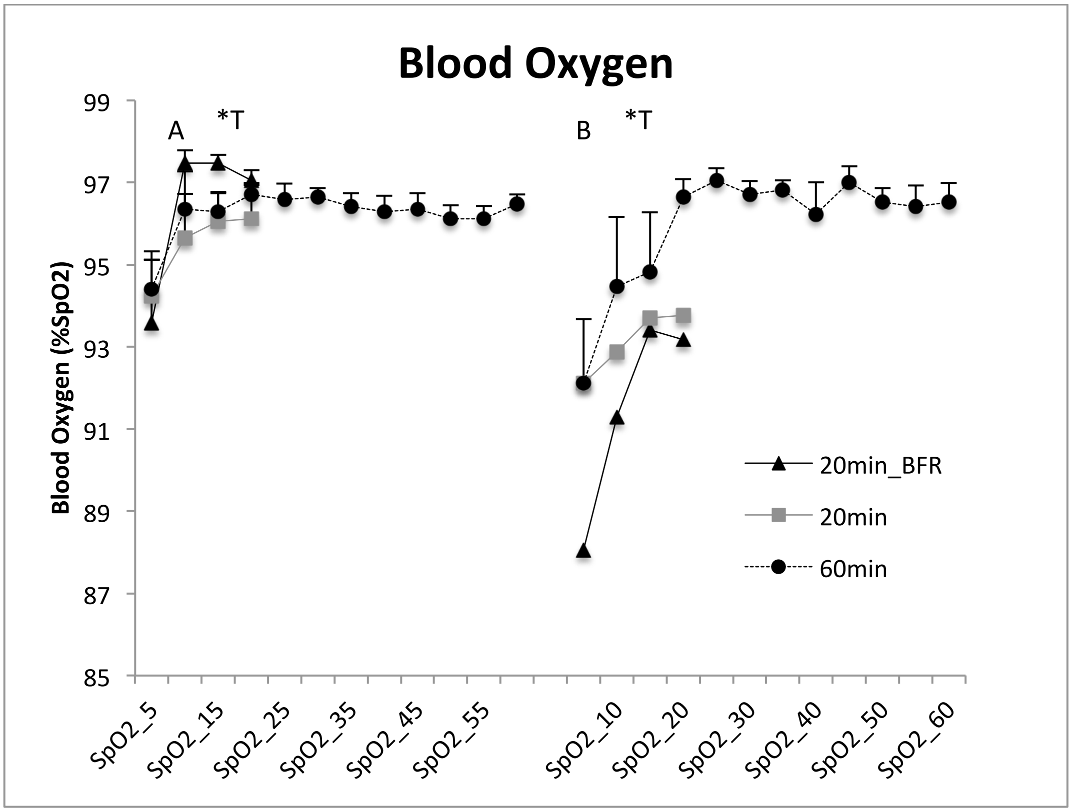
Figure 11. Heart Rate



A= Males (N=17), B= Females (N=17)
*@ Significant condition difference between the 60min and both BFR sessions (p<.02). *T Significant time difference (*p*<.01). Values reported as mean ±SE.

Figure 12 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on blood oxygen (SpO2) in males and females. Except for condition main effect, categories were statistically similar (*p*>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*gender (p<.056) interaction trend and time (p<.01) main effects.

Figure 12. Blood Oxygen

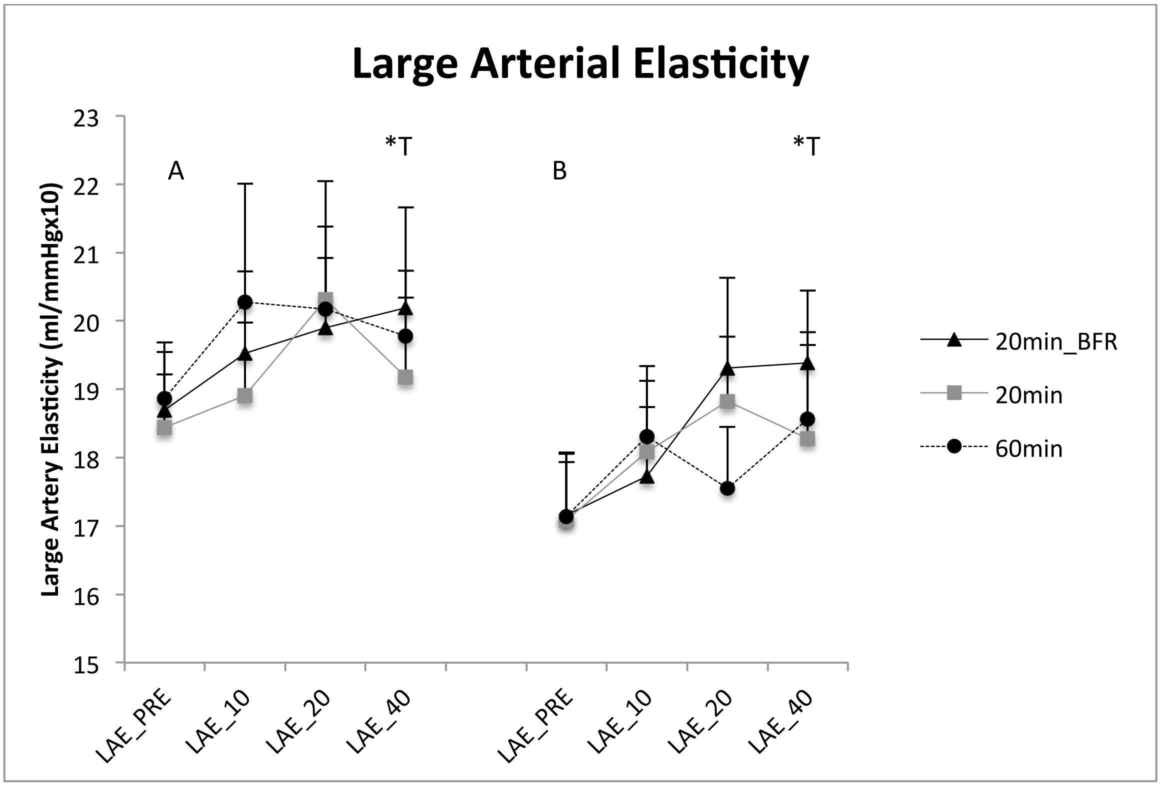


A= Males (N=17), B= Females (N=17)
*T Significant time difference (p<.05). Values reported as mean ±SE.

Arterial Compliance

Figure 13 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on large arterial elasticity (LAE) in males and females. Except for condition main effect, categories were statistically similar (p>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant time (p<.03) main effects.

