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The Acute Effects of Resistance Exercise with Blood Flow Restriction versus Traditional Resistance Exercise on Arterial Compliance and Energy Expenditure in Recreationally Active Males and Females

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THE ACUTE EFFECTS OF RESISTANCE EXERCISE WITH BLOOD FLOW RESTRICTION VERSUS TRADITIONAL RESISTANCE EXERCISE ON ARTERIAL COMPLIANCE AND ENERGY EXPENDITURE IN RECREATIONALLY ACTIVE MALES AND FEMALES

A Thesis

by

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ABSTRACT

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PURPOSE: The aim of this study was to investigate the acute effects of various intensities of volume matched resistance exercise with blood flow restriction (BFR) and traditional resistance exercise on hemodynamic variables, arterial compliance, oxygen consumption (VO_2), carbon dioxide production (VCO_2), respiratory exchange ratio (RER), and energy expenditure (EE) during exercise and after exercise.

RESULTS: Significant condition main effects ($p<0.05$) were found for RPE, HR, crPWV, fdPWV, LAE, SAE, TVI, RER during and postexercise. BFR25 cause greater increases in RPE and HR. BFR50 caused marked increases in SAE, crPWV, and fdPWV.

CONCLUSION: All BFR and traditional exercise conditions found no significant differences in EE, VCO_2, and VO_2. The lack of differences is likely due to time of protocol. Further protocols should implement greater time of exercise, as BFR had increased hemodynamic responses later in the exercise protocol, and could transpose to greater EE as measured by indirect calorimetry.

KEYWORDS: Blood flow restriction, arterial elasticity, pulse wave velocity, energy expenditure, and resistance exercise.

DEDICATION

The completion of my schooling and especially my master's thesis could not have been done without the love and support of my friends and family. On the top of the list is my role model, my hero, my father, he has led my family by example and continues to amaze me day after day. I thank you for talking with me for hours on end about life and everything. My mother has always been there for me and supported me in any of my pursuits in the best way she could. I could have also not done this without the support of my best friends or, as we call ourselves, Best Friends Forever League, bffl for short. I have spoken with them every day for the past six years, either through group or voice chat and I don't know how I would be sane without them. My siblings and their children have been there for me throughout this period always keeping up and getting together to enjoy the weekends and family celebrations, a great facet to relieve. I would also like to thank my girlfriend who has been there by my side through thick and thin and was never phased the immense amount of time I had to spend at the lab. All these people listed above also fought alongside me through one of the toughest parts of my life, cancer. Each one of them was there on the road to remission skipping work, school, and responsibilities, to support me the whole way. I sometimes had up to six of them with me at a doctor's appointment. Without their massive support, I would have never managed to not give up. Although none of you may ever read this, I thank you and love you and you will forever be in my heart and I thank God for having you in my life.

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CHAPTER I

INTRODUCTION

Cardiovascular disease (CVD) is the current leading cause of death in the United States, with over 600,000 deaths attributed to CVD in 2013 (Statistics, 2015). Globally, CVD was the most common underlying cause of death in the world, accounting for 17.3 million of the 54 million total deaths in 2013, approximately 32% of deaths (Benjamin et al., 2017). CVD can be separated into six different categories: coronary heart disease, stroke, high blood pressure, heart failure, diseases of the arteries, and other. Of these six different categories, coronary heart disease, stroke, high blood pressure, and diseases of the arteries, comprise of about 75% of the deaths related to CVD in 2011 (Mozaffarian, 2015). This is an important figure as these would be described as diseases that are related to vascular health component of CVD.

In an aging adult, loss of arterial elasticity, also known as arterial stiffening, is a common precursor to CVD. As left ventricular pressure continues to increase in conjunction with aortic stiffening, the aorta does not absorb or cushion the pressure of each left ventricular contraction as well as in healthy adults. This causes blood to be ejected at a greater velocity, which in turn causes the peripheral vascular system to absorb more of the pressure from heart contractions. This leads to damage in the micro vascularity, end-organ damage, and/or increased risk of CVD (O'Rourke & Hashimoto, 2007). This increase in stiffness and velocity can be determined by measuring the time differences in wave forms from one site to another on the body, known as pulse wave velocity (PWV). In other studies, the stiffening of the arterial system has been shown

to contribute to CVD such as hypertension, stroke, heart failure, and coronary artery disease (Shirwany & Zou, 2010). Arterial stiffness has been determined to be a marker of mortality, specifically, small arterial elasticity (SAE) has been found to be an independent risk marker for CVD events, independent of age (Grey et al., 2003; McEniery et al., 2006; Duprez et al., 2011). Arterial stiffness was found to be elevated in humans and animals that have dysfunctional left ventricular systolic and diastolic function, and clinical heart failure with preserved or reduced ejection fraction (Tsao et al., 2015).

Physical activity and exercise, as measured by kcal/week, have been shown to decrease the risk of cardiovascular events. Mora et al. (2007) found that 59% of activity-related reduction of CVD and 35.5% reduction in coronary heart disease (CHD) can be explained by its effects on the following risk factors; Inflammatory/hemostatic biomarkers, blood pressure, lipids, body mass index, glucose abnormalities, and measures of homocysteine. Experts in the field have found that structure and function of the cardiovascular system is what comprises the remaining percentage of reduction in instances of CVD or CHD related to physical activity (Tanaka, 2016).

Aerobic training interventions have shown much promise in decreasing arterial stiffness and increasing central arterial compliance, but resistance training has remained controversial (Edwards et al., 2004; Miyachi et al., 2003, 2004, & 2013; Ramos et al., 2015; Conraads et al., 2014). Initial cross-sectional studies determined that older resistance-trained adults showed less arterial compliance, when compared to their sedentary counterparts (Miyachi et al., 2003). Further studies have found resistance training to decrease arterial compliance in young healthy adult populations when compared to a control, and following a detraining period arterial compliance returned to baseline values (Miyachi et al., 2004). This led to the initial conclusion that resistance training reduces arterial compliance due to spikes in blood pressure of up to

320/250 mmHg that occur during exercise (MacDougall, 1986). Despite these studies, resistance training has continued to become widely accepted in exercises prescription and an integral component in the recommendations by major health organizations (ACSM, 2015; Eckel et al., 2014). This could negatively affect the prognosis of individuals performing resistance exercise, due to a decrease in arterial compliance. Although, there is a lack of evidence to determine if the increases in arterial stiffness in younger participants, due to resistance training inventions, are relevant to increased risk of cardiovascular disease (Miyachi, 2013). Other studies following varying populations, found high intensity resistance training to increase arterial compliance or cause no change (Rakobowchuk et al., 2005; Casey et.al., 2007; Olson et al., 2006; Maeda et al., 2006; Fahs et al., 2011).

Blood flow restriction (BFR) exercise has been one method found to attenuate the negative responses in arterial compliance due to standard resistance. BFR training is increasingly popular, as it utilizes low intensity exercise to cause disproportionate increases in physiological responses similar to higher loads. These increased physiological responses often lead to similar performance benefits as traditional resistance training (Loenneke et al., 2012). Varying results exist on its ability to attenuate the negative effects of resistance exercise on arterial compliance. These varying results could possibly be due to the lack of standardized exercise prescription, which includes exercise selection, BFR cuff pressure, duration, volume, and intensity (Park, Kwak, Harveson, Weavil, & Seo, 2015). Many of these studies used intensities ranging from greater than 70% 1RM for traditional training and 20-30% 1RM for BFR. There is a lack of studies which compare intensities greater than 30% 1RM while using BFR and greater than 70% 1RM with similar volume of traditional exercise.

Maximizing the number of calories burned through exercise can help create a greater caloric deficit to increase weight loss. ACSM recommends physical activity performed five or more days a week for 30-60 minutes at 40-60% of maximal oxygen consumption (VO_2Max) and resistance exercise varying from two to three days per week at 40-80% 1RM performing 8-20 reps for two to four sets, depending on an individual's specific goal (ACSM, 2015). Blood flow restriction training has challenged this paradigm and proven itself to be an alternative training technique for improving quality of life (Fry et al., 2007; Karabulut et al., 2010). This modality may be ideal for those in rehabilitation. Several studies confirm that BFR is an alternative that provides increased physical performance by using a decreased load for both healthy and elderly populations (Abe et al., 2006 & 2010; Karabulut et al., 2010; Ozaki et al., 2010a; Takashi et al., 2010). BFR causes a disproportionate increase in VO_2 with increasing workload over traditional training and increased muscle activation (Ozaki et al., 2010b; Takarada et al., 2000a & 2000b; Yasuda et al., 2008 & 2009). Since BFR alters VO_2 and muscle activation, it may affect oxygen and carbon dioxide intake, hence substrate utilization, energy expenditure, respiratory exchange ratio, blood pressure, excessive post-exercise oxygen consumption, and heart rate. It has been shown to alter energy expenditure in aerobic exercise, but no literature has reported these findings for volume-matched resistance exercise using varying intensities with and without BFR (Karabulut et al., 2017; Loenneke et al., 2011a).

Problem and Purpose Statement

There is insufficient research on the acute reactions of arterial elasticity to greater intensity BFR exercises. There is also an almost complete lack of calorimetric data on resistance BFR exercise and its comparison to traditional resistance training. The purpose of this study is to investigate the acute effects of volume-matched 40%, 60%, and 80% 1RM traditional resistance

exercise versus 25%, 35%, and 50% 1RM resistance exercise with BFR on arterial elasticity, PWV, and caloric expenditure.

Study Purposes

The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions at 40%, 60%, and 80% of 1RM (T40,T60, and T80) and resistance exercise sessions using BFR at 25%, 35%, and 50% of 1RM (BFR25, BFR35, and BFR50) on large and small arterial elasticity (LAE and SAE) 2) to examine how these varying training modalities affect the following cardiovascular variables: heart rate (HR), systolic and diastolic blood pressure (SBP and DBP), mean arterial pressure (MAP), pulse pressure (PP), cardiac ejection time (CEJ), cardiac output (CO), cardiac index (CI), stroke volume (SV), stroke volume index (SVI), systemic vascular resistance (SVR) and total vascular impedance (TVI) 3) to determine how the varying training modalities affect the following metabolic variables: rating of perceived exertion (RPE), volume of oxygen consumed (VO_2), carbon dioxide exhalation (VCO_2), energy expenditure (EE) during exercise and postexercise in recreationally active males and females.

Significance of the Study

There is evidence to support that traditional resistance training can improve quality of life and health indicators such as blood pressure, body composition, blood triglycerides and bone density. Yet, it has also been shown to have a negative effect on arterial compliance. In combination with low intensity blood flow restriction, resistance training has been shown to possibly negate these deleterious side effects, while maintaining benefits similar to traditional resistance exercise. BFR resistance training is successful in allowing similar adaptations using a much lower mechanical load. There are no studies venturing into the acute effects of low-to-

moderate intensity BFR resistance training when compared to traditional resistance training on cardiovascular variables such as; SAE, LAE, SBP, DBP, MAP, PP SVI, SVR, CEJ, CO, CI, SV, and TVI. Similarly, little is known on how BFR resistance training affects substrate utilization, energy expenditure, O_2 consumption, CO_2 production, BP, HR, RER, and EE during and postexercise. This study would help bridge the gap of varying intensities of BFR, outside of the norm, and how they relate to the cardiovascular markers. The study also aims to help provide information for energy expenditure data of BFR resistance training, and help in comparing the outcomes of volume-matched training at varying intensities and modalities.

Assumptions

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

Delimitations

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. Individuals with signs or symptoms of CVD were not permitted to participate in the study.
4. Individuals younger than 18 and older than 40 were excluded from this study.
5. Participants were asked to refrain from changes on their current physical activity; however, physical activity performed outside of the study was not monitored.

Research Questions

To test the hypotheses, the following research questions were addressed:

1) Would there be differences or similarities in small and large arterial elasticity and PWV following the resistance exercise protocol with varying intensities with and without BFR?

2) Would there be a change or similarity occurring in RPE, HR, SBP, DBP, MAP, CO, SV, SVR and TVI in recreationally active male and female subjects following a resistance exercise protocol with varying intensities with and without BFR?

3) Would there be a difference in energy expenditure during and after a volume-matched resistance exercise protocol with varying intensities with and without BFR?

Hypotheses

1) The low intensity 25% 1RM BFR session would elicit statistically similar responses in HR, RPE, SBP, DBP, MAP, CO, SV, SVR and TVI compared to T40, BFR35 will elicit statistically similar responses to T60, and BFR50 will elicit statistically similar responses to T80.
2) BFR conditions would produce significantly lower values of PWV and significantly greater values of large and small arterial elasticity, when compared to their traditional resistance exercise counter parts.
3) BFR conditions would elicit a significantly greater energy expenditure during and postexercise than their traditional resistance exercise counter parts.

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 five 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.
7) **Recreationally Active:** individuals who accumulated less than three days a week of physical activity.

Summary

Obesity remains one of the leading causes of preventable deaths and is associated with many chronic health conditions such as CVD. Physical activity and exercise have been shown to combat obesity through increases in energy expenditure and decreased risk of cardiovascular events. Aerobic training interventions have been successful in promoting weight loss, decreasing arterial stiffness, and increasing central arterial compliance. There is not one single right answer in how resistance training affects arterial compliance. Initial studies found resistance training to

decrease arterial compliance, due to spikes in blood pressure, but further research has found contrasting evidence, specifically with the use of low intensity BFR training (Miyachi et al., 2003 & 2004; Rakobowchuk et al., 2005; Casey et.al., 2007; Olson et al., 2006; Maeda et al., 2006; Fahs et al., 2011). It has yet to be shown whether the increases in arterial stiffness caused by resistance training inventions are relevant to cardiovascular health and disease (Miyachi, 2013). The best explanation for these differing results is a lack of standardized exercise variables, which increase for BFR due to cuff pressure and exercise selection, duration, and intensity of exercise (Park, Kwak, Harveson, Weavil, & Seo, 2015).

Currently there is a lack of studies that utilized a volume matched protocol with varying intensities and modalities for BFR resistance training. Many of the studies in the literature utilize intensities ranging from 20-30% 1RM for BFR, but rarely use intensities greater than 30% while using BFR and greater than 70% with volume matching. The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions (T40, T60, and T80) and resistance exercise sessions using BFR (BFR25, BFR35, and BFR50) on LAE and SAE 2) to examine how these varying training modalities affect HR, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI, SVR and TVI 3) to determine how the varying training modalities affect HR, RPE, VO_2, VCO_2, and EE during exercise and postexercise in recreationally active males and females.

CHAPTER II

REVIEW OF THE LITERATURE

The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions (T40, T60, and T80) and resistance exercise sessions using BFR (BFR25, BFR35, and BFR50) on LAE and SAE 2) to examine how these varying training modalities affect HR, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI, SVR and TVI 3) to determine how the varying training modalities affect HR, RPE, VO_2, VCO_2, and EE during and postexercise in recreationally active males and females.

Arterial Compliance

Arterial compliance is the is ability of the artery to distend during ventricular contraction and return to normal during ventricular relaxation, which is the change in volume of an arterial segment for a given change in pressure (O'Rourke & Mancia, 1999). This measure is inversely related to arterial stiffness. The current literature agrees that pulse wave velocity (PWV) is the gold standard index of arterial stiffness due to its simplicity, accuracy, reproducibility, and strong prediction of adverse outcomes (Cavalcante, Lima, Redheuil, & Al-Mallah, 2011). PWV can be measured non-invasively using applanation tonometry, in which a micromanometer-tipped probe is used on the surface of the skin overlying the arteries; carotid, radial, femoral, or distal (Siebenhofer, Kemp, Sutton, & Williams, 1999). Once placed on the site, the PWV apparatus attains its measurements by comparing the time from the two pressure waveforms at the two different sites along a vascular segment. A faster PWV is associated with stiffer vessels, as a

more compliant vessel will conduct the pulse wave slower than a stiffer one (Cavalcante et al., 2011). PWV measurements can be subject to other variables, such as hydration status and circadian rhythms, which was controlled in the present study, but no variance has been related to the menstrual cycle in females **(**Hayashi et al., 2006**;** Ounis-Skali, Mitchell, Solomon, Solomon, & Seely, 2006**;** Willekes, Hoogland, Keizer, Hoeks, & Reneman, 1997**;** Williams et al., 2001**)**. A stiff and uncompliant vascular system has been shown to contribute to CVD by way of hypertensions, stroke, heart failure, and coronary artery disease (Shirwany & Zou, 2010). Aerobic exercise has been shown to attenuate stiffening and decrease the risk of CVD (Edwards et al., 2004; Miyachi et al., 2003, 2004, & 2013; Ramos et al., 2015; Conraads et al., 2014). Fifty-nine percent of the reduction in activity-related reduction in CVD and 35 percent of coronary heart disease can be explained by the improvement of inflammatory/hemostatic biomarkers, blood pressure, lipids, body mass index, glucose abnormalities, and measures of homocysteine (Mora et al., 2007). Experts in the field have mentioned that the rest of the reduced CVD risk arises from the improvement of vascular structure and function (Tanaka, 2016).

Arterial Compliance and Cardiovascular Disease

CVD is the leading cause of death in the United States, accounting for over half a million deaths a year as of 2013 (Statistics, 2015). Of these deaths in 2011, three-quarters of them can be directly related with complications of the vascular system. This includes coronary heart disease, stroke, high blood pressure, and other diseases of the arteries (Mozaffarian, 2015). Arterial compliance is negatively associated with aging in older populations (Seals et al., 2008). As the vascular system ages, changes in the mechanical and structural properties of the arterial walls begin to occur leading to a decreased arterial compliance or increased arterial

stiffening(Jani & Rajkumar, 2006). The combination of an increasing stiffness in the arteries and an increased left ventricular pressure makes the aorta unable to properly absorb the pressure of each left ventricular contraction and causes the peripheral vascular system to absorb more pressure than it is meant to have (Tanaka, 2016). The system will eventually give up and lead to damage in the micro vascularity or, in worse cases, end-organ damage and increased risk of CVD (O'Rourke & Hashimoto, 2007; Tsao et al., 2015).

Arterial Compliance and Aerobic Exercise

Many research studies have shown that aerobic training interventions are successfully able to improve endothelial function and improve arterial compliance via a decrease in arterial stiffness in both healthy and clinical populations (Clarkson et al., 1999; Tanaka et al., 2000; Mora et al., 2007; Gokce et al., 2002; Tjønna, Rognmo, Bye, Stølen, & Wisløff, 2011). The American College of Sports Medicine currently recommends 150 minutes of aerobic exercise in their general health guidelines and it has for decades (ACSM, 2015; Garber et al., 2011). Aerobic exercise is known to increase maximal aerobic capacity (VO_2max), which has a strong correlation with arterial stiffness in healthy adults (Vaitkevicius et al., 1993).

Much of the literature seems to focus on moderate intensity aerobic exercise as the focus of interventions for aerobic exercise. The consideration that VO_2 max is a strong correlate to arterials stiffness led some to study high intensity interval training and its effects on arterial stiffness. Moderate and high intensity interval training have a variety of exercise prescriptions, but 60 to 65% VO_2 of sustained aerobic training and 4x4 High Intensity Interval Training (HIIT) seem to be the two most successful methods of improving endothelial function (Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015).

Arterial Compliance and Resistance Exercise

On the other hand, there are varying results and conclusions as to whether resistance training has a positive, negative, or negligible effect on arterial compliance. Arterial compliance has been shown to decrease during resistance training interventions in healthy adult aged men and women (Cortez-Cooper et al., 2005; Miyachi et al., 2003 & 2004; Okamoto, Masuhara, & Ikuta, 2006, 2009a, & 2009b). Similarly middle-aged men who participated frequently in resistance training were found to have 30% less arterial compliance than their sedentary counterparts (Miyachi et al., 2003). This reduction in arterial compliance was believed to occur due to the extremely high blood pressures, of 320/250mmHg, that are experienced by the arteries during high intensity exercise (MacDougall, Tuxen, & Sale, 1985; Petrofsky and Lind, 1975). Interestingly, DBP has not been found to increase in aerobic exercise (Ogawa et al., 1002; Stratton et al., 1994). Other resistance training studies have found differing results, in which no difference or an increase in arterial compliance occurred (Casey, Beck, & Braith, 2007; Croymans et al., 2014; Heffernan et al., 2009; Rakobowchuk et al., 2005). An inverse association has even been found with muscular strength and aortic stiffness even when controlling for aerobic fitness (Fahs et al., 2010). These differing results most likely occurred due to slight differences in modalities of the training interventions. It seems that the intensity of the exercise is the determinant of the effects on arterial stiffness. Miyachi et al. (2004) had the male participants at 80% of their one rep maximum and had failure sets included. Similarly Cortez-Cooper et al. (2005) involved their female subjects reaching failure on their sets. This has led some to conclude that the arterial stiffening that occurs due to resistance training is likely due to the performance of high intensity or failure resistance training (DeVallance et al., 2016). Collier et al. (2008) performed a study on stage-I and prehypertensive subjects finding the effects

of both resistance and aerobic training on arterial stiffness and blood pressure on thirty moderately active men and women. They found that resistance training resulted in increased arterial stiffness, where the aerobic training resulted in decreased arterial stiffness, despite similar reduction in both SBP and DBP and no change in weight. Specifically, resistance training increased central and peripheral arterial stiffness by 14.5 and 8.7%, respectively. Vasodilatory capacity increased in both trainings, but a greater extent for resistance training. Due to the vasodilatory response, Collier et al. (2008) concluded that arterial stiffness is a compensatory increase induced by the increase of flow in the microvasculature system and may not be negative.