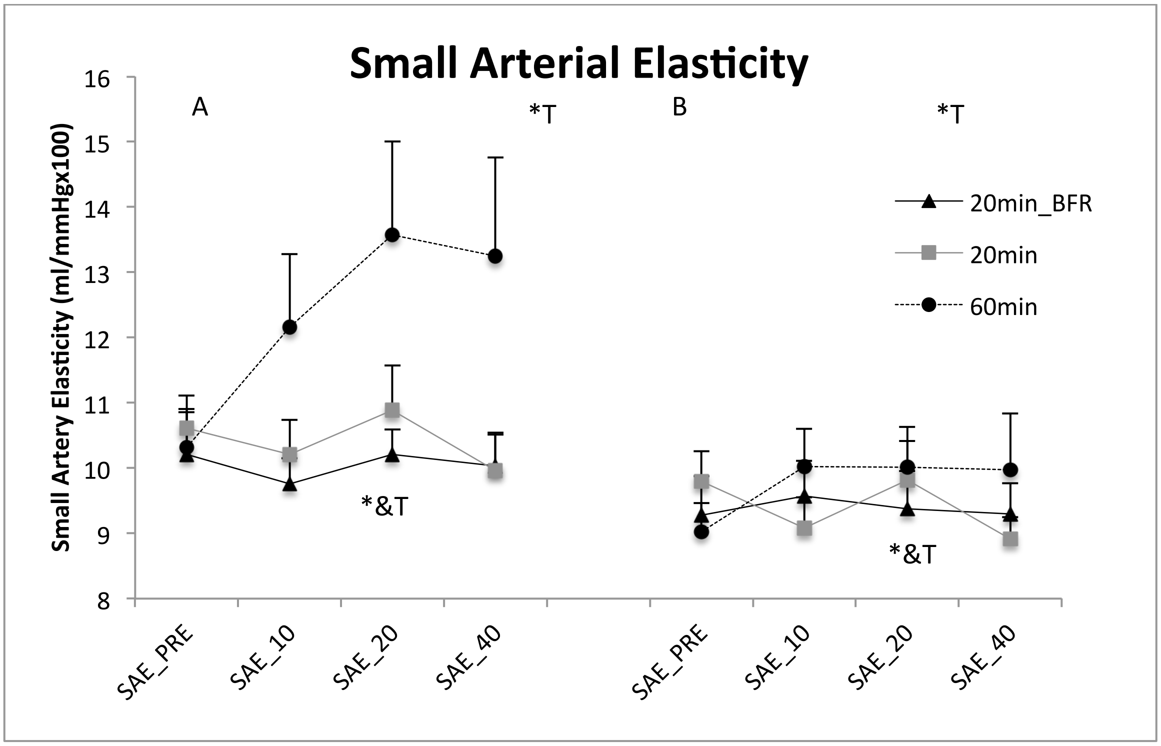
Figure 13. Large Arterial Elasticity



A= Males (N=17), B= Females (N=17)
*T Significant time difference (*p*<.03). Values reported as mean ±SE.

Figure 14 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on small arterial elasticity (SAE) in males and females. Except for condition main effect, categories were statistically similar (*p*>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*time (p<.04) interaction and condition (p<.02) main effects. In condition main effects, SAE was significantly higher small arterial elasticity was found following the 60min than the 20min_BFR session (p<.03). For condition, paired *t*-test analysis showed a SAE trend at 20 minutes, in which 60min was higher than 20min_BFR (p=.06).

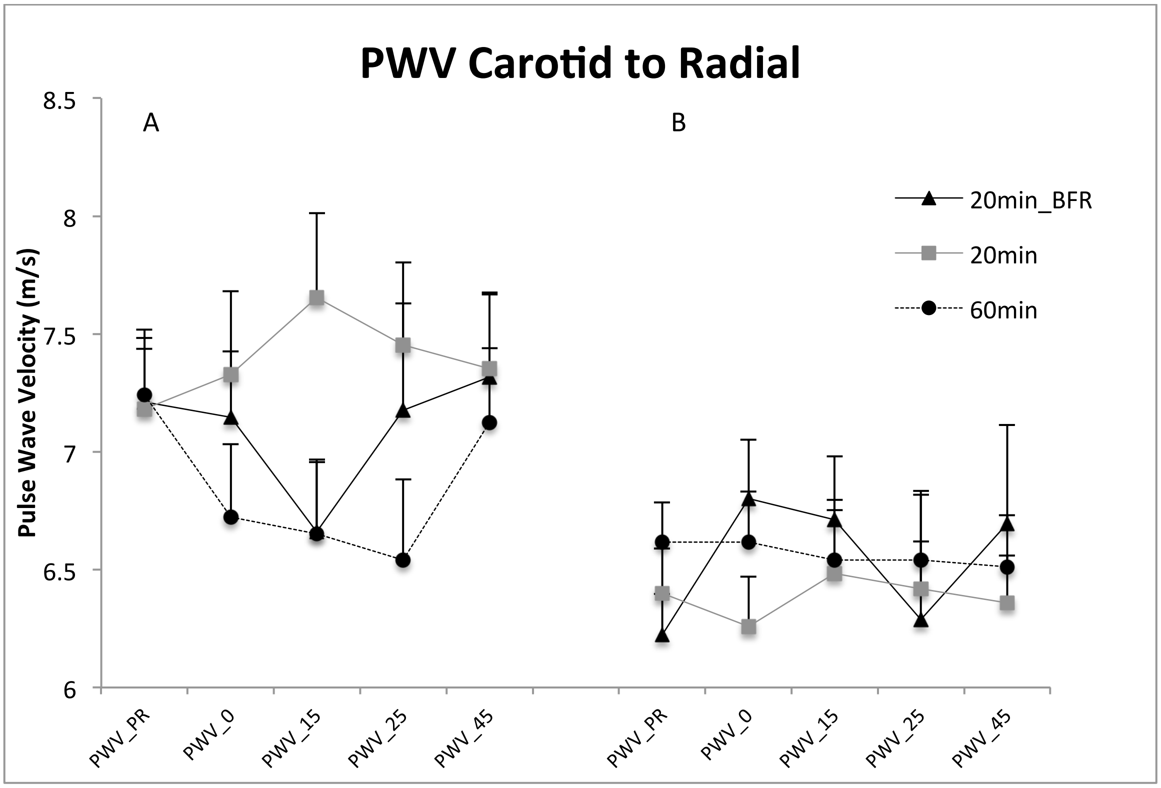
Figure 14. Small Arterial Elasticity



A= Males (N=17), B= Females (N=17)
*&T Condition trend between 60min and 20min_BFR (p=.06). *T Significant time difference (p<.01). Values reported as mean ±SE.

Figure 15 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on pulse wave velocity from the carotid to radial artery (upPWV) in males and females. Except for condition main effect, categories were statistically similar (p>.05) for all effects and interactions and were reported together. Repeated measures ANOVA found significant condition*gender (P<.03) interaction.

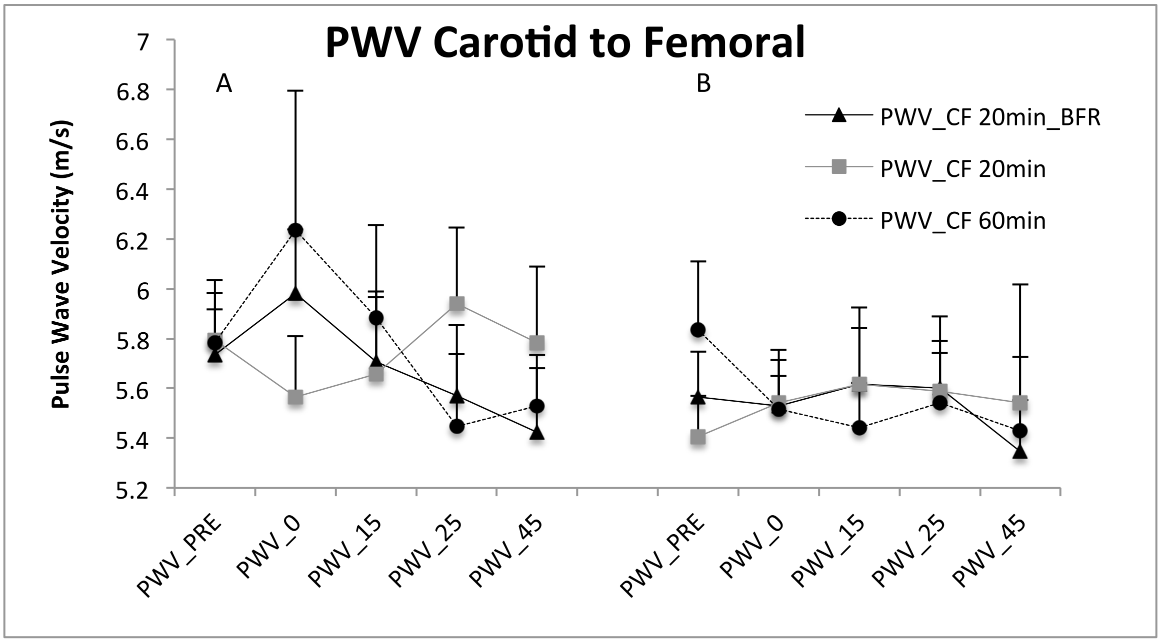
Figure 15. PWV Carotid to Radial



A= Males (N=17), B= Females (N=17)
Values reported as mean ±SE.

Figure 16 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on pulse wave velocity from the carotid to femoral artery (cPWV) in males and females. Except for condition main effect, categories were statistically similar (p>.05) for all effects and interactions and were reported together. There was no significant condition effect found in cPWV.

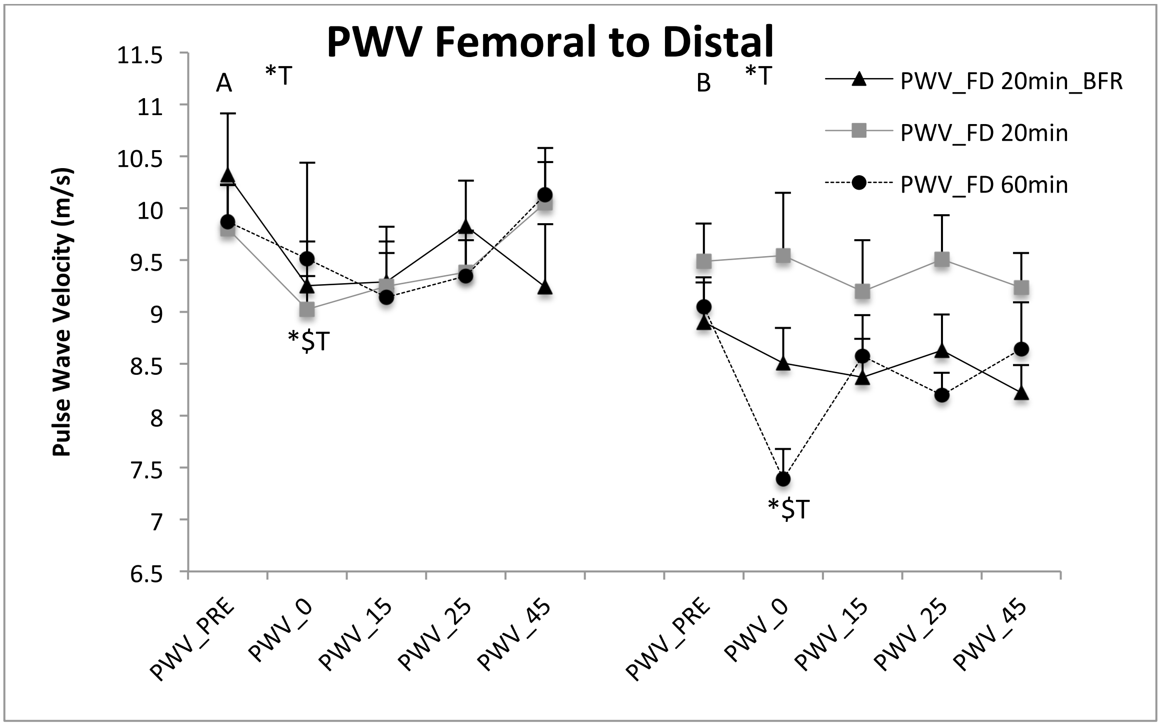
Figure 16. PWV Carotid to Femoral



A= Males (N=17), B= Females (N=17)
Values reported as mean ±SE.

Figure 17 shows the effects of short duration aerobic exercise with BFR cuffs with and without inflation and long duration aerobic exercise (60-minute) without BFR on pulse wave velocity from the femoral to posterior tibial artery (lpPWV) in males and females. Except for condition main effect, categories were statistically similar (p>.05) for all effects and interactions and were reported together. Repeated measures ANOVA showed significant condition*gender interaction (p<.02), a trend was almost found significant for condition main effects (p=.06), and time (p<.01) main effects. In condition main effects, showed a trend with the BFR session higher than the 60min session (p<.06) in lpPWV. For time main effects, lpPWV pre values were significantly higher from 0 and 15 (p<.03) minutes.