The literature depicts resistance training as generally reducing CVD, but the current pathways by which this occurs are unclear. Resistance training is known to have beneficial effects on blood pressure in prehypertension or stage I hypertension, insulin sensitivity, blood glucose levels, body mass index, body composition, and effective in preventing and treating metabolic syndrome (Sillanpää et al., 2009; Hunter et al., 2004 & 2010; Lyerly et al., 2007; Castaneda et al., 2002 & 2006; Klimcakova et al., 2006; Brooks et al., 2007; Collier et al., 2009; Malik et al., 2004). It is widely accepted to be an essential part of general health recommendations made by the American College of Sports Medicine (ACSM). ACSM currently recommends that healthy adults exercise each muscle group two to three times each week using a variety of weights and resistance machines (Garber et al., 2011). Yet, the long term clinical implications of arterial stiffness that may or may not occur due to resistance training have yet to be completely understood (Croymans et al., 2014). Researchers found that the arterial stiffness caused by resistance training could be attenuated by performing aerobic exercise in conjunction with resistance exercise (Kawano et al., 2006). It was also determined that aerobic exercise need

to be performed, following resistance exercise and not prior to it, if the stiffening effects of resistance exercise were to be attenuated (Okamoto et al., 2007). This combination of modalities has been found to be beneficial in other cases such as with patients who are diagnosed with type 2 diabetes. In these patients, an intervention using combined exercise programs found to have greater effects on glycemic control (Yavari et al., 2012). It was also determined that the effects of combined exercise on type 2 diabetes patients had a greater effect on arterial compliance (Maiorana et al., 2001). These findings were in place with ACSM's general exercise recommendations which recommend a combination of modalities such as aerobic, resistance, flexibility and neuromotor exercise conditions (Ferguson, 2014).

Blood Flow Restriction

BFR was a concept popularized in Japan by Yoshiaki Sato during the 1980's and it has been commercialized as KAATSU training. There is yet to be a universal way by which BFR is used in the literature, but a relatively similar method is used. This method consists of placing a pneumatic cuff around an appendicular limb, followed by inflation of the cuff which is then worn during exercise (Manini & Clark, 2009). It is usually inflated to a pressure that exceeds SBP, but the pressure at the artery is lower due to disassociation between cuff pressure and underlying tissues, especially in the lower body (Shaw and Murry, 1982). BFR leads to pooling of blood in the occluded muscle, due to decreased venous return (Takano et al., 2005; Iida et al., 2005). Deflating the cuffs during exercise may lead to inconsistency in anabolic hormone secretion, specifically growth hormone, and possibly the magnitude of skeletal muscle adaptations (Karabulut et al., 2011). Typically, an intensity of 20-30% is chosen, as opposed to a high load to induce mechanical stress. Campos et al. (2002) performed an 8-week resistance training study that demonstrated that hypertrophy was induced in high intensity exercise, but no significant

increase was found with low intensity training. Yet low intensity resistance training with BFR was able to induce an increase in muscle mass and strength that was statistically similar to high-intensity training without BFR, and greater than low intensity without BFR (Takarada et al., 2000b). Similarly, BFR was found to be successful in increasing muscle cross sectional area and strength in a 3-week walking protocol (Abe, Kearns, and Sato, 2006).

The breakthrough of BFR is its effectiveness in a population with orthopedic injuries. In a 16-week training study, it was found that traditional rehabilitative exercise after anterior cruciate ligament reconstruction still led to an injured limb with 35% less strength and 8% less quadriceps CSA, but with BFR there was no significant difference in muscle mass of the injured and healthy limb and only 15% less strength (Ohta et al., 2003). These hypertrophic increases were not accounted for, simply by the lack of venous return and pooling of blood in the limb, due to the similar increases in strength (Manini & Clark, 2009). BFR allows for adaptations to occur at low intensities (20-30%) that mimic high intensity training allowing for elderly and rehabilitative populations to benefit from resistance training without the high mechanical stresses on the joint (Loenneke et al., 2012; Takarada et al., 2000a; Takano et al., 2005a & 2005b; Loenneke and Pujol, 2011).

Blood Flow Restriction and Arterial Compliance

BFR training using low loads has been reported to induce either no change or an increase in arterial compliance, while a few studies caused decreases in arterial compliance. For example, Renzi et al. (2010) found a 2mph walk, with and without BFR, to decrease flow mediated dilation (FMD), a measure of endothelial function. Yet, a ten-week study by Ozaki et al. (2011) utilized walk training at 45% HRR with and without BFR in 23 sedentary men and woman, 57 to 76 years of age. Their results found both muscular strength and carotid arterial compliance

improved in walk training, but only carotid arterial compliance improved in non-BFR group. This demonstrates that BFR alone is not a cause for decrease or attenuation of arterial function.

Ozaki et al. (2013) performed a 6-week study on 19 non-resistance trained, normotensive, normal-weight young men (22-32) with bench press resistance training to compare the long-term effects on carotid arterial compliance, measured by ultrasound, with and without BFR at 30% and 75% intensity, respectively, with similar volume. Acute changes of factors that acutely affect arterial compliance were measured before, during, and after training, such as systolic arterial pressure, plasma endothelin-1, noradrenalin, and nitrite/nitrate. They found, despite similar pre-values, both modalities led to an increase in CSA and maximal dynamic strength, but high intensity resistance training led to a 21% reduction of arterial compliance and was 54% lower than the BFR groups post value of arterial compliance. No differences were found in acute changes of plasma endothelin-1, noradrenalin, and nitrite/nitrate. Acute increases in SBP were related to decreases in arterial compliance, and thigh systolic arterial pressure was significantly greater for high intensity than BFR group and was negatively correlated to training changes in carotid arterial compliance.

Yasuda et al. (2014a) performed a 12-week study in an older population, aged 61-84, using BFR resistance training, specifically leg extension and leg press at 20 and 30% intensity, respectively. They found BFR to have no change in arterial function over pre-values or sedentary control group, as determined by cardio-ankle vascular index (CAVI), and ankle brachial pressure index (ABI). Although, the BFR group trended ($p=.09$) to positive increases in FMD from pre-values. This study did not provide a resistance training without BFR group and failed to control for the pre-value of SBP. The BFR group had a significantly higher BP than the control both in pre-values (151±15 vs 126±10), which placed the average of the BFR group in

stage I hypertension and the control group as pre-hypertensive. This is a difference that should not be ignored for arterial stiffness measurements.

In two other studies, Yasuda et al. (2015 & 2016) used BFR on elastic band resistance training in older participants. They found that elastic curl and press for 12 weeks at similar intensity and repetitions did not negatively change for elastic resistance training with and without BFR for CAVI, ABI, and FMD for older participants (61-82 years) (Yasuda et al., 2015). Similarly, older women (61-86 years) underwent 12 weeks of low load BFR or middle-to-high intensity without BFR elastic band resistance training, at differing intensity and repetitions but similar volume, using knee extension and squat. They found no difference in pre-to-post values for CAVI, ABI, or SBP. Similarly, Kim et al. (2009) and Carter et al. (2009) found that four weeks of BFR resistance training did not lead to differences or pre-to post changes in LAE and SAE or PWV, respectively.

Opposingly, a 4-week forearm training study led to decreases in brachial-artery FMD in the BFR group and an increase in the non BFR group, but resistance was set at 60% of MVC and rep pace was not different (Creudeur et al., 2010). This decrease in peripheral vascular function could be due to the utilization of BFR at intensities greater than the average 20-30% for BFR, as previous handgrip studies also found the traditional group to show positive increases in baFMD also demonstrated (Alomari & Welsch, 2007).

Blood Flow Restriction and Respiratory Responses

At low intensities, BFR training has been shown to induce statistically similar respiratory benefits as high intensity training without BFR (Takarada et al., 2000a & 2000b). BFR walking causes a disproportionate increase in VO_2 with increasing workload over traditional training and increased muscle activation (Ozaki et al., 2010b; Takarada et al., 2000b; Yasuda et al., 2008 &

2009). Ozaki et al. (2010b) found that in cycling with and without BFR at 20, 40, and 60% VO_2max trended ($p=0.12$) for greater VO_2 in 60% BFR compared to non BFR. The mean VO_2 elicited during BFR the whole session was significantly greater than control, which equated 40-60%VO_2Max with BFR to 45-75%VO_2Max without BFR. The HR elicited by BFR at rest was 25% greater than non-BFR control, while SV was reduced 25% in BFR than control with CO being similar. A significant rate-pressure product was found (HR x SBP) to be significantly greater during BFR condition. Ozaki et al. (2010b) concluded that the combination of a disproportionate increase in VO_2, increased VO_2 at similar workload, and increased rate-pressure product suggests an increased energy demand for BFR condition. The increased oxygen demand is being met, despite the decrease in blood flow, through an increase arterial-venous O_2 difference. In other words, the decreases in blood flow are compensated by increase extraction of O_2. Loenneke et al. (2011) found that walk exercise at 75m/min with BFR led to significantly greater increases of VO_2, EE, and HR over walking at 75m/min without BFR. BFR elevated EE 10-29% greater than the control. It was concluded that this elevated oxygen/energy requirement could be related to altered muscle activity seen with BFR (Karabulut & Garcia, 2017; Takarada et al., 2000b; Yasuda et al., 2008 & 2009). These results were repeated by Karabulut & Garcia (2017) who found increases in EE over control during cycling in an obese population.

Araujo (2015) performed a study, similar to the present study, in which VO_2, VCO_2, RER, and EE during and postexercise were measure during resistance exercise at 80% and 20% with BFR. Resistance exercise at 80% 1RM elicited a 23% greater EE than at 20% with BFR, but upon analyzing covariates, with ANCOVA, it was identified that volume had a significant relationship with outcome of VO_2, nullifying differences in VO_2 and EE between conditions.

Conclusion

In conclusion, the review was able to highlight the efficacy of BFR training as a method of increasing muscle mass and strength whilst using low mechanical loads during resistance exercise. BFR has been found to elicit increased respiratory responses during aerobic exercise over its non-BFR equivalents of the same intensity. However, the literature outlines a need for more conclusive data on acute arterial compliance outcomes of volume matched resistance exercise with differing intensities and modalities (BFR vs traditional). There is also a complete lack of research on BFR's effects on EE during and postexercise utilizing volume matched lower body resistance exercises.

Chapter 3 contains a discussion of the methodology used to conduct the present study. In chapter 4, the results of the study are presented and discussed. Chapter 5 contains a summary of the study, conclusions that were drawn, and recommendations for future research.

CHAPTER III

METHODS

The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions (T40, T60, and T80) and resistance exercise sessions using BFR (BFR25, BFR35, and BFR50) on LAE and SAE 2) to examine how these varying training modalities affect HR, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI, SVR and TVI 3) to determine how the varying training modalities affect HR, RPE, VO_2, VCO_2, and EE during and postexercise in recreationally active males and females.

Subjects

Thirty-two healthy participants, male (17) and female (15), 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. The length of testing for each subject was one 30-minute introduction session and six experimental sessions, which were a total of 90 minutes in length, for a total of 10 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 who

3. were currently ingesting medication that might interfere with vascular function and energy expenditure.

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 who 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.
6. Participants older than 40 or younger than 18.
7. Participants consuming any supplements that could affect energy expenditure.

Recruitment

Participants were recruited from The University of Texas Rio Grande Valley through classroom recruitment; in which a professor permission script was read to the professor, and an in-person script to the students. Participants were also recruited by means of fliers and word of mouth at UTRGV. Participation in this study was voluntary and subjects could withdraw from the study at any time.

Experimental Protocol

On the first day after providing informed consent, the participants filled out questionnaires and were familiarized with the study procedures before starting the exercise sessions. Following initial screening (PAR-Q and health questionnaire) and familiarization of

experimental protocol, anthropometric measures were taken: height, weight, body composition. 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). The participants were then asked to warm-up on a cycle ergometer for five minutes, pedaling at 50 RPM with 1.5 kP of resistance. The subjects were then asked to lay on the lying leg curl machine. The pad of the leg curl machine was placed at the ankle and the arm of the machine adjusted, such that he leg was not hyperextended. The subject was asked to perform one repeptition and the range of motion was adjusted, so that the machine would stop at 90 degrees of flexion. They performed ten repetitions at ¼ of body weight (BW) following a tempo of 50BPM (top, bottom, top, bottom), and if RPE was low enough the resistance increased to ½ BW or more, with the usual progression being ¼ BW, ½ BW, ¾ BW, BW, and the next weight, if necessary, based on their RPE. The eventual goal was to have the subject fail under five reps and use NSCA Max Reps Training Load Chart to calclulate 1RM (Haff & Triplett, 2015). for a similar protocol was used to determine 1RM for leg extension. The subject sat on the machine and back adjustment was set, so that the subject's knee joint center was in line with the leg extension arm'saxis of rotation. The limb length adjustment was set at the base of their shin, and the knee adjustment angle was set so the movement began at approximately 90 degrees of flexion. The subject performed ten repetitions at ½ BW, BW, and weights in agreement with subject depeding on RPE, with a goal of failing under five repetitions.

For the next six experimental sessions, time schedules were agreed on by the subject and researcher to when it was most convenient for the subject to be both fasted (for at least eight hours), hydrated, and at least 48 hours from their last session. Hydration was measured using a

Clinical Urine Refractometer 300005 (SPER Scientific, Scottsdale, AZ, USA). The urine specific gravity was required to be 1.010 or lower. If the participants were inadequately hydrated, they were instructed to drink water to reach proper hydration. Urine samples were continuously collected until participants were deemed hydrated per preset standards.

After reaching hydration status, the subjects laid in a 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). Pulse wave velocity was then measured using SphygmoCor® CPV Pulse Wave Analyzer (AtCor Medical, Itasca, IL, USA). Baseline caloric expenditure was gathered for three minutes by indirect calorimetry using OxyconMobile (Viasys Healthcare Inc., Yorba Linda, CA).

Participants then warmed up for five minutes using a cycle ergometer. They were instructed to pedal at 50RPM with 1.5kP of resistance. During sessions with blood flow restriction, the subjects were asked to sit down on a chair, and the BFR cuffs were placed as proximal to the leg as possible, while seated. They were tightened to an initial pressure of approximately 50-55mmHg of initial pressure with the pressure recorded for future reference. The inflation of the BFR cuffs (elastic cuffs that are tightened and filled with air to restrict blood flow) (five cm wide; KAATSU-Master System, Sato Sports Plaza, Tokyo Japan) was based on the capillary refill method. For this method, the initial pressure was set to 55-60mmHg, and the cuff was inflated to 120 mmHg and, after 20 seconds, capillary refill time was tested. In order to test this, the middle of vastus medialis was firmly pressed with the thumb and a discoloration of approximately two seconds was sought before the skin returned to its original color. If the process was faster than two seconds, the cuffs would be deflated for five seconds and the

pressure would be increased in 20mmHg intervals until the desired reaction was obtained. The cuff pressure was chosen on the first session using BFR cuffs and remained the same across all BFR exercise sessions.

The subject then had a backpack adjusted on them with the OxyconMobile modules and mask placed before beginning the exercise. They performed the reps with either 25%, 35%, or 50% of 1RM with BFR or 40%, 60%, or 80% of 1RM without BFR depending on the session. Sessions were randomly ordered and counterbalance, with alternated BFR and non-BFR, depending on which session was first completed. The repetitions were volume matched across intensities using four sets of 10 repetitions with BFR50% and rest was standardized using total time to complete exercise following the 50BPM tempo with 60 seconds of rest for BFR25%, approximately 13.5 minutes. They began with leg curl and moved over to leg extension and in between sets HR and RPE were recorded.

Upon completion of the exercise session, participants laid on a bed in the supine position and post exercise arterial elasticity and hemodynamics were measured immediately post exercise, 10-minute post exercise, 20-minutes post exercise, and 30-minute post exercise. Pulse wave velocity was measured at 5, 15, and 25-minute post exercise. The time to complete each session was approximately 90 minutes. Calibration of all the equipment was performed regularly per instructions provided by the manufacturer. Throughout this time, the subjects left the OxyconMobile mask on, and it measured postexercise EE throughout the resting periods.

Instruments

Clinical Urine Refractometer

Participants were required to provide a urine sample at the beginning of each session. Hydration was being measured by using one to three 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 obtained from the sample was recorded. The device was then sanitized, and the rest of the urine was discarded into the biohazard waste.

HDI/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 during the measurements. 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.

OxyconMobile

OxyCon Mobile (VIASYS Healthcare) consists of a face mask with turbine and integrated O_2 and CO_2 electrodes. Before each test, after 15 min acclimatization, temperature, humidity and barometric pressure were determined and 2-point calibrations of turbine and gas analysis were performed. OxyCon Mobile is a telemetric system and consists of a measuring and transmitting unit and a fixed receiving unit. The measuring and transmitting units were attached to the subjects back with a harness (total weight 950 g). The transmitting unit must be within a range of 500 m of the receiving unit (Hannink et al., 2010). Expired oxygen and carbon dioxide

concentrations were continuously measured throughout the entire session (rest, exercise, and 30 minutes post exercise) to calculate oxygen (O_2) uptake, carbon dioxide (CO_2) output and respiratory exchange ratio (RER; VCO_2/ VO_2).

SphygmoCor® Pulse Wave Analyzer

Analysis of pulse wave velocity was conducted noninvasively using a pulse wave velocity analyzer; SphygmoCor® Pulse Wave Analyzer (AtCor Medical Pty. Ltd., Sydney Australia). To monitor the heart's electrical activity, three electrodes 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 laid down and had segmental measures taken at the carotid (neck), radial (wrist), femoral (groin), and the dorsalis pedis arteries (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 three different measurements: carotid to radial (upper body), carotid to femoral (central), and femoral to dorsalis pedis (lower body).

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 was 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 measured.

KAATSU Blood Flow Restriction Cuffs

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. 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 range of 55-60 mmHg. The pressure was then set for 120mmHg for 20 seconds, and capillary refill time was tested. To test capillary refill time, the middle of vastus medialis was firmly pressed with the thumb. A discoloration of approximately two seconds was sought before the skin returned to its original color. If the process was faster than two seconds, the cuffs would be deflated for five seconds and the pressure would be increased in 20mmHg intervals for 20 seconds and capillary perfusion would be retested, until the desired reaction was obtained. The cuff pressure was chosen on the first session using BFR cuffs and remained the same across all BFR exercise sessions.

Statistical Analysis

A 2-way analysis of variance (ANOVA) with repeated measures was used to determine if any significant condition or time main effects or interactions existed in SAE, LAE, SBP, DBP, MAP, PP SVI, SVR, CEJ, CO, CI, SV, TVI, VO_2, VCO_2, HR, RPE, RER, EE, and crPWV, cfPWV, and fdPWV. If condition differences were found, post-hoc pairwise analysis was completed, using a Bonferroni correction for multiple comparisons, to determine individual differences, if any, between conditions. Additionally, each time point was then analyzed for condition main effects, and, if any, a post hoc pairwise analysis was completed to determine individual condition differences. An alpha of 0.05 was used to determine statistical significance and data was analyzed using SPSS 23.0 for Windows.

CHAPTER IV

RESULTS

The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions (T40, T60, and T80) and resistance exercise sessions using BFR (BFR25, BFR35, and BFR50) on LAE and SAE 2) to examine how these varying training modalities affect HR, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI, SVR and TVI in recreationally active male and female subjects 3) to determine how the varying training modalities affect HR, RPE, VO_2, VCO_2, and EE during and postexercise in recreationally active males and females.

Subject Characteristics

Thirty-two healthy participants, male (17) and female (15), between the ages of 18 and 40 years were recruited for this research study from the University of Texas Rio Grande Valley. Table 1 Shows descriptive statistics that were taken from the study population.

Table 1. Subject Characteristics

Variables	Male (n=17)	Female (n=15)	Group (n=32)
Age (yr.)	23.4 (±0.7)	22.6 (±0.8)	23.0 (±0.5)
Height (cm)	173.9 (±1.7)	157.2 (±1.2)	166.1 (±1.8)
Weight (kg)	84.3 (±4.1)	58.3 (±2.5)	72.1 (±3.4)
Body Mass Index (kg/m^2)	27.7 (±4.6)	23.5 (±3.2)	25.8. (±4.5)

Values are reported as means (±SE)

Acute Exercise Variables

Table 2 demonstrates the weight, repetitions, volume, and effective intensity of all conditions, and demonstrates sex differences. Repeated measures ANOVA found condition differences ($p<0.001$) in weight used in both LC and LE. Post-hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found that every condition was statistically different from the other ($p<0.001$).

Repeated measures ANOVA found condition differences ($p<0.001$) in repetitions used in LC and LE. Post-hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found that every condition was statistically different from each other ($p<0.001$) in repetitions used for both LC and LE.

Repeated measures ANOVA found that volume was statistically similar across all conditions for LC and LE ($p>0.05$) for condition main effect.

Repeated measures ANOVA found condition differences ($p<0.001$) in effective intensity, weight lifted on machine compared to estimated 1RM, for both LC and LE. Pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found that all conditions were statistically different ($p<0.001$) from each other for both LC and LE.

Table 2. Exercise Condition Characteristic

Exercise	Sex	BFR25	BFR35	BFR50	T40	T60	T80
Weight (lbs.) (p<0.001)							
Leg Curl	*Group*	40.2 (±1.6)	56.0 (±2.1)	79.9 (±3.1)	63.5 (±2.5)	95.4 (±3.8)	127.7 (±5.0)
	Male	52.1 (±2.2)	72.6 (±2.9)	103.8 (±4.2)	82.4 (±3.5)	123.5 (±7.5)	164.7 (±6.9)
	Female	28.3 (±2.3)	39.3 (±3.1)	56.0 (±4.5)	44.7 (±3.7)	67.3 (±5.5)	90.7 (±7.3)
Leg Ext.	*Group*	64.0 (±2.1)	89.8 (±3.0)	127.9 (±4.3)	102.2 (±3.3)	153.3 (±5.0)	198.3 (±5.9)
	Male	80.3 (±2.9)	113.5 (±4.2)	161.2 (±5.9)	128.8 (±4.5)	192.6 (±6.9)	245.6 (±8.1)
	Female	47.7 (±3.1)	66.0 (±4.4)	94.7 (±6.3)	75.7 (±4.8)	114.0 (±7.3)	151.0 (±8.6)
Repetitions (p<0.001)							
Leg Curl	*Group*	79.8 (±0.7)	57.0 (±0.4)	40.0 (±0.0)	50.4 (±0.3)	33.4 (±0.1)	25.1 (±0.1)
	Male	79.9(±0.9)	56.9 (±0.5)	40.0 (±0.0)	50.6 (±0.5)	33.7 (±0.2)	25.2 (±0.2)
	Female	79.7 (±1.0)	57.1 (±0.6)	40.0 (±0.0)	50.3 (±0.5)	33.1 (±0.2)	24.9 (±0.2)
Leg Ext.	*Group*	79.0 (±1.0)	57.0 (±0.4)	40.0 (±0.0)	49.9 (±0.4)	33.4 (±0.2)	25.8 (±0.3)
	Male	80.3 (±1.3)	56.9 (±0.6)	40.0 (±0.0)	49.9 (±0.5)	33.5 (±0.3)	26.7 (±0.4)
	Female	77.7 (±1.4)	57.0 (±0.6)	40.0 (±0.0)	49.9 (±0.5)	33.3 (±0.3)	25.2 (±0.4)
Volume (Reps x Weight) (p>0.05)							
Leg Curl	*Group*	3204 (±125)	3194 (±126)	3196 (±125)	3202 (±125)	3197 (±126)	3198 (±121)
	Male	4156 (±172)	4141 (±172)	4153 (±170)	4161 (±172)	4167 (±173)	4139 (±166)
	Female	2252 (±183)	2248 (±183)	2240 (±183)	2242 (±183)	2233 (±184)	2258 (±177)
Leg Ex.	*Group*	5078 (±179)	5111 (±170)	5117 (±173)	5107 (±170)	5127 (±171)	5152 (±176)
	Male	6452 (±245)	6461 (±232)	6447 (±237)	6444 (±233)	6469 (±234)	6515 (±241)
	Female	3704 (±261)	3762 (±247)	3787 (±252)	3769 (±248)	3784 (±249)	3789 (±257)
Effective Intensity (%1RM) (p<0.001)							
Leg Curl	*Group*	25.2 (±0.2)	35.1 (±0.2)	50.1(±0.2)	39.8 (±0.2)	59.9 (±0.2)	80.2 (±0.2)
	Male	25.3 (±0.2)	35.4 (±0.3)	50.5(±0.2)	40.0 (±0.3)	60.0 (±0.3)	80.0 (±0.2)
	Female	25.1 (±0.3)	34.9 (±0.3)	49.6(±0.2)	39.6 (±0.3)	59.8 (±0.3)	80.5 (±0.2)
Leg Ext.	*Group*	25.1 (±0.1)	35.2 (±0.2)	50.1(±0.2)	40.1 (±0.2)	60.2 (±0.2)	78.4 (±0.6)
	Male	25.0 (±0.0)	35.3 (±0.3)	50.1(±0.3)	40.1 (±0.3)	60.0 (±0.3)	76.9 (±0.8)
	Female	25.2 (±0.2)	35.1 (±0.3)	50.2(±0.3)	40.1 (±0.3)	60.3 (±0.3)	79.9 (±0.8)

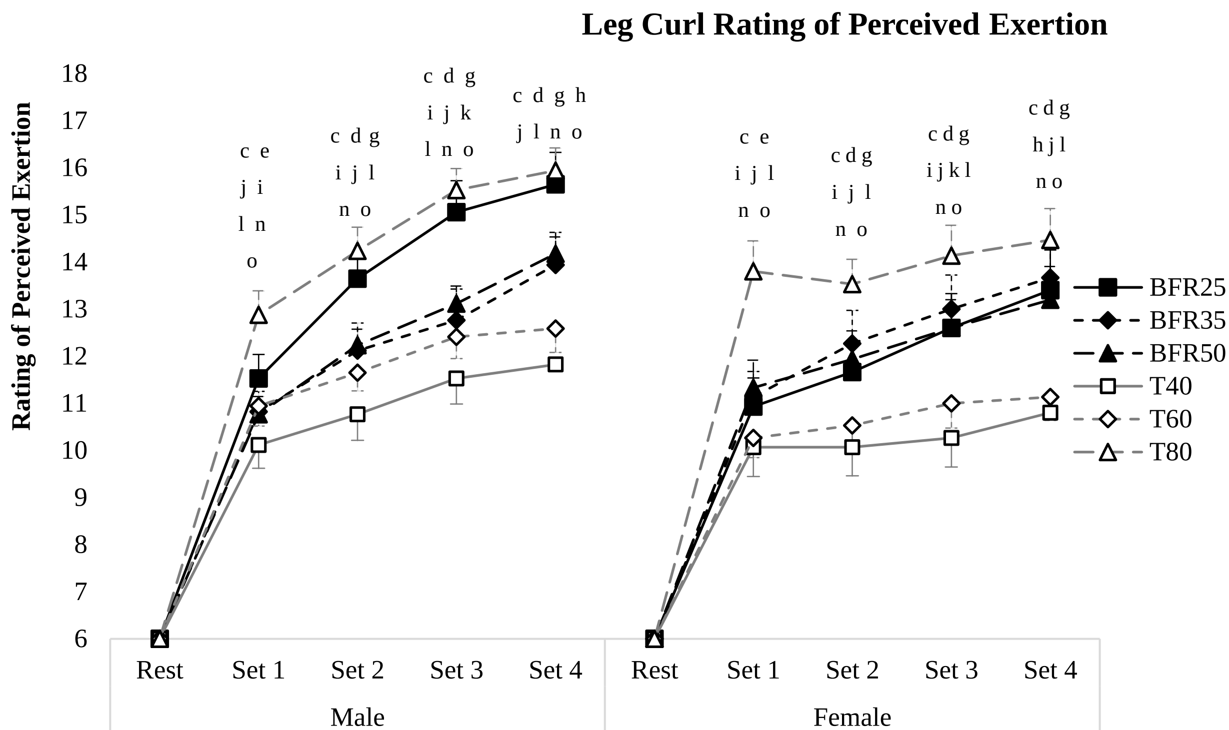
Values are reported as means (±SE)

Subjective Performance

Figure 1 shows the effects of the six different types of resistance exercise combinations with and without BFR on RPE recorded immediately after each set of LC. Repeated measures ANOVA found significant condition ($p<0.01$), time main effects ($p<0.01$), condition*time interaction ($p<0.01$), and time*sex interaction ($p<0.01$). Post hoc pairwise comparisons, using a Bonferroni adjustment, found all BFR conditions ($p<0.01$) to have greater RPE scores than T40. BFR25 and BFR50 had greater RPE scores than T60 ($p<0.01$) & $p<0.03$). T80 had significantly greater RPE scores than BFR35 ($p<0.02$), BFR50 ($p<0.01$), T40 ($p<0.01$), and T60 ($p<0.01$).

Each time point was then analyzed using repeated measures ANOVA. Post hoc pairwise comparisons, using a Bonferroni adjustment, found BFR25 ($p<0.02$) and BFR50 ($p<0.03$) to have greater RPE scores than T40, and T80 had greater RPE scores than BFR25 ($p<0.02$), BFR35 ($p<0.01$), BFR50 ($p<0.01$), T40 ($p<0.01$), and T60 ($p<0.01$), during the first set. T40 ($p<0.01$) and BFR25 ($p<0.01$) elicited greater RPE than T60, while T80 was found to elicit greater RPE scores than BFR35 ($p<0.04$), BFR50 ($p<0.01$), T40 ($p<0.01$), and T60 ($p<0.01$) during the second set. During the third set, all BFR conditions had greater RPE scores than T40 ($p<0.01$). RPE for the third set was greater for BFR25 ($p<0.01$) and BFR50 ($p<0.04$) than T60. T80 had greater RPE than BFR35 ($p<0.02$), BFR50 ($p<0.01$), T40 ($p<0.01$), and T60 ($p<0.01$) during the third set. During the fourth set, all BFR conditions had greater RPE than T40 and T60 ($p<0.01$). T80 had a greater RPE than T40 and T60 ($p<0.01$) and was statistically similar to BFR groups.

Figure 1. Leg Curl Rating of Perceived Exertion



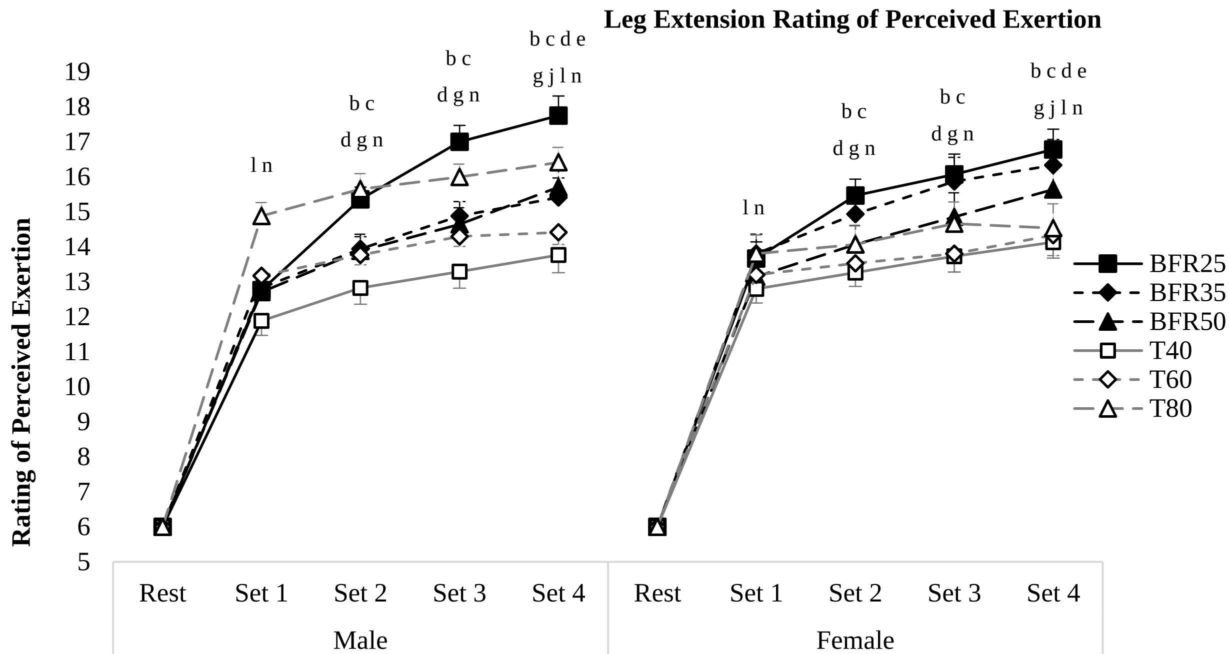
Males (N=17), Females (N=15)

[c] Significant condition differences were found between BFR25&T40. [d] Significant condition differences were found between BFR25&T60. [e] Significant condition differences were found between BFR25&T80. [g] Significant condition differences were found between BFR35&T40. [h] Significant condition differences were found between BFR35&T60. [i] Significant condition differences were found between BFR35&T80. [j] Significant condition differences were found between BFR50&T40. [k] Significant condition differences were found between BFR50&T60. [l] Significant condition differences were found between BFR50&T80. [n] Significant condition differences were found between T40&T80. [o] Significant condition differences were found between T60&T80. Values reported as mean ±SE.

Figure 2 shows the effects of the six different types of resistance exercise with and without BFR on RPE recorded immediately after each set of LE. Repeated measures ANOVA found significant condition ($p<0.01$) and time main effects ($p<0.01$), and condition*time ($p<0.01$) and time*sex interactions ($p<0.01$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found all BFR groups and T80 to have a significantly greater RPE than T40 ($p<0.03$). BFR25 had a greater RPE than T60 ($p<0.01$).

Each time point was then analyzed using repeated measures ANOVA. Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found T80 to have greater RPE scores than BFR50 ($p<0.02$) and T40 ($p<0.01$) on the first set. During the second set, BFR25 ($p<0.01$) was found to elicit a greater RPE than BFR50, T40, and T60. BFR35 and T80 had greater RPE scores than T40 ($p<0.01$). During the third set, all BFR groups and T80 were found to have greater RPE scores than T40 ($p<0.01$). BFR25 had greater RPE scores than BFR50 and T60 ($p<0.01$). T80 had greater RPE scores than T60 ($p<0.04$). During the fourth set, all BFR groups and T80 had greater RPE scores than T40 ($p<0.02$). BFR25 ($p<0.01$) and BFR50 ($p<0.04$) had greater RPE scores than T60. BFR25 had greater RPE scores than BFR50 ($p<0.01$) and T80 ($p<0.01$).

Figure 2. Leg Extension Rating of Perceived Exertion



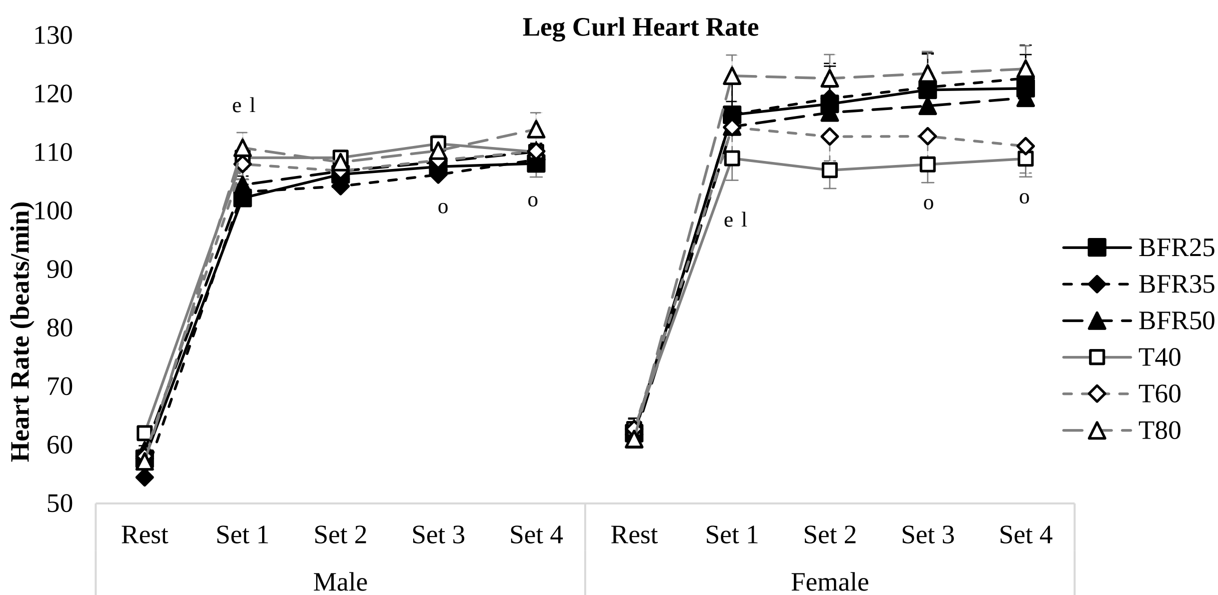
Males (N=16), Females (N=13)
[b] Significant condition difference between BFR25&BFR50. [c] Significant condition difference between BFR25&T40. [d] Significant condition difference between BFR25&T60. [e] Significant condition difference between BFR25&T80. [g] Significant condition difference between BFR35&T40. [j] Significant condition difference between BFR50&T40. [k] Significant condition difference between BFR50&T60. [l] Significant condition difference between BFR50&T80. [n] Significant condition difference between T40&T80. [o] Significant condition difference between T60&T80.
Values reported as mean ±SE.

Hemodynamic Responses

Figure 3 shows the effects of the six different types of resistance exercise with and without BFR on HR following each set of LC. Repeated measures ANOVA found significant condition ($p<0.03$) and time main effects ($p<0.01$), condition*time interaction ($p<0.01$), and condition*sex interaction ($p<0.01$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found that T80 elicited a greater HR than T60 ($p<0.028$) and there was a trend for a greater HR than T40 ($p<0.07$).

Each set was then analyzed using repeated measures ANOVA. Post-hoc pairwise comparisons found subjects had a lower HR during T80 than BFR25 ($p<0.05$) and BFR50 ($p<0.02$) for the first set. No significant differences ($p<0.05$) were found after the second set. After the third set, T80 was found to have significantly greater HR than T60 ($p<0.05$). After the fourth set, T80 was found to have significantly greater HR than T60 ($p<0.02$).

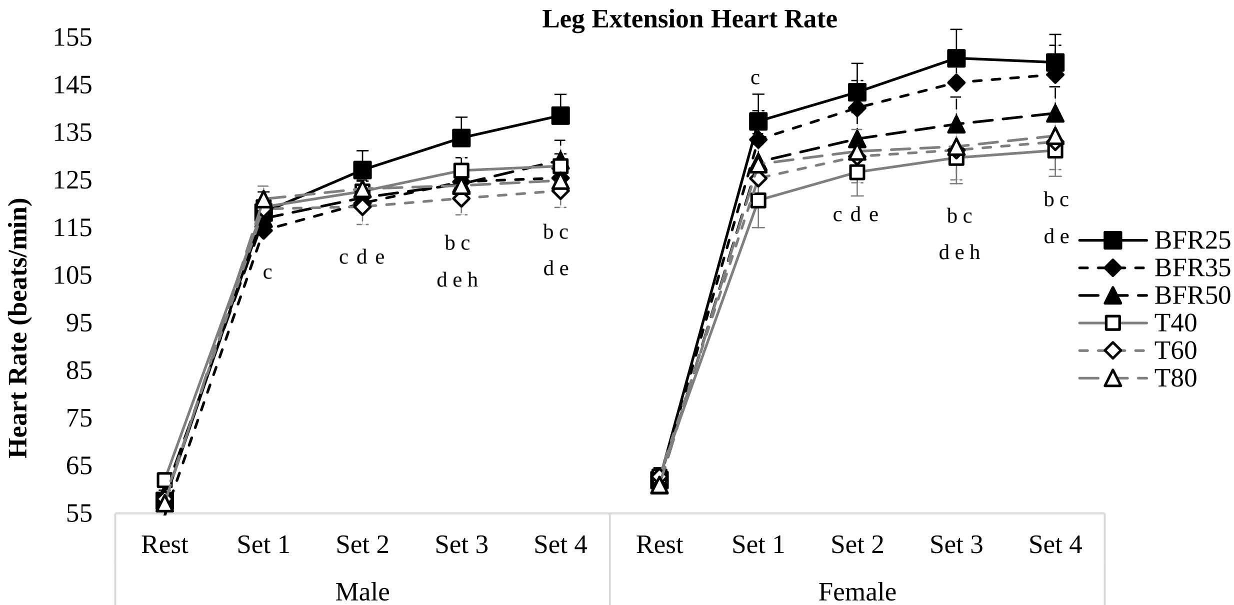
Figure 3. Leg Curl Heart Rate



Males (N=17), Females (N=15)
[e] Significant condition difference between BFR25&T80(p<0.05). [1] Significant condition difference between BFR50&T80 (p<0.02). [o] Significant condition difference between T60&T80 (P<0.05).
Values reported as mean ±SE.

Figure 4 shows the effects of the six different types of resistance exercise with and without BFR on HR following each set of LE. Repeated measures ANOVA found a significant condition ($p<0.01$) and time main effects ($p<0.01$), condition*time interaction ($p<0.01$), and condition*sex interaction ($p<0.01$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found BFR25 to have a significantly greater HR than BFR50 ($p<0.05$), T40 ($p<0.01$), T60 ($p<0.01$), T80 ($p<0.01$). Each time point was then analyzed using repeated measures ANOVA. Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found BFR25 to have a greater HR than T40 ($p<0.01$) on the first set. During the second set, BFR25 had a greater HR than T40 ($p<0.01$), T60 ($p<0.01$), and T80 ($p<0.03$). During the third set, BFR25 had a greater HR than BFR50 ($p<0.01$), T40 ($p<0.01$), T60 ($p<0.01$), T80 ($p<0.01$), and BFR35 had a greater HR than T60 ($p<0.03$) during the third set. During the fourth set BFR25 had a greater HR than BFR50 ($p<0.03$), T40 ($p<0.01$), T60 ($p<0.01$), and T80 ($p<0.01$).

Figure 4. Leg Extension Heart Rate

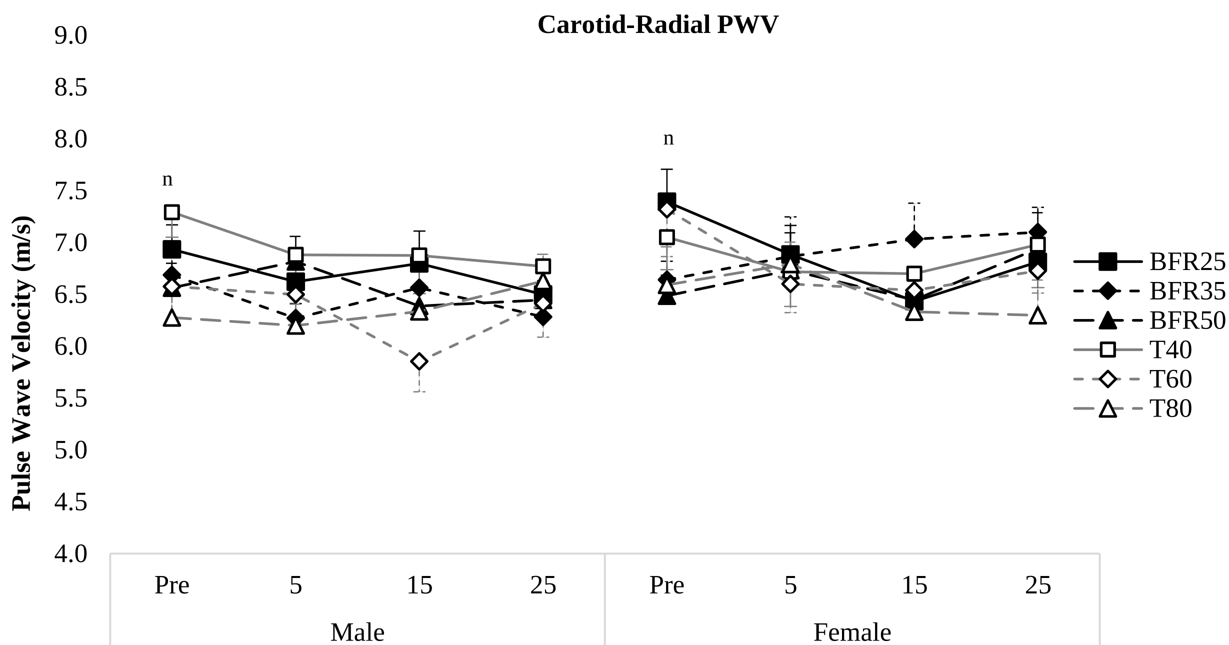


Males (N=17), Females (N=15)

[b] Significant condition difference between BFR25&BFR50. [c] Significant condition difference between BFR25&T40. [d] Significant condition difference between BFR25&T60. [e] Significant condition difference between BFR25&T80(p<0.05). [l] Significant condition difference between BFR50&T80 (p<0.02). [h] Significant condition difference between BFR35&T60.
Values reported as mean ±SE.