Figure 17. Femoral to Distal



A= Males (N=17), B= Females (N=17)
*$ Condition trend between 60min and 20min (p=.06). *T Significant time difference (*p*<.01).
Values reported as mean ±SE.

CHAPTER V

DISCUSSION

The primary findings of the present study are as follows. First, blood pressure, heart rate, and stroke volume were significantly different in the 60-minute session when compared to the 20-minute sessions with and without BFR. This was primarily due to a sustained effect of the autonomic system caused by the length of the exercise session, 60 minutes. Second, systemic vascular resistance and total vascular impedance were significantly lower in the 60-minute session as compared to the 20-minute sessions with and without BFR; this may have been caused by the release of nitric oxide. Third is the trend found in small arterial elasticity and lower peripheral pulse wave velocity in the 60 minutes when compared to the 20-minute sessions with and without BFR. The trend could have been caused by the insufficient release of NO or stimulus of vascular tone.

Hemodynamic Responses

A decrease in all post systolic and diastolic blood pressure (BP) time points, in the 60-minute session in comparison to the two 20 minute sessions with and without BFR, were found. In a recent study on a young and healthy population, BFR was found to increase BP in an aerobic study when compared to the control and speculated that it was caused by the sustained elevations in systemic vascular resistance (SVR) that was caused by the cuffs (Renzi et al., 2010). Similarly, Sakamaki et al. (2008) stated that the elevation in BP was higher when walking with BFR when compared to the control session due to the occlusive pressure the cuffs applied on the working limbs in elderly participants. Evidence that BFR is the cause for increases in BP is supported by increases in mean arterial pressure (MAP), stroke volume (SV), stroke volume index, SVR, and total vascular impedance (TVI). When using BFR in a resistance setting, increases in BP were found using the pneumatic cuffs and speculated to be caused by the BFR induced decrease in SV and increased HR in males (Kumagai et al., 2012). Similarly, Sugawara also found an increase in BP, while using BFR, and speculated it to be caused by the hypertensive response in the aorta in sedentary or recreationally active adults (Sugawara, Tomoto, & Tanaka, 2015). An increase in BP was speculated to be caused by greater cardiac work in healthy participants (Brandner, Kidgell, & Warmington, 2015; Sugawara, 2010) and a hypertensive population (Araújo et al., 2014; Pinto & Polito, 2015) while using BFR. In opposition, other studies found a decrease in BP, with the use of BFR, and speculated it to be caused by the nitric oxide (NO) release in an elderly population (Moriggi et al., 2015) and a decreased arterial compliance and maximal venous outflow in a young and healthy population (Loenneke et al., 2013). In the present study, no significance was found between the two 20-minute sessions with and without BFR. In the current literature, BP has been found to increase or decrease with the use of BFR, while no study has found similar findings in BP as seen in the present study. In the present study, the large drop in BP and SVR in the 60-minute session could be due to a decrease in the autonomic nervous system in aerobic endurance exercise as seen in a study conducted by Rowell (1974). It can be speculated that the 20-minute sessions with and without BFR, did not elicit an appropriate response to the autonomic nervous system to acquire the same BP response of the 60-minute session.

MAP is the product of cardiac output (CO) and SVR plus central venous pressure (CVP) [MAP= (CO x SVR) + CVP] (Pettersson, Ricksten, Towle, Hedner, & Hedner, 1988). CVP is the direct measurement of BP in the vena cava and right atrium. The present study did not measure CVP, but is though to have decreased similarly to a study conducted by Mortensen et al. (2013) in an aerobic training study. In a study by Renzi (2010), MAP was higher than that of the control in an aerobic setting due to the sustained elevations in SVR and increases in CO similarity between the sessions. In a resistance training protocol, BFR usage decreased MAP due to decreases in BP in a young population (Maior, Simao, Martins, de Salles, & Willardson, 2015; Neto et al., 2015). In the current study, MAP was not significant, which can be due to having a high CO and low SVR in the 60-minute session and the opposite in the 20-minute sessions with and without BFR.

Heart rate (HR) is known to increase in correlation to exercise intensity and duration. In exercise, changes in autonomic activity causes an increase in sympathetic activity, which increases HR, and a decrease in parasympathetic activity (Smith, Guyton, Manning, & White, 1976; Victor, Seals, & Mark, 1987). The present study found that the 60-minute session at 65% VO2 was significantly higher HR values than the 20-minute sessions with and without BFR at 40% VO2 during exercise and post values. A recent study investigated the effect BFR had on an aerobic setting and found that the BFR session increased HR significantly when compared to the control (Abe et al., 2010). The study used the same walking speed in both the control and the BFR sessions, which can be speculated that the use of BFR caused the body to perceive the exercise as a higher intensity and thus induced a higher HR response. In a resistance training protocol, an increased HR was speculated to be caused by the increased intensity between the sessions in a hypertensive population while using BFR cuffs (Araújo et al., 2014). When using a young population, an increased HR was found when using BFR and was thought to be caused by the reduction of SV (Kumagai et al., 2012), an induced a hypertensive response in the aorta in a young population (Sugawara, 2010), and/or greater exertion in response to low blood oxygen (SpO2) in young men (G. R. Neto et al., 2016). HR while using the 20-minute sessions with and without BFR had similar responses that parallel a recent BFR walking study that speculated that HR was not related to the decrement in the walking economy stimulated by the use of BFR (Mendonca, Vaz, Pezarat-Correia, & Fernhall, 2015). In the case of the present study, it is possible that the use of BFR at 40% VO2 was lower in intensity than the hour session at 65% VO2 and thus elicited a lower sympathetic response and thus lower response in HR.

SV dropped significantly post exercise in the 60-minute session when compared to the 20-minute sessions with and without BFR. The increased HR leads to the decline of SV (Johnson, 1987) by decreasing the ventricular filling time (Bevegard, Jonsson, Karlof, Lagergren, & Sowton, 1967; Ross, Linhart, & Brauwald, 1965). Across literature, BFR sessions have had lower SVs and higher HRs, in a relatively young population, than the control sessions (Renzi et al., 2010; Sugawara, 2010), which can be caused by the use of the same exercise intensity between the sessions. The current study had no significant SV difference between the 20-minute sessions with or without BFR, which has not been found in BFR literature. A prolonged bout of exercise at or above 30-minutes causes a significant reduction in SV (Ekelund, 1967; Ekelung & Holmgren, 1964) as seen in the 60-minute session used in the present study. In the present study, reductions in SV were seen in post exercise cardiac ejection time (CET), although there were no significant findings between the sessions for this measurement.