Figure 5 shows the effects of the six different types of resistance exercise combinations with and without BFR had PWV from carotid to radial measured at pre-exercise and 5, 15, and 25 minutes post workout (Pre/Post5/Post15/Post25). Repeated measures ANOVA found a significant condition main effect ($p<0.02$) and time main effect ($p<0.03$). No significant differences were found for other interactions ($p>0.05$). Post-hoc comparisons, using a Bonferroni correction, found T40 to have significantly greater values than T80 ($p<0.02$). Each time point was then analyzed using repeated measures ANOVA. Pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found T40 to have greater PWV than BFR50 ($p<0.02$) for the Pre, but no significant differences were found for Post5, Post15, and Post25 ($p>0.05$).

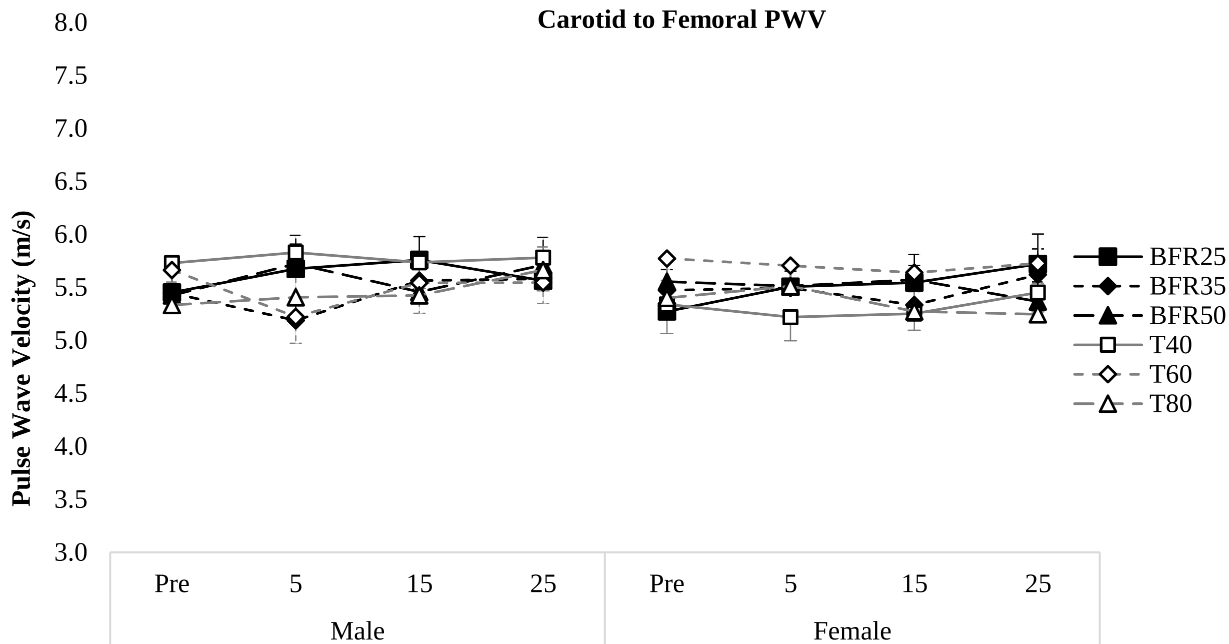
Figure 5. Carotid to Radial PWV



Males (N=17), Females (N=15)
[n] Significant condition difference between T40&T80.
Values reported as mean ±SE.

Figure 6 shows the effects of the six different types of resistance exercise combinations with and without BFR on PWV from carotid to femoral measured at Pre, Post5, Post15, and Post25. Repeated measures ANOVA found that the groups were statistically similar for condition and time main effects and interactions (p>0.05).

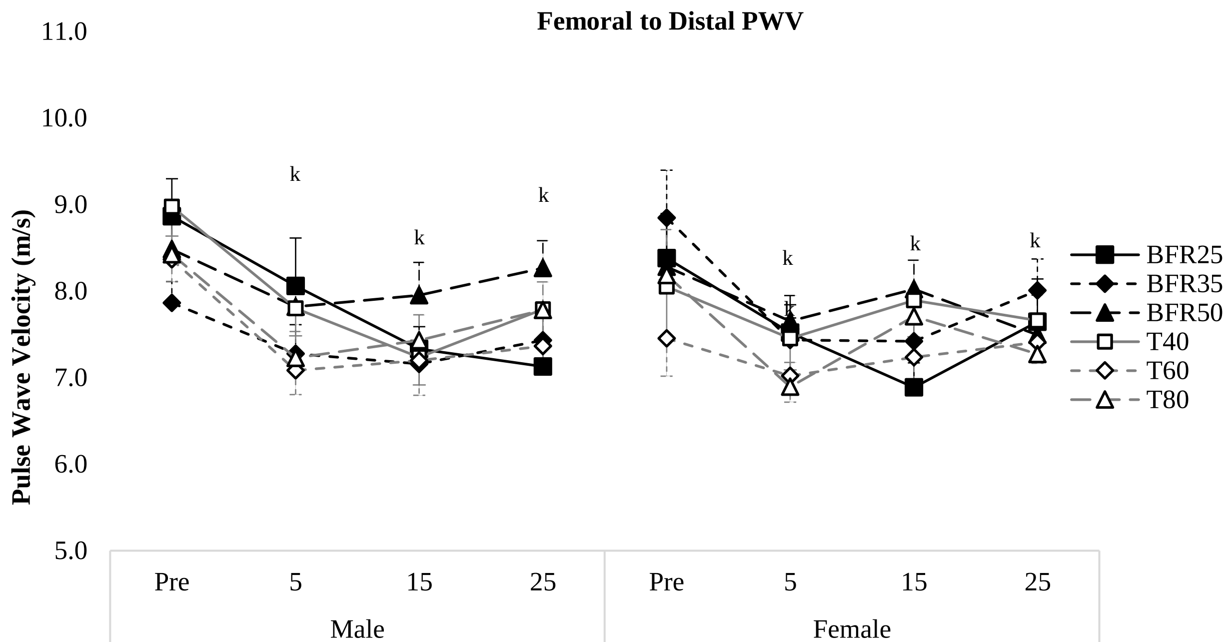
Figure 6. Carotid to Femoral PWV



Males (N=16), Females (N=15)
Values reported as mean ±SE.

Figure 7 shows the effects of the six different types of resistance exercise combinations with and without BFR on PWV from the femoral to distal artery measured at Pre, Post5, Post15, and Post25. Repeated measures ANOVA found a significant condition main effect ($p<0.05$) and time main effect ($p<0.01$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found BFR50 to have significantly greater PWV than T60 ($p<0.032$). Each time point was analyzed using repeated measures ANOVA and condition difference was found at Post15. Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, no significant difference between conditions at Pre, Post5, Post15, Post25.

Figure 7. Femoral to Distal PWV



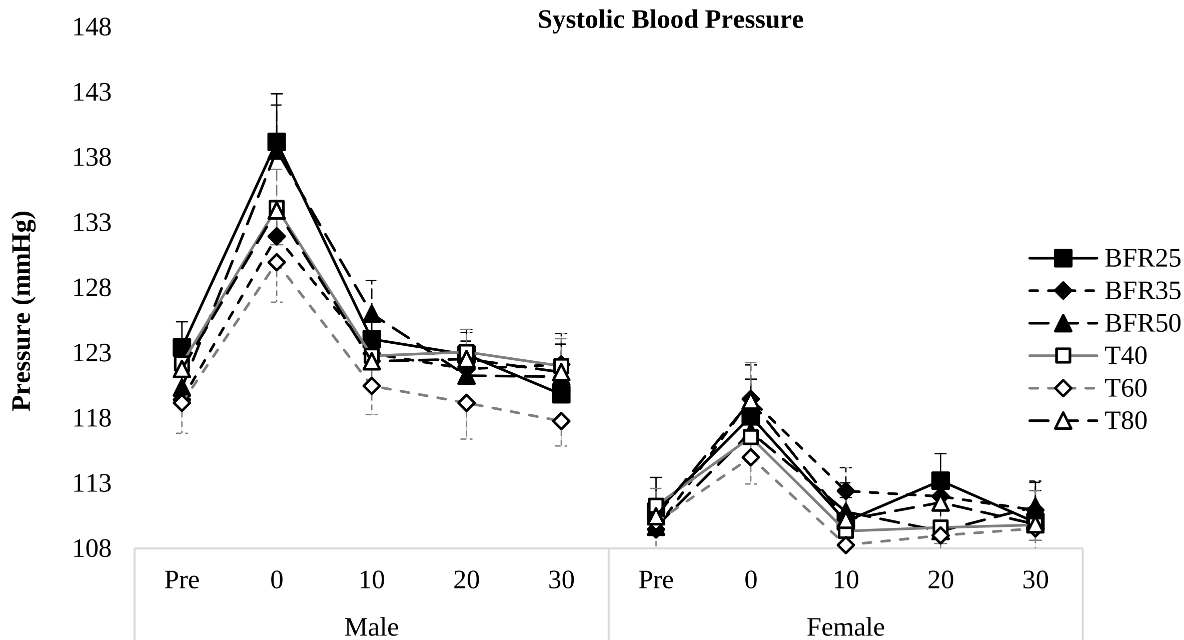
Males (N=17), Females (N=13)

[k] Significant condition differences between BFR50&T60 ($p<0.032$).

Values reported as mean ±SE.

Figure 8 shows the effects of the six different types of resistance exercise combinations with and without BFR on SBP measured at pre-exercise and 0, 10, 20, and 30-minutes post workout (Pre/Post0/Post10/Post20/Post30). Repeated measures ANOVA found a significant time main effect ($p<0.01$) and time*sex interaction ($p<0.01$). All categories were statistically similar ($p>0.05$) for condition main effect and all other interactions ($p>0.05$).

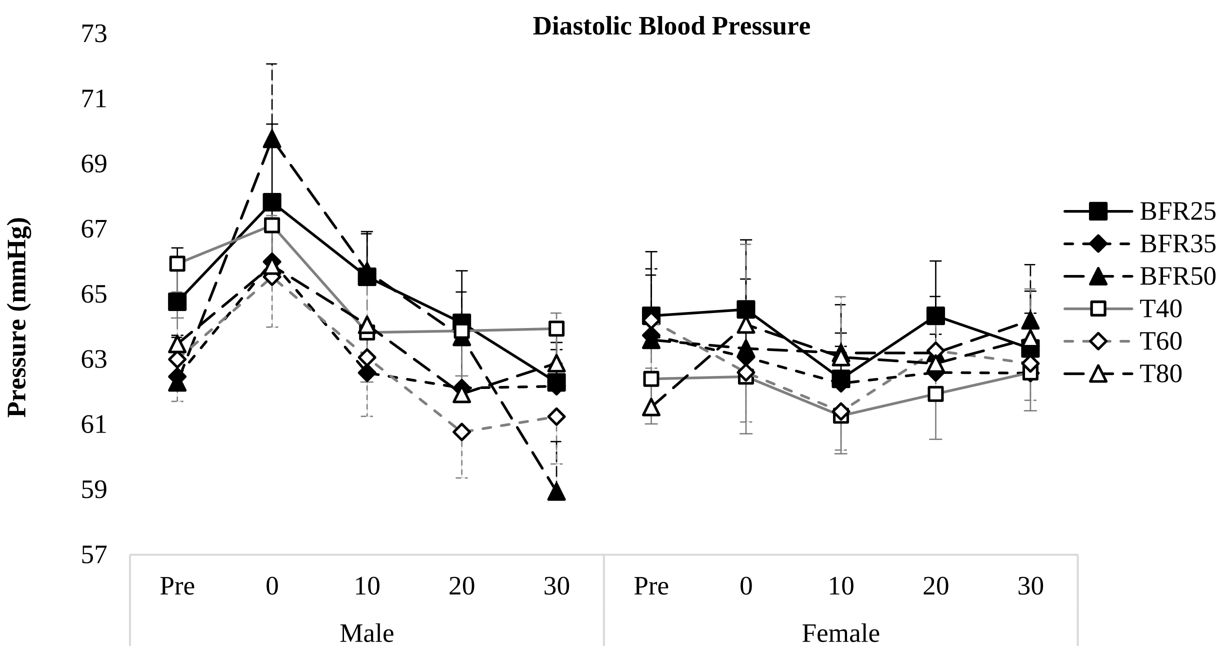
Figure 8. Systolic Blood Pressure



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 9 shows the effects of the six different types of resistance exercise combinations with and without BFR on DBP measured at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect ($p<0.01$) and time*sex interaction ($p<0.01$). All categories were statistically similar for condition main effect and all other interactions ($p>0.05$).

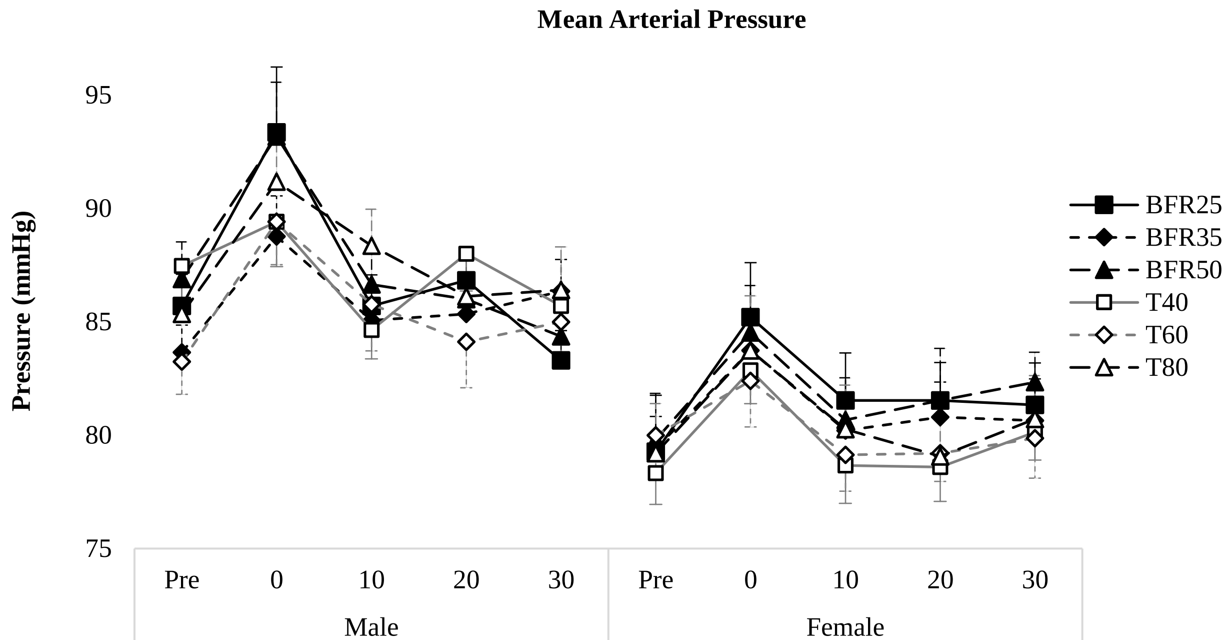
Figure 9. Diastolic Blood Pressure



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 10 shows the effects of the six different types of resistance exercise combinations with and without BFR on MAP measured at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect (p<0.01). All conditions were statistically similar for condition main effect and all other interactions (p>0.05).

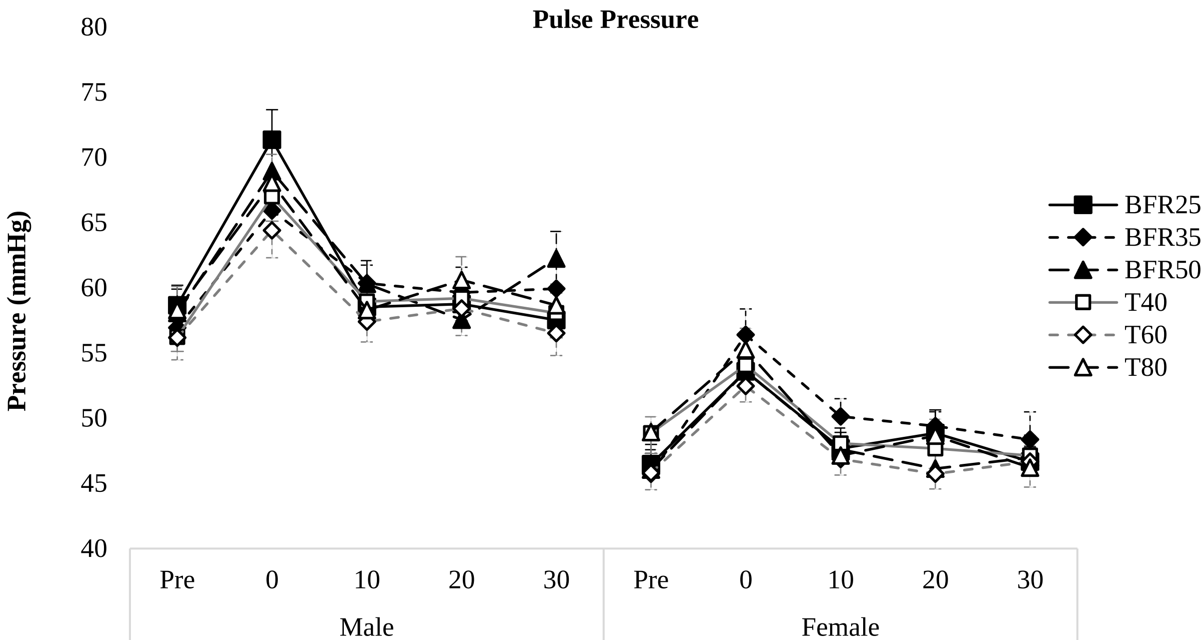
Figure 10. Mean Arterial Pressure



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 11 shows the effects of the six different types of resistance exercise combinations with and without BFR on PP measured at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect ($p<0.01$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

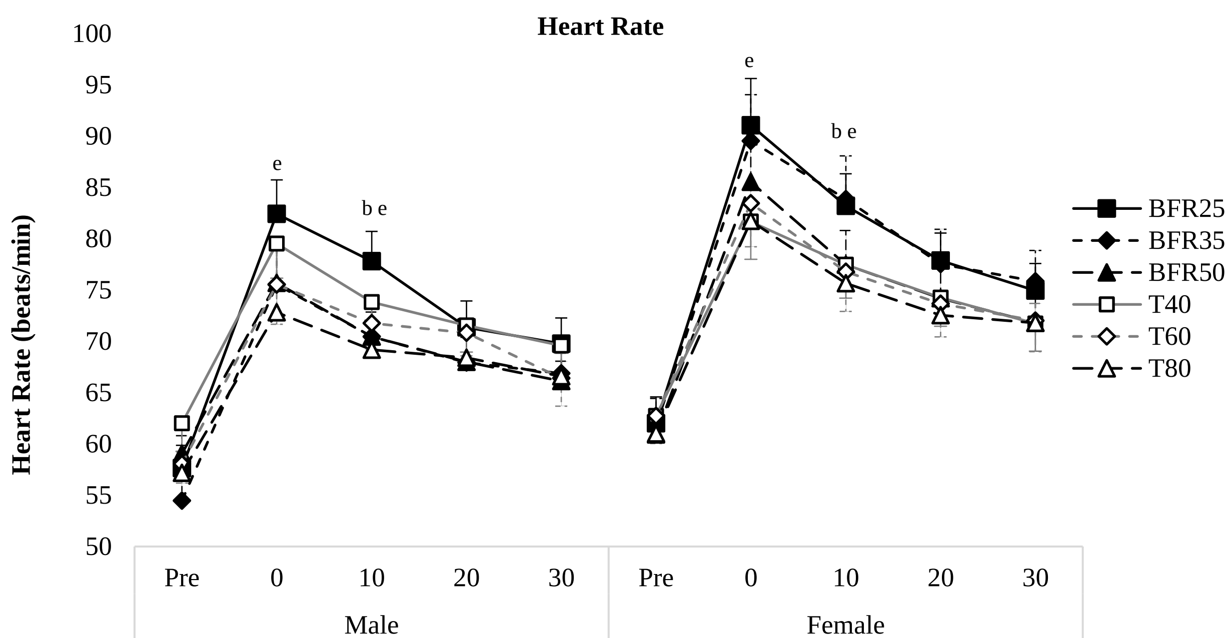
Figure 11. Pulse Pressure



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 12 shows the effects of the six different types of resistance exercise combinations with and without BFR on HR measured at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a trend for a condition main effect (p=.052), and a significant time main effect (p<0.01), and condition*time interaction (p<0.01). Categories were statistically similar for all other interactions (p>0.05). Post hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found BFR25 to have a significantly greater HR than T80 (p<0.05). Each time point was then analyzed using repeated measures ANOVA. Post hoc pairwise comparisons, using a Bonferroni adjusted for multiple comparisons, found no differences for Pre, Post20, and Post30 (p>0.05). During Post0, BFR25 had a significantly greater HR than T80 (p<0.02). During Post10, BFR25 had significantly greater HR than BFR50 (p>0.04) and T80 (p>0.01).