CO is the product of SV and HR, which fluctuates in the increase or decrease of either function (van Lieshout, Pott, Madsen, van Goudoever, & Secher, 2001). CO is significantly higher in the 60-minute session, when compared to the 20-minute sessions with and without BFR, greatly due to the increase in HR. With the use of BFR, in resistance training exercise, a higher CO response was found with the BFR session due to an increased HR and SV when compared to the control (Brandner et al., 2015; Pinto & Polito, 2015). A study conducted by Renzi et al. (2010), found no significance in CO, which were similarly found in the present study when compared with the 20-minute sessions with and without BFR, although the reason it occurred in Renzi's study was because SV decreased and HR increased in the BFR session and the opposite occurred in the control. The present study had no significant differences between HR and SV, and thus a similar CO was found between the20-minute sessions with and without BFR.

The 60-minute condition elicited a decrease in SVR. It is assumed that post exercise hypotension is due to a drop in SVR, which is not offset by an increase in CO (Brown, Li, Chitwood, Anderson, & Boatwright, 1993; Cleroux, Kouame, Nadeau, Coulombe, & Lacourciere, 1992; Coats et al., 1989), which occurred during the 60-minute session. In a study by Cooper, SVR was maintained by the local production of NO, a vasodilator, for further reductions in local resistance (Cooper et al., 1996). Renzi et al. (2010) found a decrease in SVR during the BFR session when compared to the control, to which they stated that it was caused by the augmentation of the left ventricle from the use of BFR cuffs. The present study showed no significance between the 20-minute sessions with and without BFR in SVR and there is currently no literature that has similar results between the BFR and control sessions. It can be speculated that the 60-minute session triggered a larger release of NO than the 20-minute sessions with and without BFR and that the 20-minute sessions released similar concentrations of the vasodilator.

TVI is related to systolic BP and associated with changes in SVR (Corrick, Hunter, Fisher, & Glasser, 2013). TVI is defined as the ratio of the components of the local waveform of blood pressure and blood volume (Brands, Hoeks, Rutten, & Reneman, 1996). In the 60-minute session, BP, SVR, and TVI were lower than the 20-minute sessions with and without BFR and the 20-minute sessions had no significant changes between time points. TVI and NO have an inverse effect on each other (Lakatta, 2003); in the case of this study, it can be speculated that there was a large release of NO in the 60-minute session that lead to the drop in TVI.

BFR induces muscle ischemia, an inadequate blood supply to a part of the body, which may increase BP and myocardial oxygen demand by decreasing SVR and accumulation of metabolites (Takarada, Nakamura, et al., 2000; Takarada, Takazawa, et al., 2000). This study showed no significant differences in SpO2 between the 20-minute sessions with and without BFR and the 60-minute sessions. A study conducted by Fry et al. (2010) investigated the effects BFR had on a resistance exercise protocol had on oxygen using pulse oximeter on the toe instead of the fingers of the participants. This study found no significance, in SpO2, between BFR and control sessions and speculated that insufficient hypoxic stress occurred. A similar study used BFR while acquiring SpO2 through a similar finger device used in the present study (Gabriel R. Neto et al., 2016). Neto et al. (2016) found that BFR reduced SpO2 due to the decrease in blood mobilization from the lack arterial expansion that was caused by the inadequate release of NO. In the literature, no current study has investigated the effect SpO2 has on an aerobic setting with BFR with the pulse oximeter used in the present study. It can be speculated that the 60-minute session induced a similar SpO2 response as the 20-minute sessions with and without BFR due to the intensity difference.

Arterial Compliance

There is currently no literature that has used the measures taken for arterial compliance that this study used with BFR during aerobic exercise. In the present study, large arterial elasticity (LAE) did not show significance between any of the sessions. An acute study conducted by Nickel et al. (2011) investigated the acute effects of aerobic exercise, at 50% heart rate reserve, on LAE in a population that was older than 60. This study failed to find significance in LAE, which may have needed multiple and consistent exercises to elicit significant changes in arterial compliance. Another study found similar finding in an 8-week aerobic training study with elderly participants with hypertension using a 65% heart rate reserve (Ferrier et al., 2001). No significance was found in LAE and speculated that prolonged exposure to hypertension may cause irreversible stiffening to the arteries. The present study collected data from a relatively young population and found no significance in the acute exercise protocol and the studies conducted by Nickel and Ferrier also found no significance in a training study on an elderly population(Ferrier et al., 2001; Nickel et al., 2011). It can be speculated that significance may be found if using a moderately healthy and young population in a long duration training study.

A trend was found in SAE, in which SAE was higher at the 60-minute when compared to the 20-minute sessions with and without BFR in this study. The regulation of SVR and NO production can further decrease local resistance; SVR established the role NO has on SAE, in which and inhibition of NO narrows arterial arteries (Cooper et al., 1996; Gilani et al., 2000). Nickel et al. (2011) found a significant increase in small arterial elasticity (SAE) post exercise of 30 minutes. In the present study, a significant decrease was found in SVR and a trend in SAE in the 60 minute session when compared to 20-minute sessions with and without BFR. It can be speculated that increased trend in SAE could be related to the decrease in SVR, which elicited a NO release.

All three sessions failed to create a significant effect on central (cPWV) or upper body peripheral (upPWV) pulse wave velocity (PWV), although a trend was found in the lower peripheral PWV (lpPWV) at post 10 minutes to which the 60-minute was lower than 20-minute sessions with and without BFR. In central arteries, arterial stiffening is greater than those in the periphery due to the higher collagen and elastin content and the chronic exposure to augmentation of arterial pressure (Nichols, 1998). The speculation stated by Nichols et al. (1998) coincides with the findings of the present study as well as a study conducted by Munir et al. (2008), which found similar values in baseline and recovery in cPWV after 12 minutes of cycling with increasing workloads. Another similar study found a similar reduction in cPWV after a 30-minute endurance bout and speculated the reduction to be caused by the release of NO in a young and healthy population (Perdomo et al., 2016). A study conducted by Kingwell et al. (1997) found a reduction in upPWV and cPWV following a 30-minute bout of moderate cycling in an elderly population. The study speculated the decrease in cPWV and upPWV could be caused by the elevation in whole body compliance. In the present study, no significance was found in upPWV, which was similar to the response McClean et al. (2011) found after a 60-minute session of aerobic exercise, set at 60% heart rate max while cycling, that may have been caused by lack of multiple post measurements. In opposition, Naka et al. (2003) found a reduced upPWV and lpPWV following a maximal treadmill exercise bout at 10 minutes post exercise, which was speculated to occur due to changes in vascular tone. The significance found, at the post 10-minute time point, in Naka’s study is similar to the trend found on lpPWV in the present study. The lack of cPWV and upPWV changes is most likely related to the lack of change in large arterial elasticity and vasodilation in the exercising muscle beds (Kingwell et al., 1997) while the lpPWV trend could be related to the changes in vascular tone.

Conclusions

The purposes of this study were to 1) investigate the acute effects of a 20-minute walk/run at 40% VO2 with and without blood flow restriction (BFR) cuffs on large and small arterial elasticity and pulse wave velocity (PWV) when compared to a 60-minute walk/ run at 65% VO2 without BFR, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in males and females.

The research questions asked were:

1) Would there be a change in small and large arterial elasticity and PWV following the use of BFR at a 20-minute walk/run at 40% VO2 when compared to a 60-minute walk/ run at 65% VO2?

2) Would there be a change occurring in SpO2, HR, SBP, DBP, MAP, CO, SV, SVR and TVI in males and females following the use of BFR at a 20-minute walk/run at 40% VO2 when compared to a 60-minute walk/ run at 65% VO2?

Research Hypothesis 1

Similar values will be found in the 20-minute run/walk BFR session with inflation to the 60-minute session in SpO2, HR, SBP, DBP, MAP, CO, SV, SVR and TVI.

The results acquired from this study partially support this hypothesis. MAP and SpO2 measurements were not significantly different between the sessions. In contrast, HR, SBP, DBP, MAP, CO, SV, SVR, and TVI had a significant difference between the 60-minute session at 65%VO2 and the two 20-minute session at 40% VO2 with and without BFR.

Research Hypothesis 2

The 20-minute run/walk BFR session will have similar values to the 60-minute session in PWV and arterial elasticity.

The results acquired from this study partially support this hypothesis. There were no significant changes in LAE, cPWV, and upPWV. However, a trend found in SAE might indicate that the changes were too close to be significant between the 60-minute session at 65% VO2 and the 20-minute session at 40% VO2 with BFR. A trend in lpPWV was found between 60-minute session at 65% VO2 and the 20-minute session at 40% VO2 without BFR.

This is the first study to investigate the effects of BFR at a higher walking speed than 2.5 mph and collected values to compare to a higher intensity at a longer aerobic exercise on LAE, SAE, central PWV, and peripheral PWV using both CR-2000 and SphygmoCor instruments. This study concluded that duration might be necessary to acquire increases in arterial compliance. Secondly, this study showed that a 60-minute duration exercise, at 65% VO2, may provoke a greater increase in small arterial elasticity than a 20-minute BFR session at 40% VO2.

This study also concludes that a 60 min session at a moderate aerobic intensity resulted in the greatest decrease in vascular resistance and total vascular impedance indicating that the 60-minute session may have a greater potential to improve arterial compliance compared to a 20-minute BFR session. Future studies should further investigate the acute and chronic effects of different duration and modes of aerobic exercise with different BFR pressures and/or cuffs on arterial compliance.

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APPENDIX A

APPENDIX A

DEFINITIONS

1) PAR-Q: PAR-Q (Physical activity readiness questionnaire) is a screening tool that is designed to determine whether a subject may perform the exercise in a safe and risk free manner.
2) Blood Flow Restriction (BFR): BFR is a technique that restricts venous blood return during exercise. This process involves cuffs placed over the inguinal crease, which are inflated to a specific pressure. The cuffs are 5 centimeters wide and contain an inflatable bladder.
3) Arterial compliance: the measurement of the elastic properties of the arteries, which has an inverse relationship with arterial stiffness.
4) Hemodynamics: Analysis of physical aspects of blood circulation and blood flow.
5) Pulse Wave Velocity: Noninvasive assessment of arterial compliance in which velocity of blood pressure wave forms traveling between two different sites are measured.
6) Hydration: Hydration status was deemed adequate when urine specific gravity measured 1.010 and lower as determined by a clinical urine refractometer.

APPENDIX A

LIST OF ABBREVIATIONS

ANOVA -Analysis of Variance
BFR -Blood Flow Restriction
CET -Cardiac Ejection Time
CO -Cardiac Output
DBP -Diastolic Blood Pressure
HR -Heart Rate
LAE -Large Arterial Elasticity
MAP -Mean Arterial Pressure
PAR-Q -Physical Activity Readiness Questionnaire
PP -Pulse Pressure
PR -Pulse Rate
PWV -Pulse Wave Velocity
SAE -Small Arterial Elasticity
SBP -Systolic Blood Pressure
SV -Stroke Volume
SVI -Stroke Volume Index
SVR -Systemic Vascular Resistance
TVI -Total Vascular Impedance
USG -Urine Specific Gravity

APPENDIX–FORMS

APPENDIX FORMS

1. RECRUITMENT FLYER

The University of Texas Rio Grande Valley
IRB APPROVED
IRB# 2015-237-11
Expires: 12/09/2016

UTRGV **Participants Needed**

MALES AND FEMALES BETWEEN THE AGES OF 18 AND 40 YEARS OLD

You are invited to participate in a research study at the Health and Human Performance Department at the University of Texas at Brownsville. The purpose of the study is to assess the acute effects of moderate intensity aerobic exercise durations, with and without blood flow restriction, on large and small arterial stiffness, hemodynamics, blood oxygen, and vascular resistance. Total time required for completion of the study is 4 visits for a total of about 6 hours.

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APPENDIX FORMS

2. INFORMED CONSENT

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

Project Title: The Acute Effects of Aerobic Exercise with Blood Flow Restriction Cuffs on Arterial Compliance in Recreationally Active Males and Females

Principal Investigator: Maria Margarita Gonzalez
Co-Investigators: Brittany Esparza, Patrick Murphy and Danny Dominguez
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 acute effects on the use of blood flow restriction (BFR) cuffs during aerobic exercise when compared to a longer aerobic session without BFR on large and small arterial elasticity, 2) examine how various aerobic exercise durations, with and without BFR, elicit changes in hemodynamics by measuring blood oxygen level (SpO2), resting heart rate (RHR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR) and total vascular impedance (TVI) in recreationally active male and female subjects.

Number of Participants
40 recreationally active participants (20 male and 20 female) will take part of this study.

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

a. You will be required to visit the research labs in the Department of Health and Human Performance on 4 separate days for a total time commitment of about 6 hours.

b. On the first visit (about 60 minutes), you will fill out the health status questionnaire and be familirized with the study procedures. You will also read and sign an informed consent and PAR-Q before any testing takes place (these forms will also be emailed to participants). 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.