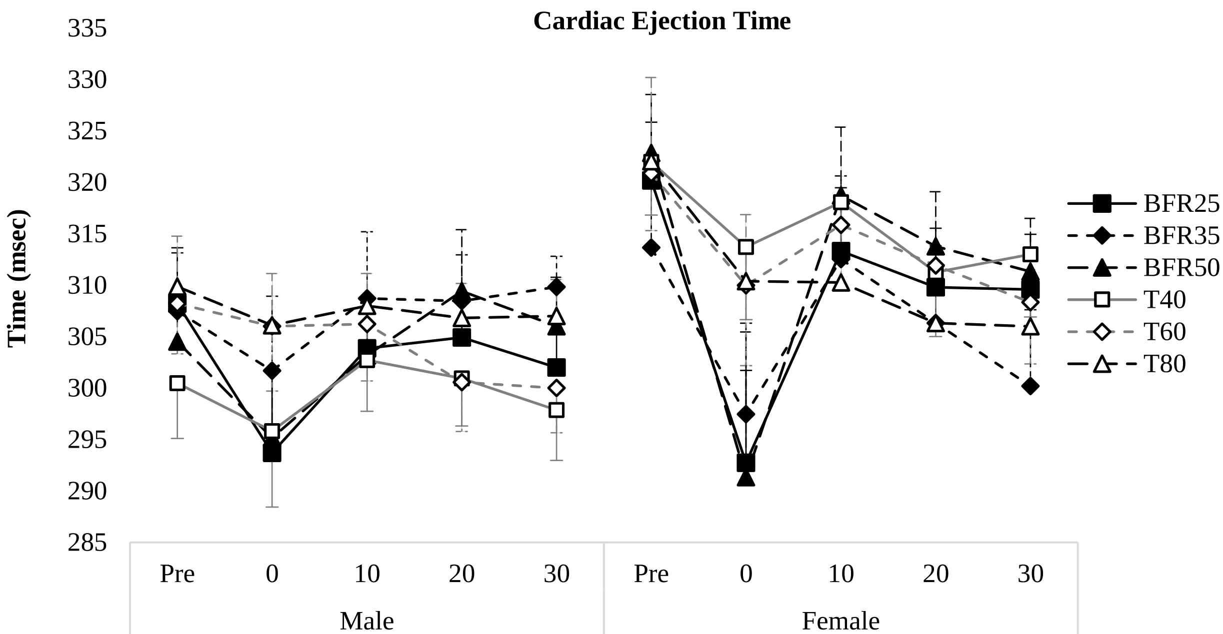
Figure 12. Heart Rate



Males (N=15), Females (N=13)
[b] Significant condition difference between BFR25&BFR50. [e] Significant condition difference between BFR25&T80. Values reported as mean ±SE.

Figure 13 shows the effects of the six different types of resistance exercise combinations with and without BFR on CEJ measured at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect ($p<0.01$) and condition*time interaction ($p<0.02$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

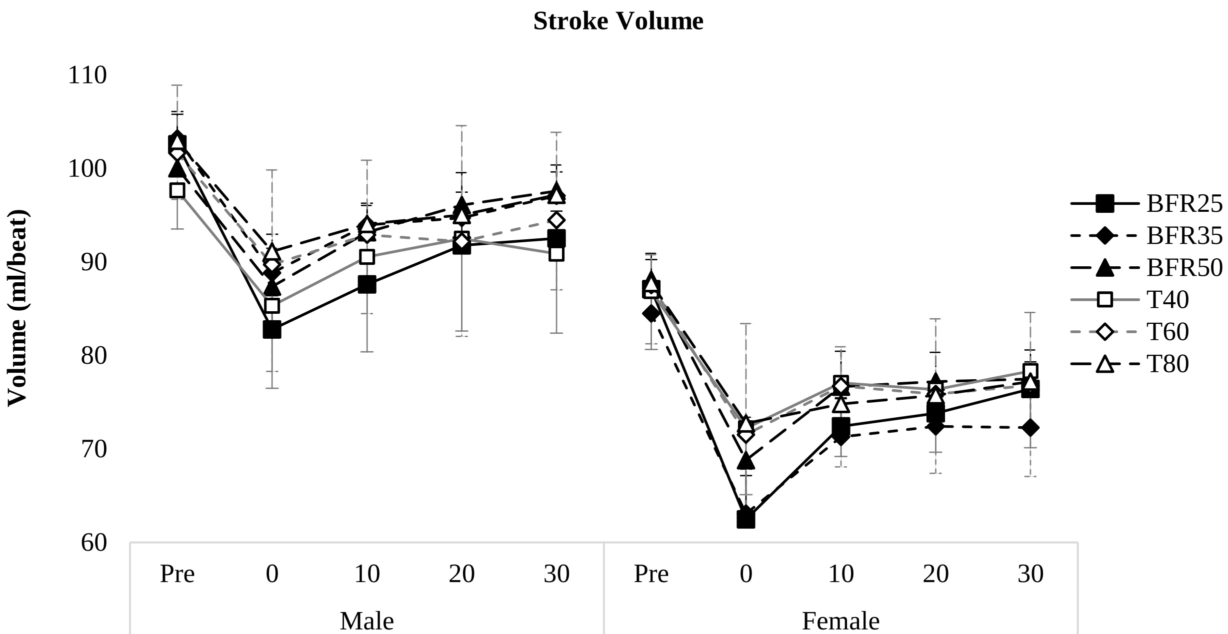
Figure 13. Cardiac Ejection Time



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 14 shows the effects of the six different types of resistance exercise combinations with and without BFR on SV measured at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect ($p<0.01$) and condition*time interaction ($p<0.03$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

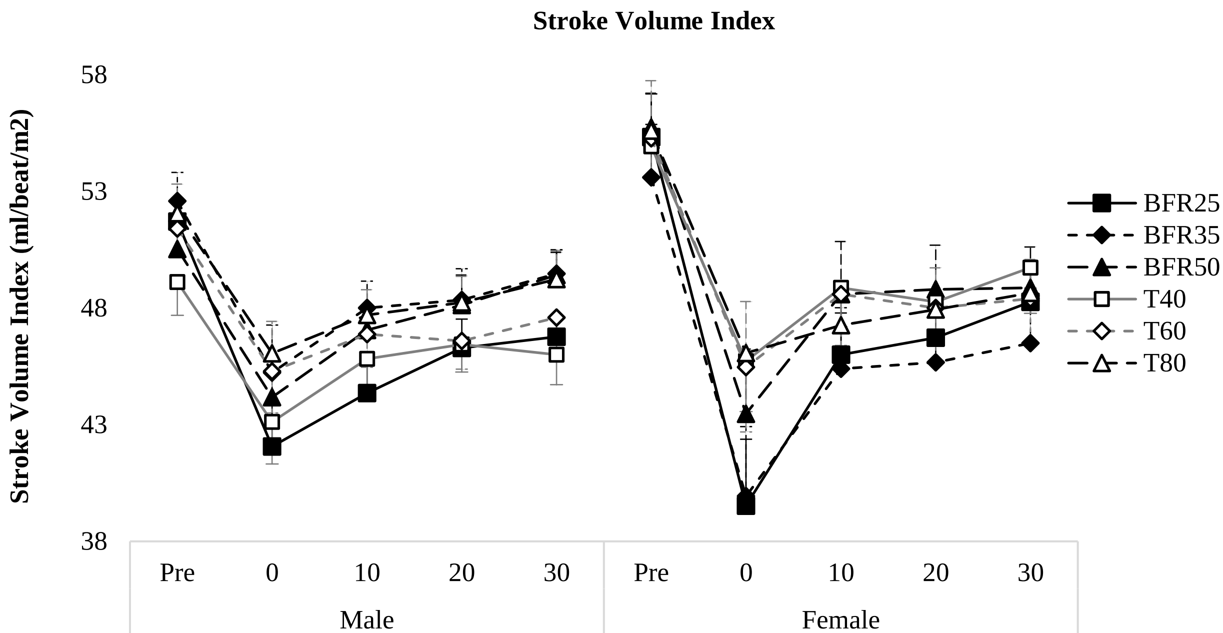
Figure 14. Stroke Volume



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 15 shows the effects of the six different types of resistance exercise combinations with and without BFR on SVI at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect (p<0.01), time*sex interaction (p<0.01), and condition*time interaction (p<0.01). All conditions were statistically similar for condition main effect and all other interactions (p>0.05).

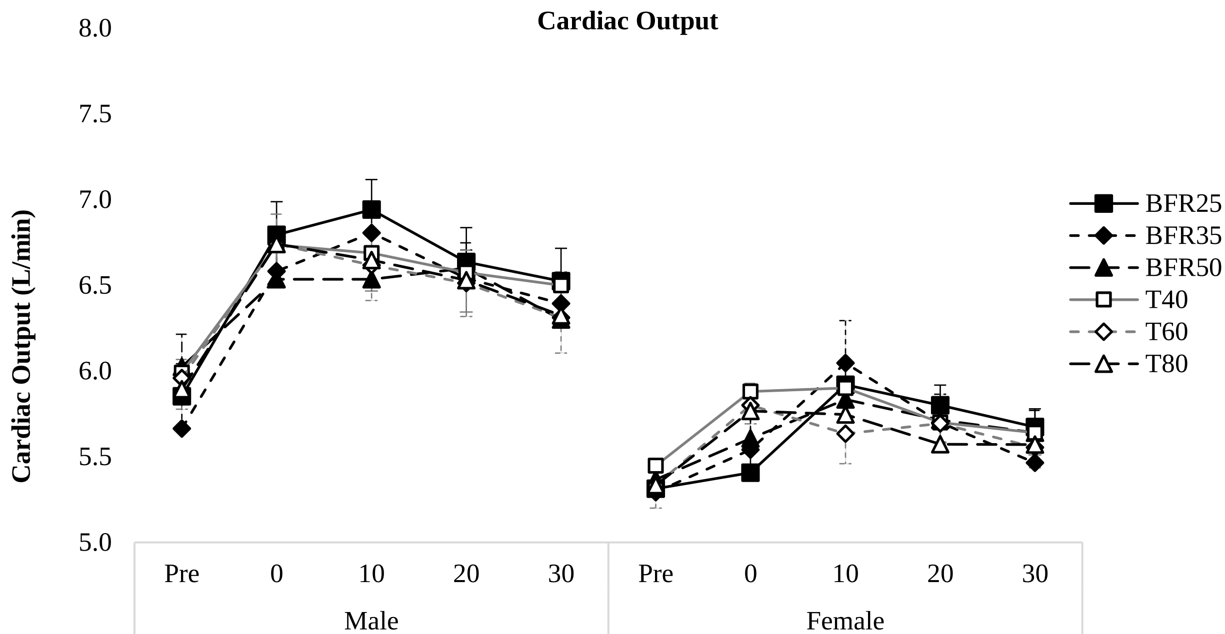
Figure 15. Stroke Volume Index



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 16 shows the effects of the six different types of resistance exercise combinations with and without BFR on SVI at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect ($p<0.01$), time*sex interaction ($p<0.01$), and condition*time interaction ($p<0.01$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

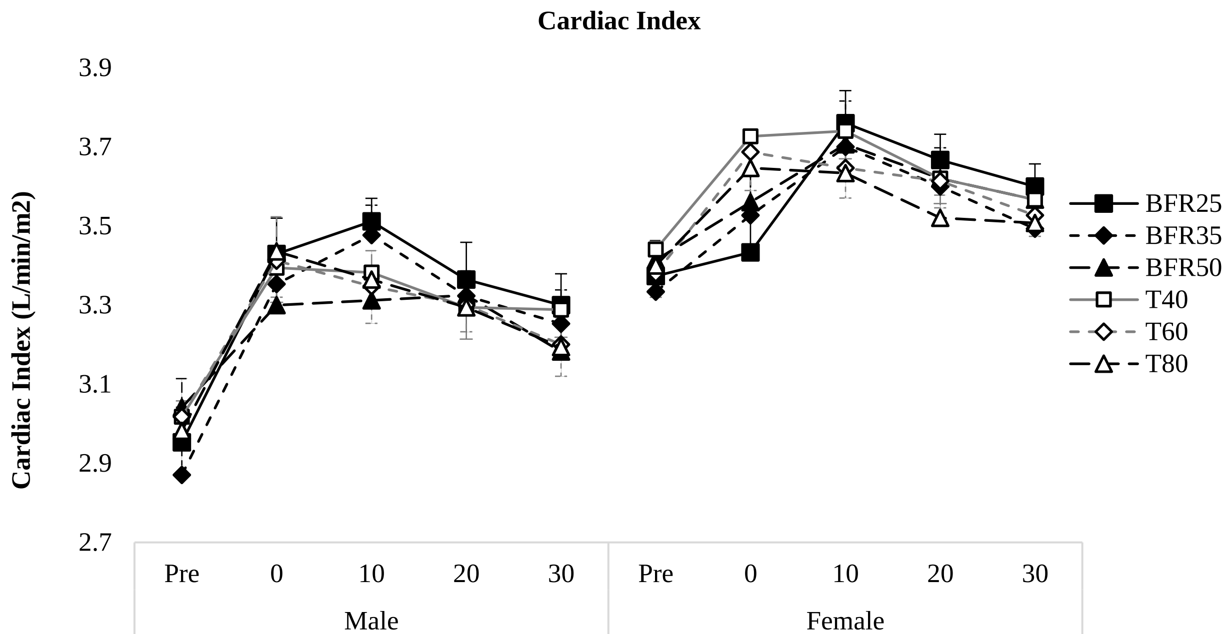
Figure 16. Cardiac Output



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 17 shows the effects of the six different types of resistance exercise combinations with and without BFR on CI at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found a significant time main effect ($p<0.01$), time*sex interaction ($p<0.03$), and condition*time interaction ($p<0.01$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

Figure 17. Cardiac Index

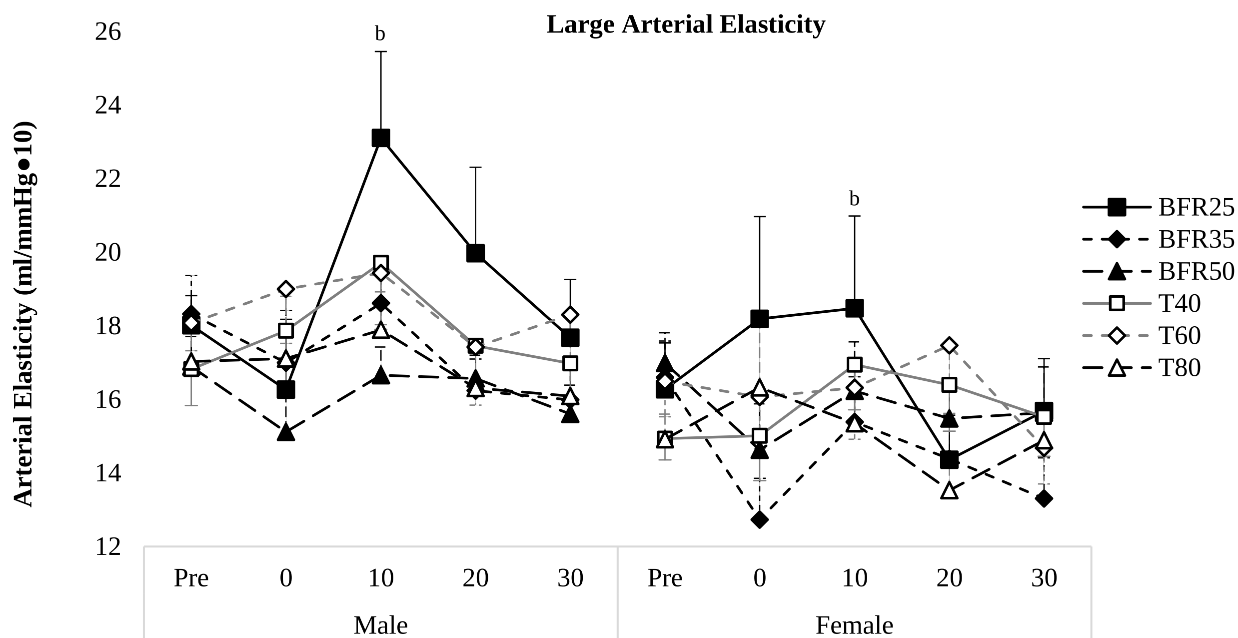


Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 18 shows the effects of the six different types of resistance exercise combinations with and without BFR on LAE at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found significant condition ($p<0.045$) and time main effects ($p<0.01$). All other interactions were statistically similar ($p>0.05$). Post-hoc pairwise analysis, using a Bonferroni correction, found no significant differences ($p>0.05$).

Each time point was then analyzed using repeated measures ANOVA. No significant differences were found for Pre, Post0, Post20, and Post30 ($p>0.05$). At Post10, LAE for BFR25 was significantly greater than BFR50 ($p<0.03$)

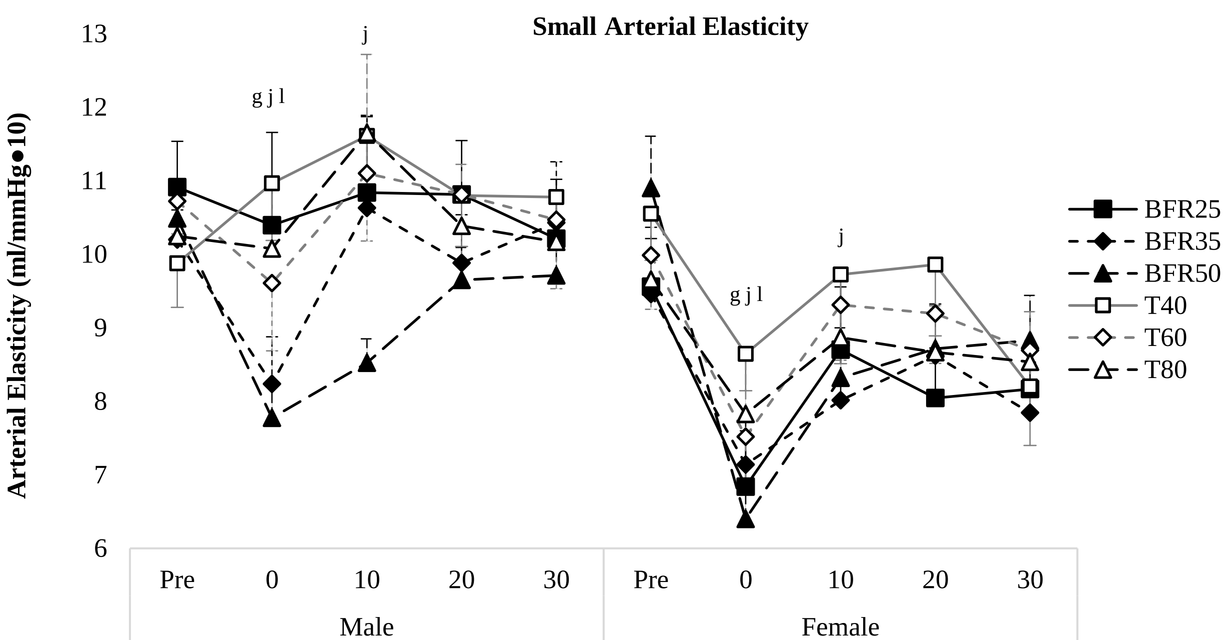
Figure 18. Large Arterial Elasticity



Males (N=15), Females (N=13)
[b] Significant condition difference between BFR25&BFR50.
Values reported as mean ±SE.

Figure 19 shows the effects of the six different types of resistance exercise combinations with and without BFR on SAE at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found significant condition ($p<0.04$) and time main effects ($p<0.01$), and time*sex interaction ($p<0.05$). All conditions were statistically similar for all other interactions ($p>0.05$). Post hoc pairwise comparisons, using Bonferroni correction, found T40 to have greater SAE than BFR50 ($p<0.01$). Each time point was then analyzed using repeated measures ANOVA. No significant differences were found for Pre, Post20, and Post30. Post hoc pairwise comparisons, using Bonferroni correction, found T40 ($p<0.01$) to have a significantly greater SAE than BFR35 and BFR50 at Post0. T80 ($p<0.01$) had a significantly greater SAE than BFR50 at Post0. During Post10, T40 ($p<0.05$) had significantly greater SAE than BFR50 and T60 showed trends ($p=.064$) to be greater than BFR50.