You will then have anthropometric measures taken, that include blood oxygen level (SpO2) (uses red and infrared light to measure how much hemoglobin in blood is carrying oxygen), resting heart rate (RHR), blood pressure (BP), height, weight, body composition, and thigh circumference will be performed. Weight and body fat percentage will be measured using the Tanita Body Composition Analyzer (sends a low frequency signal from one foot to the other to determine the body composition based on the level of conductance). Thigh circumference will be taken at the mid-point of the greater trochanter and lateral epicondyle. Inflation of the BFR cuffs (tightened and filled with air to restrict blood flow) will be based on thigh circumference: <45–50 cm = 120 mmHg; 51–55 cm = 150 mmHg; 56–59 cm = 180 mmHg; and ≥60 cm = 210 mmHg. Once your body anthropometric and body composition measurements have been taken, you will preform the Bruce Protocol on a treadmill. Testing consists of running on a treadmill, with increasing speeds and incline, until exhaustion. You will be fitted with a mask that is attached to the metabolic cart (the mask will be connected to the metabolic cart via breathing tube to measure inspired oxygen and expired carbon dioxide that will be

The University of Texas Rio Grande Valley
IRB APPROVED
IRB# 2015-237-11
Expires: 12/09/2016

IRB APPROVED UTRGV

analyzed and calculated to measure maximum oxygen consumption). Gas exchange and heart rate (via Polar chest strap and watch) will be monitored continuosly by metabolic cart machine while performing VO2 Max testing and endurance exercise on a treadmill. This first session will take about 60 minutes.
c. Participants will be required to show up hydrated (which the subject will provide a urine sample at the beginning of each session that will be measured by a urine refractometer and must clear hydration status at or below 1.010) and at least 8-hour fast during the three separate randomized sessions. The subjects will lie down in the supine position for a minimum of 10 minutes and baseline arterial elasticity and hemodynamics will be measured using HDI (conducts measurements of arterial stiffness via pulse at the right wrist and a cuff to the left arm to measure blood pressure) and measurement of pulse wave velocity using SphygmoCor (which is conducted noninvasively using a pulse wave velocity analyzer in segmental measures at the carotid, femoral, and the dorsalis pedis while wearing three electrodes on the chest to monitor the heart's electrical activity).. Testing sessions will consist of running on a treadmill at a moderate speed (65% or 40% VO_2max). Conditions will be randomized into three sessions, a 60-minute walk/run without BFR cuffs at 65% VO2 intensity, 20-minute walk/run at 40% VO2 intensity with the BFR cuffs inflated, and 20-minute walk/run at 40% VO2 intensity with the BFR cuffs un-inflated. HR and SpO2 will be measured in 5-minute intervals during the length of the 20- or 60-minute session. Upon completion of exercise, participants will lie back down and post exercise arterial compliance and hemodynamics will be assessed at 10 min, 20 min, 30 min, and 40 min. The total time required to complete each of these sessions will be approximately 120 min, 90 min, and 90 min that will be separated with at least 48 hours between each session.

Length of Participation
You will be required to visit the research labs in the Department of Health and Human Performance on 4 separate days for a total time commitment of approximately 6 hours.

Risks
The study has the following risks:
You understand there are minimal risks to heathy individuals when performing any of the requirements for this project. The minimal risk include discomfort using BFR cuff (for the two 20-minute run/walk sessions) and performing the VO2max test (the subject may feel tired right after the test and feel sore a day after the test). However, even though these standard protocols have been approved at numerous other institutions and will be performed by qualified and trained personnel. You should be aware of the following:

Benefits
The benefits to participation are: You can receive information about your anthropometric measures such as height, weight, body fat percentage, resting BP and HR. Also, you will obtain information about your cardiovacular health when performing endurance exercise, and arterial health from Pulse Wave Analysis assessment.

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 and if medical assistance is needed they will be aware that it will need to be provided through their personal health insurance. However, you or your insurance company may be expected to pay the usual charge from this treatment. The University of Texas at Rio Grande Valley has set no funds to compensate you in the event of injury.

Confidentiality
In published reports, there will be no information included that will make it possible to identify you without your permission. Research records will be stored securely for 3 years after completion of the study and only approved researchers will have access to the records.

The University of Texas Rio Grande Valley
IRB APPROVED
IRB# 2015-237-11
Expires: 12/09/2016

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

Costs
There is no cost for participation.

Compensation
You will not be reimbursed for you time and participation in this study.

Rights
Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You can discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

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.

_____ I consent to being quoted directly.

_____ I do not consent to being quoted directly.

Research Team Qualifications
The research team is required to calibrate all the equipment (will be performed regularly according to instructions provided by the manufacturer), know how to properly use the equipment, and have all documentation done to conduct research. The research team will conduct measurements on the subject of the same gender.

Who to Contact for Questions Regarding the Research
If you have 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 to speak to the principal investigator Margarita Gonzalez at (956) 545-3174 or email maria.m.gozalez01@utrgv.edu; the research assistants Brittany Esparza at Brittany.esparza01@utrgv.edu, Patrick Murphy at Patrick.murphy01@utrgv.edu, and Danny Dominguez at danny.dominguez01@utrgv.edu; or the faculty advisor Dr. Murat Karabulut, Ph. D., at (956) 882-7236 or e-mail Murat.Karabulut@utrgv.edu.

Who to Contact Regarding Your Rights as a Participant: 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. I have 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# 2015-237-11
Expires: 12/09/2016

IRB APPROVED UTRGV

APPENDIX FORMS

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

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.

APPENDIX FORMS

4. IRB APPROVAL LETTER

The University of Texas
Rio Grande Valley

The Institutional Review Board for Human Subjects Protection (IRB)
Division of Research, Innovation, and Economic Development

Office of Research Compliance

NOTICE OF APPROVAL

Dear Researcher,

This email is regarding your UTRGV IRB study titled "The Acute Effects of Aerobic Exercise with Blood Flow Restriction Cuffs on Arterial Compliance in Recreationally Active Males and Females" – IRB# 2015-237-11.

The IRB protocol referenced above has been reviewed and APPROVED.

Basis for approval: Full Review

Approval expiration date: December 9, 2016

Recruitment and Informed Consent: You must follow the recruitment and consent procedures that were approved. If your study uses an informed consent form or study information handout, you will receive an IRB-approval stamped PDF of the document(s) for distribution to subjects.

Modifications to the approved protocol: Modifications to the approved protocol (including recruitment methods, study procedures, survey/interview questions, personnel, consent form, or subject population), must be submitted in writing to the IRB at irb@utrgv.edu for review. **Changes must not be implemented until approved by the IRB.**

Approval expiration and renewal: Your study approval expires on the date noted above. Before that date you will need to fill out, sign and submit the continuing review form to irb@utrgv.edu. Failure to return the form will result in your study file being closed on the approval expiration date.