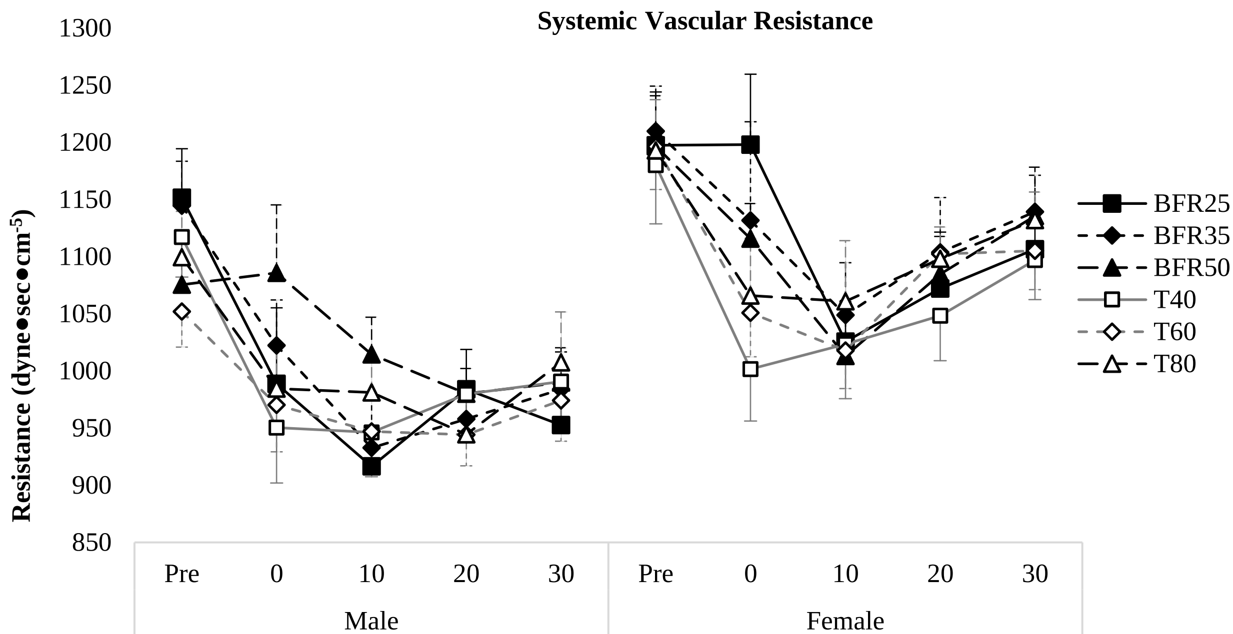
Figure 19. Small Arterial Elasticity



Males (N=15), Females (N=13)
[g] Significant condition differences between BFR35&T40 ($p<0.01$). [j] Significant differences between BFR50&T40 ($p<0.05$). [l] Significant condition differences between BFR50&T80 ($p<0.01$).
Values reported as mean ±SE.

Figure 20 shows the effects of the six different types of resistance exercise combinations with and without BFR on SVR at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found significant time main effect ($p<0.01$) and condition*time interaction ($p<0.04$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

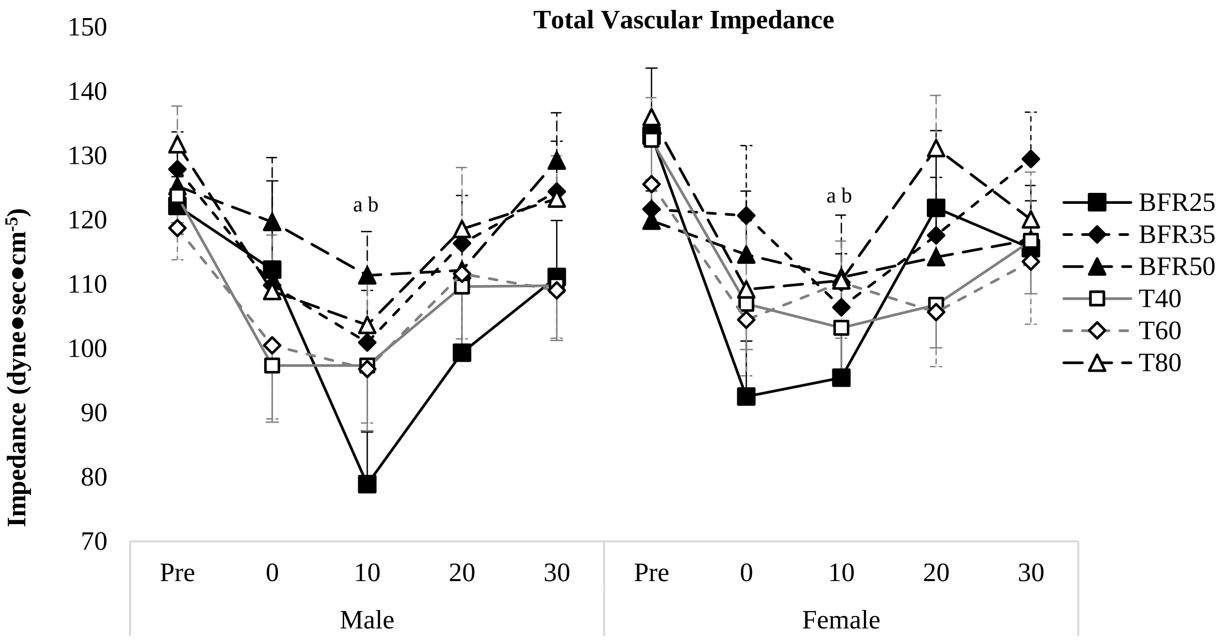
Figure 20. Systemic Vascular Resistance



Males (N=15), Females (N=13)
Values reported as mean ±SE.

Figure 21 shows the effects of the six different types of resistance exercise combinations with and without BFR on TVI at Pre, Post0, Post10, Post20, and Post30. Repeated measures ANOVA found significant condition ($p<0.01$) and time main effects ($p<0.01$). All conditions were statistically similar for all other interactions ($p>0.05$). Post hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found trends for BFR25 having a lower TVI than BFR35 ($p=0.69$) and BFR50 ($p=0.88$) Each time point was then analyzed using repeated measures ANOVA. Post hoc pairwise comparisons for the time points, using Bonferroni correction, found no significant differences for Pre, Post0, Post20 and Post30 ($p>0.05$). During Post10, BFR35 ($p<0.02$) and BFR50 ($p<0.01$) had significantly greater TVI than BFR25.

Figure 21. Total Vascular Impedance



Males (N=15), Females (N=13)

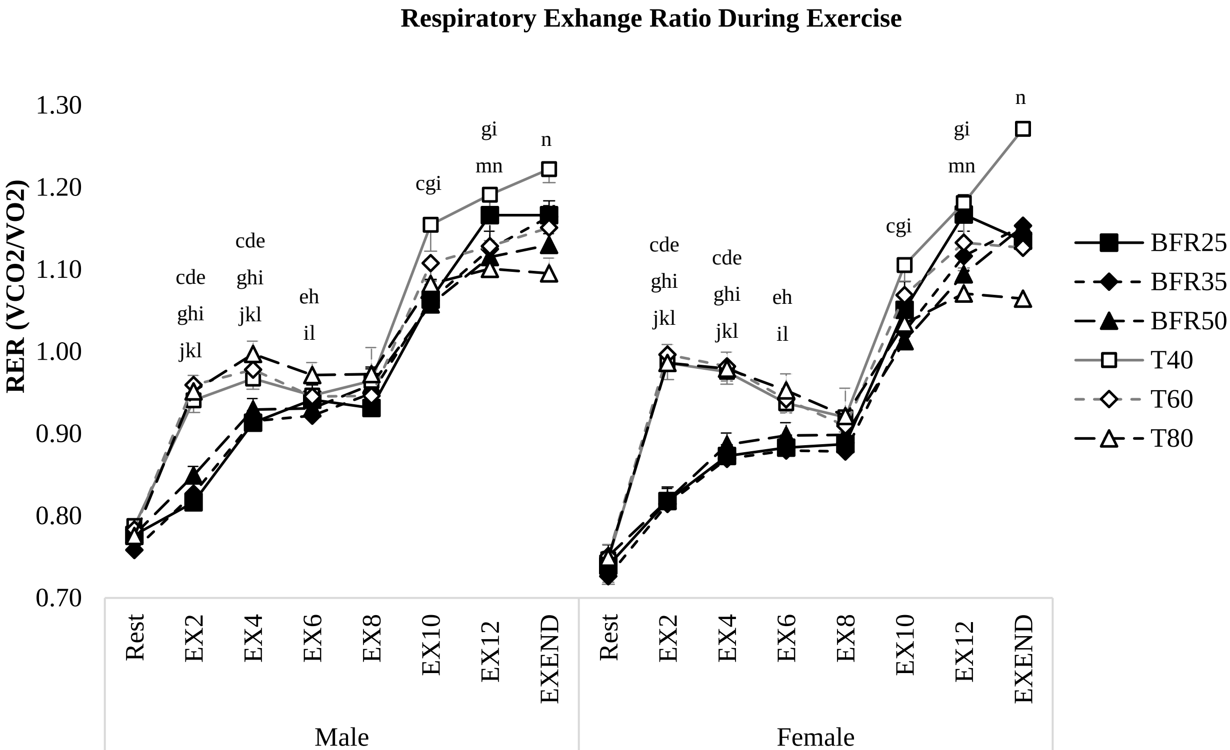
[a] Significant condition differences between BFR25&BFR35 ($p<0.02$). [b] Significant condition differences between BFR25&BFR50 ($p<0.01$).

Values reported as mean ±SE.

Respiratory Responses

Figure 22 shows the effects of the six different types of resistance exercise combinations with and without BFR on average RER every two minutes, during exercise, up to 14 minutes (Ex2, Ex4, Ex6, Ex8, Ex10, Ex12, and ExEND). Repeated measures ANOVA found significant condition ($p<0.01$) and time main effects ($p<0.01$), and a condition*time interaction ($p<0.01$). All conditions were statistically similar for all other interactions ($p>0.05$). Post hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found T40 to have a significantly greater RER than all BFR groups ($p<0.01$) and T60 had a significantly greater RER than BFR 35 ($p<0.02$) and BFR50 ($p<0.01$). Each time point was then analyzed using repeated measures ANOVA. All time points demonstrated significant condition differences, with exception of Ex8 ($p<0.05$). Post hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found all traditional groups to have significantly greater RER than the BFR groups at Ex2 and Ex4 ($p<0.01$). At Ex6, T80 had significantly greater RER than BFR25 ($p<0.03$), BFR35 ($p<0.01$), and BFR50 ($p<0.02$) and T60 was significantly greater than BFR35 ($p<0.01$). At Ex10, T40 had a significantly greater RER than BFR25 ($p<0.02$), BFR35 ($p<0.02$), and BFR50 ($p<0.01$). At Ex12, T40 had a significantly greater RER than BFR35, BFR50, T60, and T80 ($p<0.01$). At ExEND, T40 had a significantly greater RER than T80 ($p<0.01$).

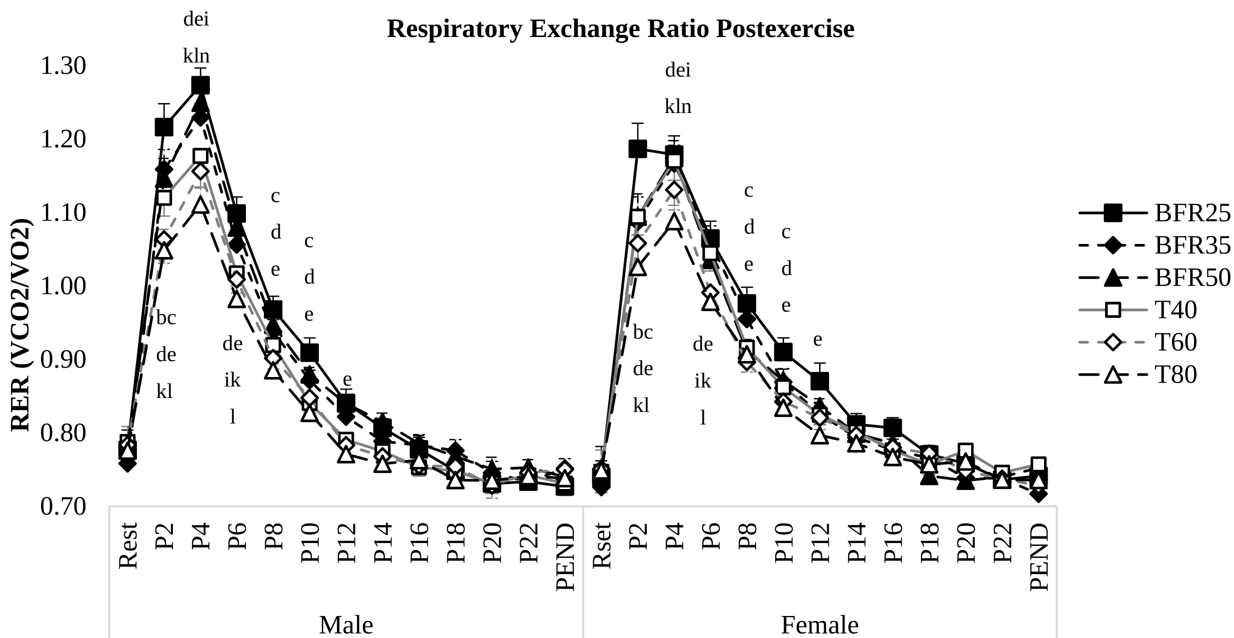
Figure 22. Respiratory Exchange Ratio During Exercise



Males (N=13), Females (N=11)
[c] Significant condition differences between BFR25&T40. [d] Significant condition differences between BFR25&T60.
[e] Significant condition differences between BFR25&T80. [g] Significant condition differences between BFR35&T40.
[h] Significant condition differences between BFR35&T60. [i] Significant condition differences between BFR35&T80.
[j] Significant condition differences between BFR50&T40. [k] Significant condition differences between BFR50&T60.
[l] Significant condition differences between BFR50&T80. [m] Significant condition differences between T40&T60.
[n] Significant condition differences between T40&T80.
Values reported as mean ±SE.

Figure 23 shows the effects of the six different types of resistance exercise combinations with and without BFR on average RER every two minutes, post-exercise, up to 25minutes (Post2, Post4, Post6, Post8, Post10, Post12, Post14, Post16, Post18, Post20, Post20, Post22, and PostEND). Repeated measures ANOVA found condition ($p<0.01$) and time main effects ($p<0.01$), and condition*time interaction ($p<0.01$). All conditions were statistically similar for all other interactions ($p>0.05$). Post hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found BFR25 to have a significantly greater RER than T60 and T80 ($p<0.01$). Each time point was then analyzed using repeated measures ANOVA. Significant condition differences were found at Post2 ($p<0.01$), Post4 ($p<0.01$), Post6 ($p<0.01$), Post8 ($p<0.01$), Post10 ($p<0.01$), Post12 ($p<0.01$), but the rest of the time points were statistically similar ($p>0.05$). Post hoc pairwise comparisons, using Bonferroni adjustment for multiple comparisons, found BFR25 to have a significantly greater RER than BFR50 ($p<0.04$) and all traditional groups ($p<0.01$) at Post2. At Post 4, BFR25 had a significantly greater RER than T60 ($p<0.02$) and T80 ($p<0.01$) and BFR35 was greater than T60 ($p<0.04$). BFR50 had a significantly greater RER than T60 and T80 ($p<0.01$). T40 had a significantly greater RER than T60 ($p<0.01$). At Post6, all BFR groups had significantly greater RER than T80 ($p<0.05$), and BFR25 and BFR50 was significantly greater than T40 ($p<0.01$). At Post8 and Post10, BFR25 had a significantly greater RER than T40 ($p<0.04$), T60 ($p<0.01$), and T80 ($p<0.02$). At Post12, BFR25 had a greater RER than T80 ($p<0.02$).

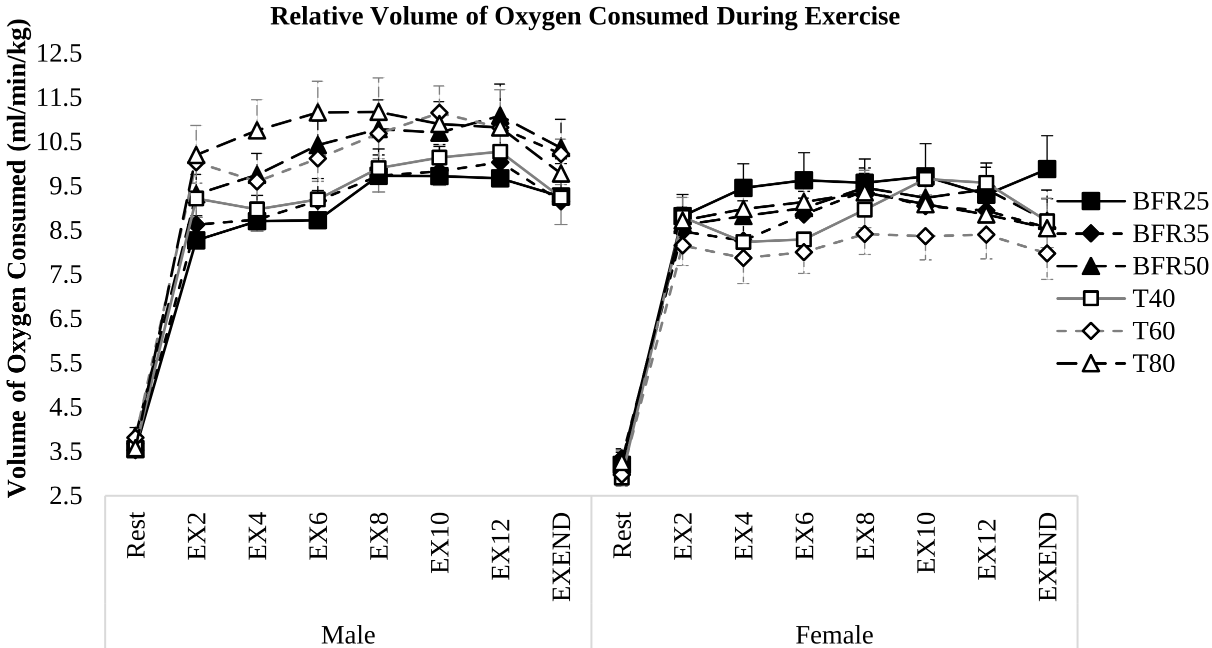
Figure 23. Respiratory Exchange Ratio Post-Exercise



Males (N=13), Females (N=8)
[b] Significant condition differences between BFR25&BFR50. [c] Significant condition differences between BFR25&T40. [d] Significant condition differences between BFR25&T60. [e] Significant condition differences between BFR25&T80. [i] Significant condition differences between BFR35&T80. [k] Significant condition differences between BFR50&T60. [l] Significant condition differences between BFR50&T80. [n] Significant condition differences between T40&T80.
Values reported as mean ±SE.

Figure 24 shows the effects of the six different types of resistance exercise combinations with and without BFR on average VO_2 (ml/min/kg) every two minutes, during exercise, up to 14 minutes (Ex2, Ex4, Ex6, Ex8, Ex10, Ex12, and ExEND). Repeated measures ANOVA found a significant time main effect ($p<0.01$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

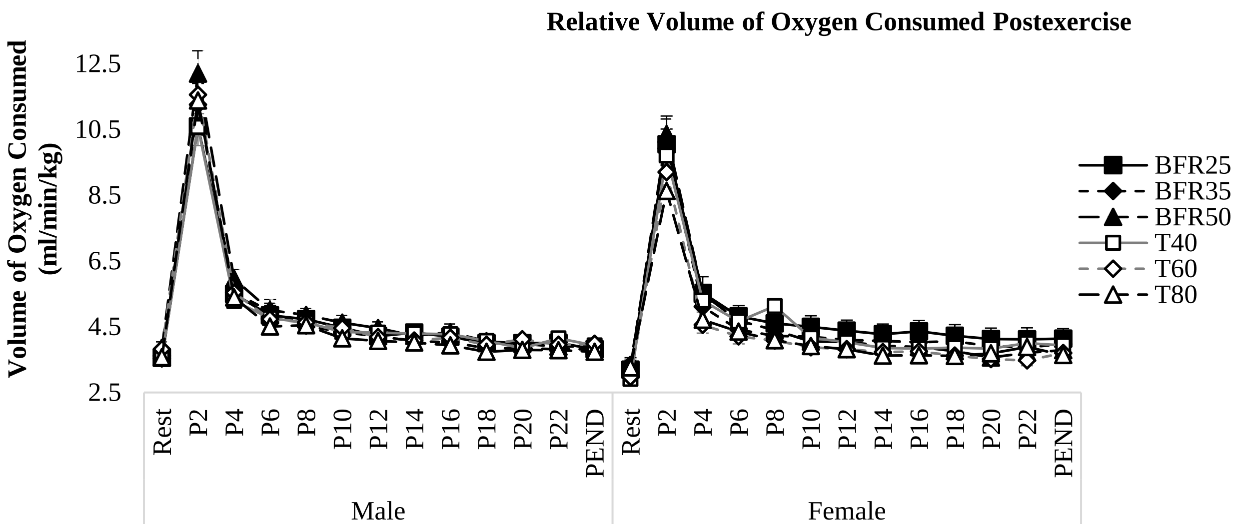
Figure 24. Relative Volume of Oxygen Consumed During Exercise



Males (N=13), Females (N=12)
Values reported as mean ±SE.

Figure 25 shows the effects of the six different types of resistance exercise combinations with and without BFR on average relative VO_2 every two minutes, post-exercise, up to 25minutes (Post2, Post4, Post6, Post8, Post10, Post12, Post14, Post16, Post18, Post20, Post20, Post22, and PostEND). Repeated measures ANOVA found a significant time main effect ($p<0.01$). All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

Figure 25. Relative Volume of Oxygen Consumed Postexercise

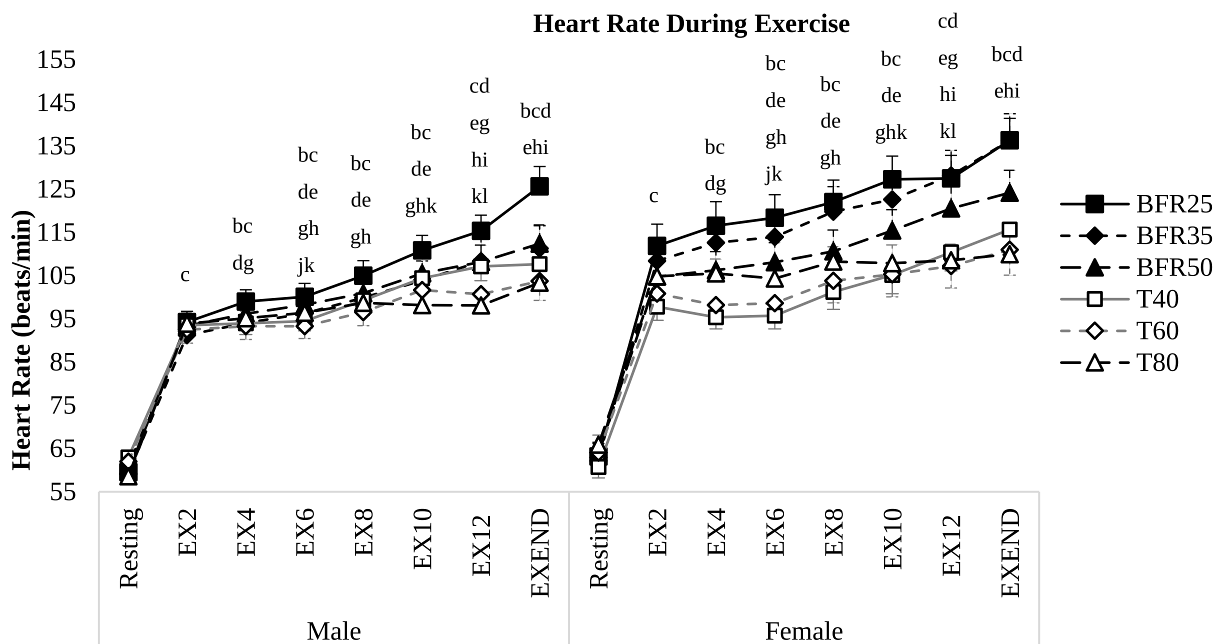


Males (N=13), Females (N=8)
Values reported as mean ±SE.

Figure 26 shows the effects of the six different types of resistance exercise combinations with and without BFR on average HR measured every two minutes by the OxyCon Mobile unit, during exercise, up to 14 minutes (Ex2, Ex4, Ex6, Ex8, Ex10, Ex12, and ExEND). Repeated measures ANOVA found significant condition ($p<0.01$) and time main effects ($p<0.01$) and condition*time and condition*sex ($p<0.03$) interactions. All conditions were statistically similar for all other interactions ($p>0.05$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found BFR25 to have significantly greater HR for BFR50 ($p<0.02$) and all traditional groups ($p<0.01$). BFR35 had significantly greater HR than T40 ($p<0.03$) and T60 ($p<0.01$). BFR50 had significantly greater HR than T60 ($p<0.05$). Each time point was then analyzed using repeated measures ANOVA. Condition main effects were found for Ex2 ($p<0.01$), Ex4 ($p<0.01$), Ex6 ($p<0.01$), Ex8 ($p<0.01$), Ex10 ($p<0.01$), Ex12 ($p<0.01$), and ExEND ($p<0.01$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found BFR25 to have a significantly greater HR than T40 ($p<0.04$) at Ex2. At Ex4, BFR25 had a significantly greater HR than BFR50 ($p<0.02$), T40 ($p<0.01$), and T60 ($p<0.01$). BFR35 had a significantly greater HR than T40 ($p<0.02$). At Ex6, BFR25 had a significantly greater HR than BFR50 ($p<0.02$), T40 ($p<0.01$), T60 ($p<0.01$), and T80 ($p<0.01$). BFR35 ($p<0.01$) and BFR50 ($p<0.02$) had significantly greater HR than T40 and T60. At Ex8, BFR25 had a significantly greater HR than BFR50 ($p<0.01$), T40 ($p<0.01$), T60 ($p<0.01$), and T80 ($p<0.01$). BFR35 had a significantly greater HR than T40 ($p<0.01$) and T60 ($p<0.03$). At Ex10, BFR25 had a significantly greater HR than BFR50 ($p<0.03$), T40 ($p<0.01$), T60 ($p<0.01$), and T80 ($p<0.01$). BFR35 had a significantly greater HR than T40 ($p<0.04$) and T60 ($p<0.01$). BFR50 had a significantly greater HR than T60 ($p<0.03$). At Ex12, BFR25 ($p<0.01$) had a significantly greater HR than T40, T60, and T80 and BFR35 had a significantly greater HR than

T40 (p<0.03), T60 (p<0.01), and T80 (p<0.01). BFR50 had a significantly greater HR than T60 (p<0.01) and T80 (p<0.04). At ExEND, BFR25 (p<0.01) had a significantly greater HR than BFR35 and all traditional resistance groups and BFR35 (p<0.02) had a significantly greater HR than T60 and T80.

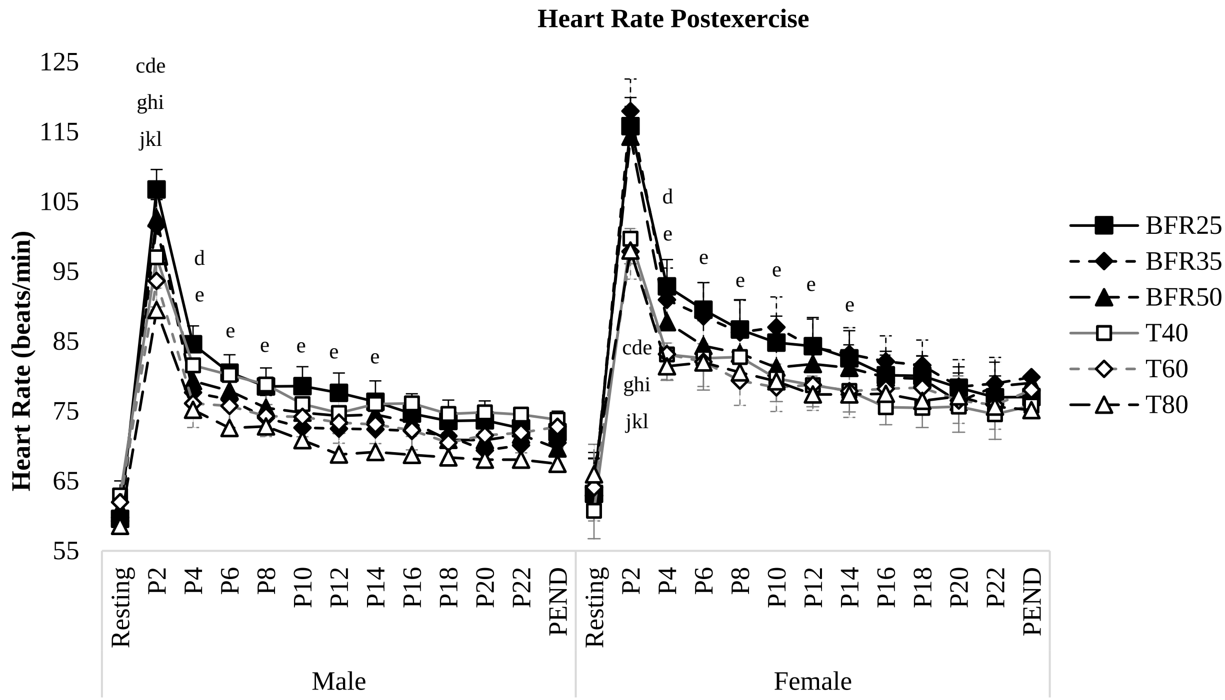
Figure 26. Heart Rate During Exercise



Males (N=12), Females (N=12)
[b] Significant condition differences between BFR25&BFR50. [c] Significant condition differences between BFR25&T40. [d] Significant condition differences between BFR25&T60. [e] Significant condition differences between BFR25&T80. [g] Significant condition differences between BFR35&T40. [h] Significant condition differences between BFR35&T60. [i] Significant condition differences between BFR35&T80. [i] Significant condition differences between BFR50&T40. [k] Significant condition differences between BFR50&T60. [l] Significant condition differences between BFR50&T80.
Values reported as mean ±SE.

Figure 27 shows the effects of the six different types of resistance exercise combinations with and without BFR on average HR measured every two minutes by the OxyconMobile unit, postexercise, up to 25 minutes (Post2, Post4, Post6, Post8, Post10, Post12, Post14, Post16, Post18, Post20, Post22, Post24, and PostEND). Repeated measures ANOVA found condition ($p<0.01$) and time main effects ($p<0.01$) and a condition*time ($p<0.01$) interaction. All conditions were statistically similar for all other interactions ($p>0.05$). Each time point was then analyzed using repeated measures ANOVA. Condition main effects were found for Post2 ($p<0.01$), Post4 ($p<0.01$), Post6 ($p<0.03$), Post8 ($p<0.03$), Post10 ($p<0.01$), Post12 ($p<0.01$), Post14 ($p<0.01$), and Post16 ($p<0.04$). Post hoc pairwise comparisons, using a Bonferroni adjustment for multiple comparisons, found all BFR ($p<0.01$) groups to have a significantly greater HR than T60 and T80. BFR25 ($p<0.01$), BFR35 ($p<0.04$), and BFR50 ($p<0.02$) had a significantly greater HR than T40 at Post2. At Post4, BFR25 had a significantly greater HR than T60 ($p<0.04$) and T80 ($p<0.01$). At Post6, BFR25 had a significantly greater HR than T80 ($p<0.05$). At Post8, BFR25 had a significantly greater HR than T80 ($p<0.04$). At Post10, BFR25 had a significantly greater HR response than T80 ($p<0.04$). At Post12, BFR25 had a significantly greater HR than T80 ($p<0.01$). At Post14, BFR25 had a significantly greater HR than T80 ($p<0.02$).

Figure 27. Heart Rate Postexercise



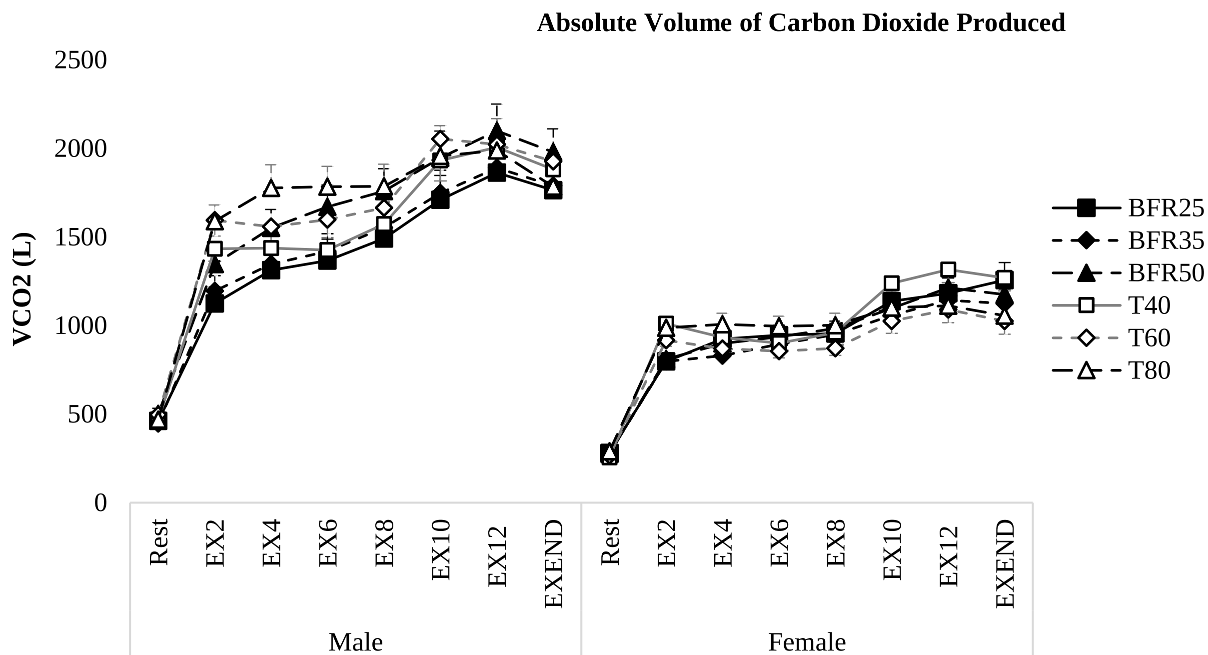
Males (N=9), Females (N=4)

[c] Significant condition differences between BFR25&T40. [d] Significant condition differences between BFR25&T60.
[e] Significant condition differences between BFR25&T80. [g] Significant condition differences between BFR35&T40.
[h] Significant condition differences between BFR35&T60. [i] Significant condition differences between BFR35&T80.
[j] Significant condition differences between BFR50&T40. [k] Significant condition differences between BFR50&T60.
[l] Significant condition differences between BFR50&T80.

Values reported as mean ±SE.

Figure 28 shows the effects of the six different types of resistance exercise combinations with and without BFR on absolute VCO_2 measured totaled every two minutes by during exercise up to 14 minutes (Ex2, Ex4, Ex6, Ex8, Ex10, Ex12, and ExEND). Repeated measures ANOVA found a significant time main effect ($p<0.01$) and condition*time ($p<0.01$), condition*sex ($p<0.05$), and time*sex ($p<0.01$) interactions. All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

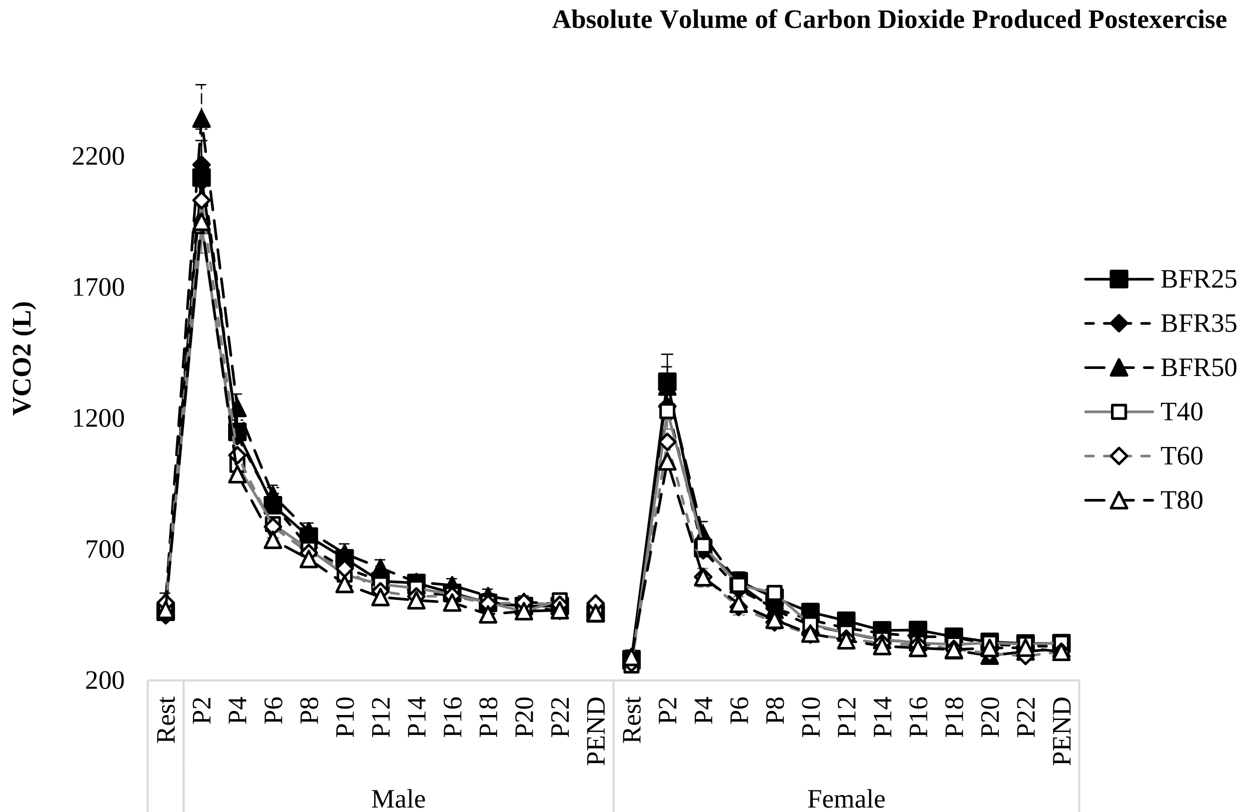
Figure 28. Volume of Carbon Dioxide Produced During Exercise



Males (N=13), Females (N=11)
Values reported as mean ±SE.

Figure 29 shows the effects of the six different types of resistance exercise combinations with and without BFR on absolute VCO_2 measured totaled every two minutes postexercise, up to 25 minutes (Post2, Post4, Post6, Post8, Post10, Post12, Post14, Post16, Post18, Post20, Post22, Post24, and PostEND). Repeated measures ANOVA found a time main effect ($p<0.01$), condition*time ($p<0.01$) and time*sex ($p<0.05$) interactions. All conditions were statistically similar for condition main effects and all other interactions ($p>0.05$).

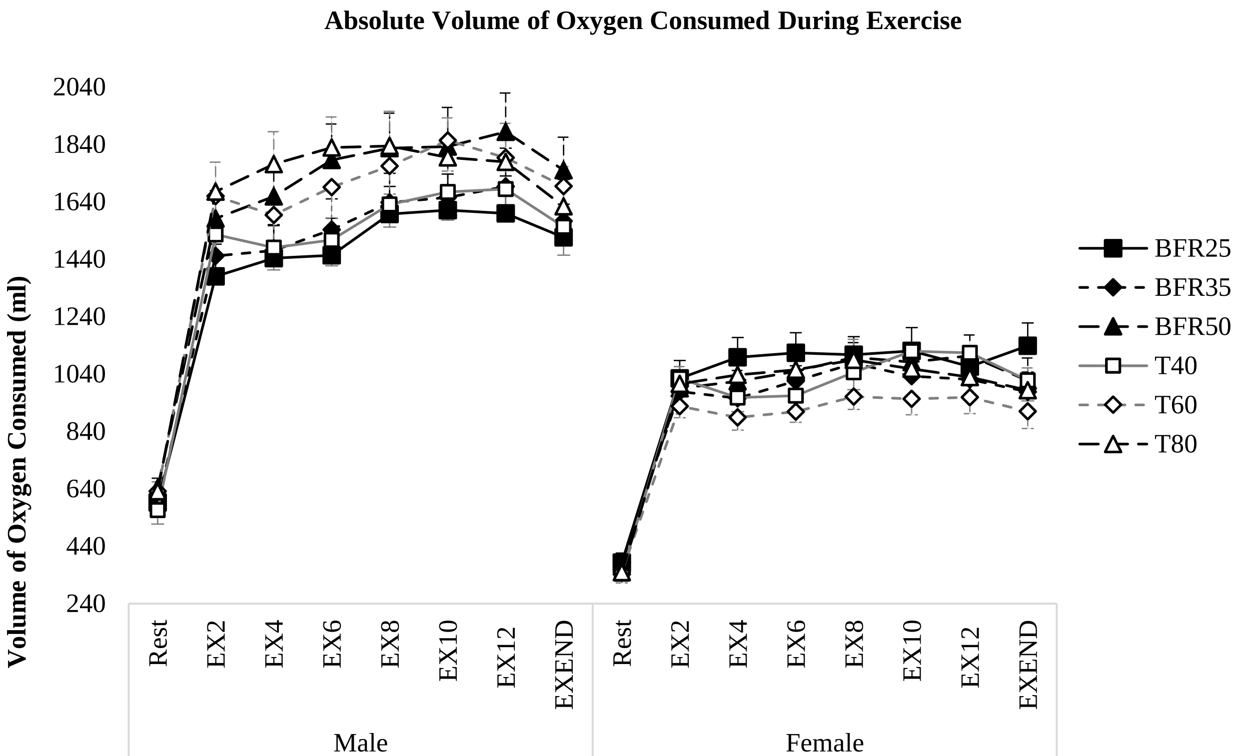
Figure 29. Volume of Carbon Dioxide Produce Postexercise



Males (N=13), Females (N=4)
Values reported as mean ±SE.

Figure 30 shows the effects of the six different types of resistance exercise combinations with and without BFR on absolute VCO_2 measured totaled every two minutes by during exercise up to 14 minutes (Ex2, Ex4, Ex6, Ex8, Ex10, Ex12, and ExEND). Repeated measures ANOVA found a significant time main effect ($p<0.01$) and condition*time ($p<0.01$), condition*sex ($p<0.05$), and time*sex ($p<0.01$) interactions. All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

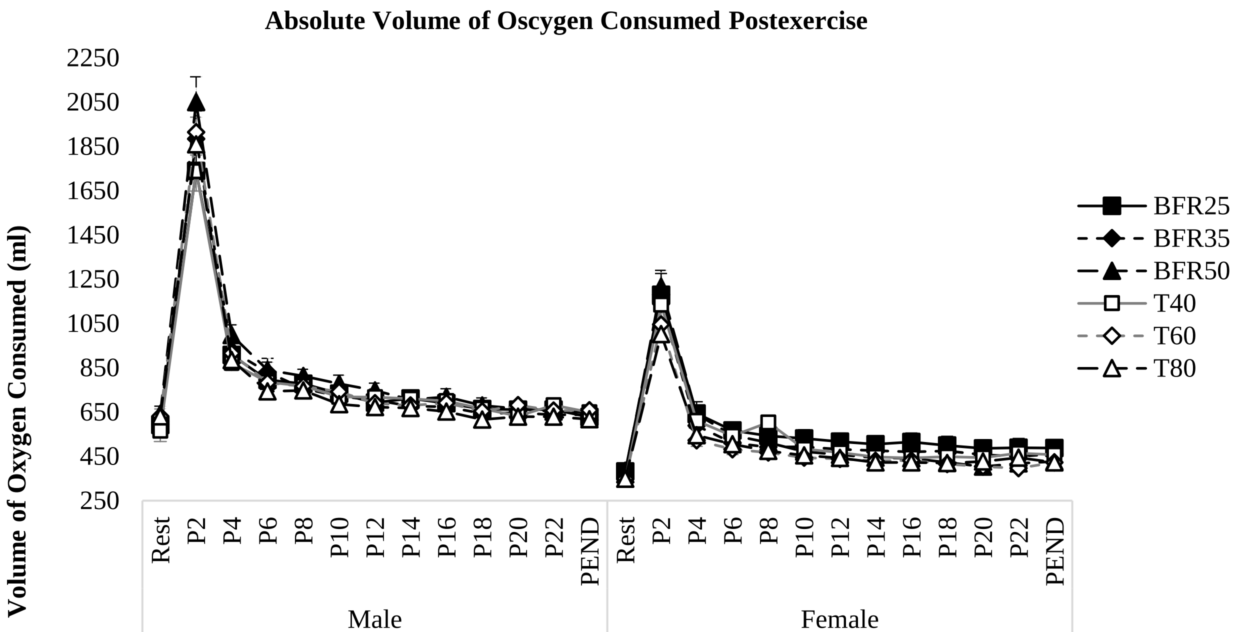
Figure 30. Absolute Volume of Oxygen Consumed During Exercise



Males (N=13), Females (N=11)
Values reported as mean ±SE.