Data retention: All research data and signed informed consent documents should be retained for a minimum of 3 years after completion of the study.

Closure of the Study: Please be sure to inform the IRB (irb@utrgv.edu) when you have completed your study, have graduated, and/or have left the university as an employee. A final report should be submitted for completed studies or studies that will be completed by their respective expiration date.

Approved by: ______________________
Dr. Sharon Schembri on behalf of the Institutional Review Board
Chair, Institutional Review Board

APPENDIX FORMS

5. DATA COLLECTION SHEET

HDI/*PulseWave*™ CR-2000
Research CardioVascular Profile Report

Research Subject ID:

Research Subject Name:

Date:
Time:
Age:
Gender:
Height:
Weight:
BSArea:
Body Mass Index:

Average Blood Pressure Waveform

PARAMETER	RESEARCH SUBJECT VALUE
SYSTOLIC BLOOD PRESSURE	
DIASTOLIC BLOOD PRESSURE	
MEAN ARTERIAL BLOOD PRESSURE	
PULSE PRESSURE	
PULSE RATE (beats/min)	
ESTIMATED CARDIAC EJECTION TIME (msec)	
ESTIMATED STROKE VOLUME (ml/beat)	
ESTIMATED STROKE VOLUME INDEX (ml/beat/m^2)	
ESTIMATED CARDIAC OUTPUT (L/min)	
ESTIMATED CARDIAC INDEX (L/min/m^2)	
LARGE ARTERY ELASTICITY INDEX (ml/mmHg x 10) (Capacitive Arterial Compliance)	
SMALL ARTERY ELASTICITY INDEX (ml/mmHg x 100) (Oscillatory or Reflective Arterial Compliance)	
SYSTEMIC VASCULAR RESISTANCE (dyne•sec•cm^{-5})	
TOTAL VASCULAR IMPEDANCE (dyne•sec•cm^{-5})	

Eagan, MN 55121 +1-651-687-9999 Toll-Free: 1-888-*PulseWave* (785-7392)

Form: 00017-001 (Rev. A / 08.Oct. 99) *"For Research Purposes Only"*

APPENDIX FORMS

6. DATA COLLECTION SHEET 2

Name:_______________________________________

Day _____________________ USG:_______________________________

Speed:___________________ mmHg:_____________________________

Min	HR	SpO2
5		
10		
15		
20		

Carotid:___________________

Radial:____________________

Femoral:__________________

Distal:____________________

	C -> R	C -> F	F -> D
Pre			
0			
15			
25			
45			

Weight:_____________________

Height:_____________________

BF%:_______________________

Day _____________________ USG:_______________________________

Speed:___________________ mmHg:_____________________________

Min	HR	SpO2
5		
10		
15		
20		

Carotid:___________________

Radial:____________________

Femoral:__________________

Distal:____________________

	C -> R	C -> F	F -> D
Pre			
0			
15			
25			
45			

Day ____________________ USG:______________________________
Speed:____________________

Min	HR	SpO2
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		
60		

Carotid:____________________
Radial:____________________
Femoral:____________________
Distal:____________________

	C -> R	C -> F	F -> D
Pre			
0			
15			
25			
45			

APPENDIX FORMS

7. PROFESSOR PERMISSION SCRIPT

The University of Texas Rio Grande Valley
Professor Permission Script

My name is Maria Margarita Gonzalez; I am a graduate student and a staff member 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 Affects of Aerobic Exercise with Blood Flow Restriction Cuffs on Arterial Compliance on Recreationally Active Males and Females.

As part of participation, students will be asked to perform 4 sessions, which will include: the Bruce protocol, run/walk for 20 minutes at a 40% VO2 with blood flow restriction cuffs on two separate sessions (one with and one without inflation), and run/walk for 60 minutes at a 65% VO2. You will be asked to come in hydrated (which will be tested via urine sample), 8-hours fasted, and have pre and post (0, 10, 20, and 40) values on the 3-run/walk sessions. The total time commitment is 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 Brittany Esparza, Patrick Murphy, Danny Dominguez, Murat Karabulut, and/or myself 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 prior to and during students' involvement in my study to reduce any possible feeling of coercion to participate in the study.

Extra credit will be offered through participation of the study I will conducting or by means of writing a report that is relevant to the material in the course if the professors 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 researcher, please feel free to contact me at (956) 545-3174 or maria.m.gonzalez01@utrgv.edu, Brittany Esparza Brittany.esparza01@utrgv.edu, Patrick Murphy at Patrick.murphy01@utrgv.edu, and Danny Dominguez at danny.dominguez01@utrgv.edu; or the faculty advisor 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. Ulku 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) Mr. Guillermo Perez?

APPENDIX FORMS

8. IN-PERSON RECRUITMENT SCRIPT

The University of Texas Rio Grande Valley
Recruitment Script

My name is Maria Margarita Gonzalez; I am a graduate student and a staff member 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 to The Affects of Aerobic Exercise with Blood Flow Restriction Cuffs on Arterial Compliance on Recreationally Active Males and Females.

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

In order to participate you must be between the ages of 18-40, not be hypertensive, and dependent on answers selected on PAR-Q 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 4 sessions, which will include: the Bruce protocol, run/walk for 20 minutes at a 40% VO2 with blood flow restriction cuffs on two separate sessions (one with and one without inflation), and run/walk for 60 minutes at a 65% VO2. You will be asked to come in hydrated (which will be tested via urine sample), 8-hours fasted, and have pre and post (0, 10, 20, and 40) values on the 3 run/walk sessions. The total time commitment is 6 hours. All data will be confidential by being collected by Brittany Esparza, Murat Karabulut, and/or myself and later stored in a locked file cabinet for 3 years.

If you would like to participate in this research study, please e-mail Maria Margarita Gonzalez (maria.m.gonzalez01@utrgv.edu), Brittany Esparza (Brittany.esparza01@utrgv.edu), Patrick Murphy at Patrick.murphy01@utrgv.edu, and Danny Dominguez at danny.dominguez01@utrgv.edu; or the faculty advisor Murat Karabulut (murat.karabulut@utrgv.edu to set up an appointment.

Do you have any questions now? If you have questions later, please contact me by telephone at (956) 545-3174 or by email at maria.m.gonzalez01@utrgv.edu.

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

BIOGRAPHICAL SKETCH

Maria M. Gonzalez, Bachelors degree in Exercise Science May 2014 acquired from the University of Texas at Brownsville, Masters degree in Exercise Science May 2016 acquired from the University of Texas Rio Grande Valley, Certified Strength and Conditioning Specialist (CSCS) June 2014; 311 Rancho Viejo Blvd., Brownsville, Texas 78526