Figure 31 shows the effects of the six different types of resistance exercise combinations with and without BFR on absolute VCO_2 measured totaled every two minutes postexercise, up to 25 minutes (Post2, Post4, Post6, Post8, Post10, Post12, Post14, Post16, Post18, Post20, Post22, Post24, and PostEND). Repeated measures ANOVA found significant time main effect ($p<0.01$) and condition*time ($p<0.01$), and time*sex ($p<0.05$) interactions. All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

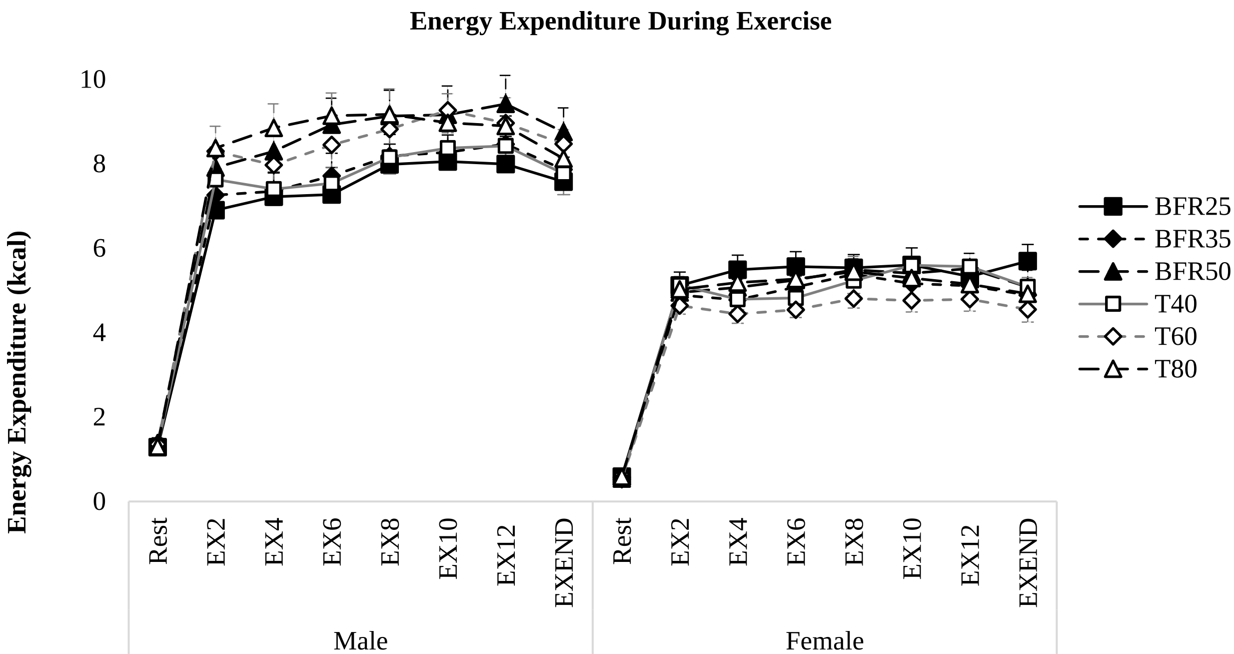
Figure 31. Absolute Volume of Oxygen Consumed Postexercise



Males (N=13), Females (N=4)
Values reported as mean ±SE.

Figure 32 shows the effects of the six different types of resistance exercise combinations with and without BFR on EE totaled every two minutes during exercise up to 14 minutes (Ex2, Ex4, Ex6, Ex8, Ex10, Ex12, and ExEND). Repeated measures ANOVA found significant time main effect ($p<0.01$), and condition*sex ($p<0.04$) and time*sex ($p<0.05$) interactions. All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

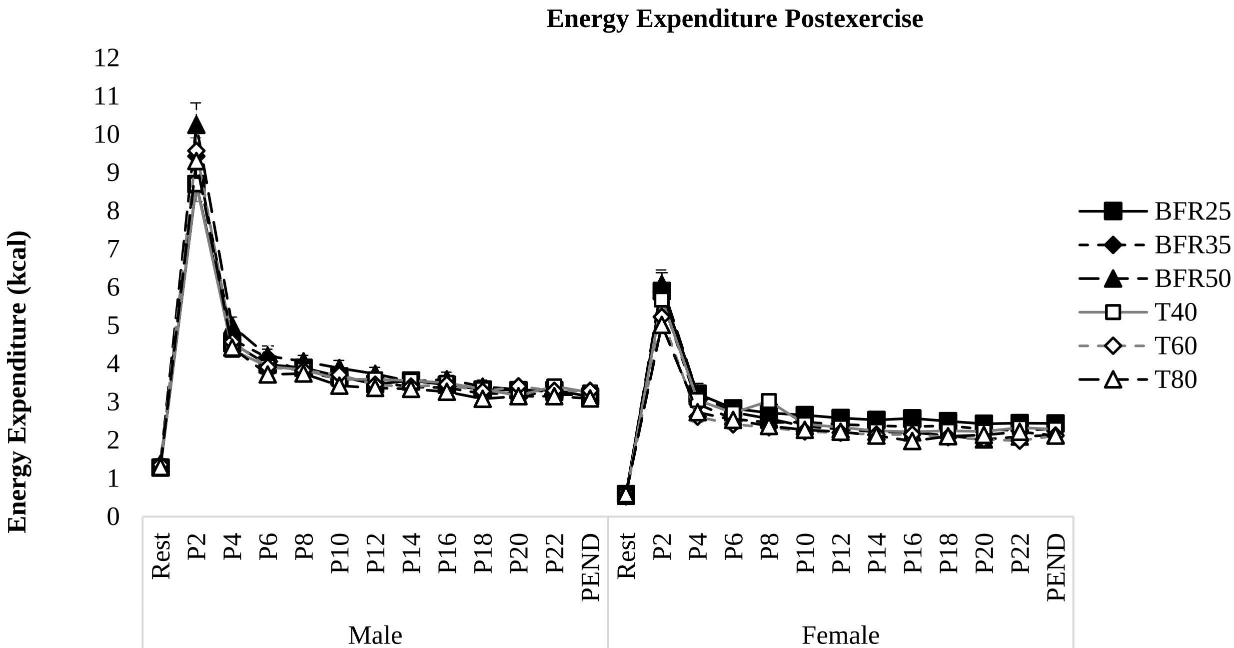
Figure 32. Energy Expenditure During Exercise



Males (N=13), Females (N=11)
Values reported as mean ±SE.

Figure 33 shows the effects of the six different types of resistance exercise combinations with and without BFR on absolute VCO_2 measured totaled every two minutes postexercise, up to 25 minutes (Post2, Post4, Post6, Post8, Post10, Post12, Post14, Post16, Post18, Post20, Post22, Post24, and PostEND). Repeated measures ANOVA found a significant time main effect ($p<0.01$) and time*sex ($p<0.05$) interaction. All conditions were statistically similar for condition main effect and all other interactions ($p>0.05$).

Figure 33. Energy Expenditure Postexercise



Males (N=13), Females (N=4)
Values reported as mean ±SE.

CHAPTER V

DISCUSSION

The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions (T40, T60, and T80) and resistance exercise sessions using BFR (BFR25, BFR35, and BFR50) on LAE and SAE 2) to examine how these varying training modalities affect HR, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI, SVR and TVI in recreationally active male and female subjects 3) to determine how the varying training modalities affect HR, RPE, VO_2, VCO_2, and EE during and postexercise in recreationally active males and females.

Subjective Performance

The present study found condition and time main effects ($p<0.05$) in RPE between the six conditions during the leg curl sets. T80 had the greatest RPE ($p<0.05$) during the first set versus BFR25, BFR35, BFR50, T40, and T60 (13.3±0.4 vs. 11.3±0.4, 11.0±.03, 11.0±.04, 10.1±0.4, and 10.6±0.3), while BFR25 and BFR50 had greater RPE than T40 ($p<0.05$). Yet by the fourth set BFR25, BFR35, and BFR50 were statistically similar ($p>0.05$) in RPE to T80 (14.5±0.5, 13.8±0.5, 13.7±.04, and 15.2±0.4), and were all significantly greater ($p<0.05$) than T40 and T60 (11.3±0.4 and 11.9±0.4). Leg extensions also demonstrated condition and time main effects ($p<0.05$) for RPE. Following the first set of leg extensions, T80 had a greater ($p<0.05$) RPE than BFR50 and T40 (14.3±0.3, 12.9±0.3, and 12.3±0.3), but was statistically similar ($p>0.05$) to BFR25, BFR35, and T60 (13.2±0.3, 13.3±0.3, and 13.1±0.3). By the completion of the fourth

set, BFR25 showed a trend ($p=0.56$) towards having a significantly greater RPE than BFR35 (17.2±0.4, 15.7±0.5) and had a greater RPE ($p<0.05$) than BFR50, T40, T60, and T80 (15.7±0.4, 13.9±0.4, 14.4±0.4, and 15.3±0.4). BFR35, BFR50, and T80 had greater ($p<0.05$) RPE than T40, while BFR35 had a greater ($p<0.05$) RPE than T60. The present study differs from prior studies, in which BFR provided a lower RPE than traditional resistance exercise (Yasuda et al., 2011; Wernbom et al., 2006 & 2009; Araujo, 2015). Wernbom et al. (2006 & 2009) found that when sets to failure were performed, at the same percent 1RM, RPE of the non-occluded and occluded leg were similar. Similarly, Araujo (2015) found 80% intensity to elicit a much greater RPE (eight vs six) than BFR. The different outcomes could be due to the methodological differences between studies, due to the nature of failure sets, the non-BFR condition performed to failure requires a greater amount of repetitions and volume to attain failure compared to the BFR condition, of which volume was controlled in the present study (Wernbom et al., 2006 & 2009). Loenneke et al., (2013) found RPE to be greater during BFR exercise in the non-failure protocol, as in the present study. Araujo (2015) used a rotation of full body exercises (bench press, squat, barbell bent-over row and deadlift), as opposed to isolated exercises in the present study. Isolation exercises have been found to elicit greater RPE in BFR conditions over traditional resistance training in previous studies (Loenneke et al., 2010; Neto et al., 2016; Poton & Polito, 2014; Vieira et al., 2015). RPE is greater in isolation BFR exercises, due to hyperemia and hydrogen ion concertation increasing more in an occluded limb, but in a full body protocol the high mechanical stress of non-occluded muscles, such as the gluteus maximus and pectoralis can lead to a greater RPE (Loenneke et al., 2010; Neto et al., 2017b).

Hemodynamic Performance

In the present study, HR was measured pre-training, immediately following each set, Post0, Post10, Post20, and Post 30, and continuously through training and 30 minutes post exercise using OxyCon Mobile. There were significant condition and time main effects ($p<0.05$) for HR recorded after every set of leg curl and extension. During the leg curl, T80 was found to have greater HR ($p<0.05$) than T60 with a trend ($p=0.07$) to being greater than T40 (117±2, 111±2, and 109±2), while being statistically similar ($p>0.05$) to BFR25, BFR35, and BFR50 (112±3, 112±3, and 112±3). Following the first set, T80 had a greater ($p<0.05$) HR than BFR25 and BFR50 (117±2, 109±3, and 109±3), while being similar ($p>0.05$) to BFR35, T40, and T60. By the fourth set, the BFR conditions and T40 (115±3, 116±, 115±3, and 109±3) were statistically ($p>0.05$) similar to T80 in HR response, but T80 was significantly greater than T60 (119±2 and 110±3). Following the first set of BFR leg extensions, BFR25 had a greater ($p<0.05$) HR response than T40, while all other conditions remained statistically similar. At the end of the final set, BFR25 showed a trend ($p=0.57$) for eliciting a significantly greater HR than BFR35, and had a greater ($p<0.05$) HR response than BFR50, T40, T60, and T80 (144±4 vs, 134±4, 133±4, 130±4, 126±3, 123±3) while all other conditions remained statistically similar ($p>0.05$) to each other. The OxyCon Mobile found similar results with BFR25 causing greater ($p<0.05$) average HR than BFR50 and all traditional resistance conditions for the exercise session. BFR25 began to be significantly greater than these conditions at Ex6 (3^{rd} set), signifying that HR was elevated over traditional resistance exercises.

Postexercise HR using HDI, found that HR for all conditions remained elevated over rest throughout the measurement period. BFR25 elicited a greater ($p>0.05$) HR response than T80 (73.5±1.8 and 69.4±1.6) for a more extended period, while others were statistically similar

($p>0.05$). The increased HR ($p<0.05$) elicited by BFR25 over T80 remained statistically significant during Post0 and Post10, in which BFR25 had a greater HR than BFR50. At Post10, there were trends for significance ($p=.095$) with BFR25 and T60. Similar to post exercise HR measured by HDI, OxyCon Mobile found the BFR groups elicited a greater HR ($p<0.05$) than all the traditional resistance exercise groups for the first two minutes of postexercise measurements. BFR25 maintained a significantly greater ($p<0.05$) HR than T80, until the Post14 time point.

This present study is supported with previous studies, in which, the HR response during exercise of BFR for both aerobic and resistance exercise was greater than those of traditional training protocols in low, medium, and high intensities (Takano et al., 2005a & 2005b; Neto et al., 2016; Renzi et al., 2010; Araujo, 2014; Vieira et al., 2013; Loenneke et al., 2011a; Abe et al., 2006; Hollander et al., 2011). Physiologically the increase in HR during exercise occurs, due to a decrease in SV during exercise caused by the inhibition of venous return by BFR (Renzi et al., 2010; Takano et al., 2005a & 2005b; Sumide et al., 2009). Takano et al. (2005a) saw a 30% decrease in blood flow and a reduction in cardiac preload, two factors affecting SV. Renzi et al. (2010) determined that, although SV was lower, CO was not different between conditions. HR remains elevated for BFR sections because SV x HR =CO, a decrease in SV would lead to an increase in HR to match the cardiac needs of the body. Contrary to our results other studies saw high intensity and low intensity traditional resistance exercise to elicit a greater HR response than with BFR (Down et al., 2014; Kacin & Strazar, 2011; Okuno et al., 2014; Loenneke et al., 2012). The nature of this differences could arise due to lack of control of volume. The present study and those in agreement with the results controlled for volume or did not use volitional failure as a set point, unlike with those that reported greater HR responses from resistance exercise without BFR.

The postexercise HR response of the current study supported by previous studies, in which BFR HR remain similar or elevated over non BFR conditions (Vieira et al., 2013; Neto et al., 2016; Araújo et al., 2014; Loenneke et al., 2010a & 2012). Vieira et al. (2013), Neto et al. (2016), and Araujo et al. (2014) did not explicitly describe the exercise protocol, such as reps and sets, and failure was not mentioned, as in the present study. In a previous study by Loenneke et al. (2012a), matched volume for BFR and traditional resistance training and found BFR elicited a greater HR response postexercise, but only one postexercise HR measure was taken. Loenneke et al. (2012b) completed repetitions to failure and found the non BFR condition to have 32% more volume, yet their postexercise HR response was statistically similar. Contrary to the present study, previous research found high intensity resistance training to elicit a greater HR response postexercise than BFR conditions (Okuno et al., 2014; Fahs et al., 2011b). The protocol for traditional resistance exercise in Fahs et al. (2011b) called for 73% more volume than its BFR counterpart, but the increase in HR over low intensity BFR was only 35% and 28% at 15 and 30 minutes post exercise. The low intensity exercise with BFR elicited a statistically similar postexercise HR to low intensity traditional exercise. This difference could be, due to the use of a compound movement, leg press, of which was not used in the present study (Fahs et al., 2011b; Neto et al., 2017b). Okuno et al. (2014) found high intensity to have the greater ($p<0.05$) HR than low intensity with BFR, which was greater than low intensity without BFR. Similar to the present study, low intensity BFR had an elevated HR for 30 minutes exercise. This study did not control for work and allowed for sets to failure, which does not control all variables, and did not measure HR during exercise.

ACSM recommends physical activity performed five or more days a week for 30-60 minutes at 40-60% of heart rate reserve (HRR) and resistance exercise varying from two to three

days per week at 40-80% 1RM for two to four sets (ACSM, 2015). Previous studies have shown the efficacy of low intensity BFR to provide increases in physical performance by using a decreased load (Abe et al., 2005 & 2010; Karabulut et al., 2010; Ozaki et al., 2010a; Takashi et al., 2010). The present study followed suit with prior studies and the BFR25 condition caused the greatest average HR of 113±3 in the LC, 137±4 in the LE, and using OxyCon Mobile data an average exercise HR of 115±3. Using the Karvonen formula as HR max prediction, with an average age of 23.5±3.1 and average resting HR of 60±1, the BFR25 condition elicited a heart rate reserve (HRR) response of ~ 40.4-58.7%HRR or ~41.9%HRR with the continuous OxyCon Mobile data (Karvonen et al., 1957). Applying this to BFR35, BFR50, T40, T60, and T80; the range of each is as follows: 40.4-52.6% HRR; 39.6-51.8% HRR; 37.3-49.5% HRR; 38.9-48.8% HRR; 43.4-50.3% HRR. Using the continuous average HR for every condition, the following percentages occur: 38.1% HRR; 35% HRR; 30.5% HRR; 30.5% HRR; 32% HRR.

Contrary to Hollander et al. (2011), the present study found for BFR groups to have a significantly greater RPE and HR to a moderate load of T60 and T40. Hollander et al. (2011) found BFR and traditional exercise to elicit similar RPE, but BFR had significantly greater HR. This was corroborated by the findings in Neto et al. (2016 & 2017) that found lower body RPE to be greater for BFR than traditional exercise, while HR remained statistically similar, and upper body RPE and HR response was higher than BFR. The present study controlled for volume, unlike Neto et al. (2016 & 2016), in which traditional exercise performed a 71% and 27% greater workload, respectively. Similarly, Hollander et al. (2011) reached failure in their experimental protocol and traditional exercise condition underwent 64% increased volume over BFR. The present study demonstrated significant condition*time interactions ($p<0.001$) for HR and RPE, during LC and LE. This was due to the low initial HR and RPE response to BFR,

before blood pooling began to cause disproportionate increases over traditional conditions. This led to greater peak RPE and HR by BFR50, BFR35, and BFR25 (133.2 and 15.7; 133.7 and 15.7; 144.3 and 17.2), while T40, T60, and T80 elicited the lowest peak HR and RPE (123.97 and 13.9; 126.3 and 14.4; 128.2 and 15.3). Although the reactions to exercise may be low during initiation of BFR exercise, once blood and metabolite pooling begin to occur, they elicited a greater peak RPE, which was accompanied by a greater peak HR. The present study is the first to observe, under volume-matched conditions, RPE and HR are both significantly increased during BFR conditions over traditional exercise and the first to note that increases were associated.

SBP, DBP, MAP, PP, CEJ, SVI, CO, CI, and SVR did not have condition main effects ($p>0.05$), but all demonstrated time main effects ($p<0.05$). The average of all conditions showed no difference in Pre-values for SBP, DBP, MAP, PP, LAE, SAE, CEJ, SV, SVI, SVR, and TVI. Significantly different Pre-values were found for CO and CI, in which BFR35 presented lower Pre-values than BFR50. Resistance exercise elicited a significant increase in SBP from Pre-to Post0, but returned to baseline for remaining measurements. DBP showed slight trends towards significance ($p=0.116$) to elicit an increase from Pre-to Post0, but returned to baseline values for remaining measurements. MAP and PP significantly increased from Pre-to Post0, but returned to baseline by Post10. SV and, similarly SVI, despite accounting for body surface area, were decreased by resistance exercise from Pre-to Post0 and remained below baseline for all measured time points. CEJ was significantly decreased at Post0, but it continued to increase until Post10 and Post20, but Post30 remained statistically similar to Post0, failing to return to baseline. CO and CI were significantly increased from Pre-to Post0, when BFR35 was included or removed in statistical analysis, and did not return to baseline during the postexercise measuring period. SVR

and TVI both decreased from Pre-to Post0 and SVR did not return to baseline values, while TVI returned to baseline at Post30. TVI was found to be significantly more decreased for BFR25 than BFR35 and BFR50 at Post10.

The variables SBP, DBP, MAP, PP, CEJ, SV, SVI, CO, CI, SVR, and TVI are all interconnected to each other. CO is calculated using a multivariate algorithm using CEJ, which was derived from the radial artery waveform (Zimlichman et al., 2005).

$$MAP = \frac{SBP+2(DBP)}{3}\,;\, PP = SBP - DBP;\, SVR = \frac{MAP}{CO};\, CO = SVxHR\,;\, SVI = \frac{SV}{BSA}$$

Therefore, it is reasonable to state that the increases in SBP and DBP led to similar increases in MAP and PP in Post0. CEJ was decreased in Post0, 20, and 30 caused by the inhibition of venous return that BFR elicited, which then decreased SV Post0-30, causing the increase in HR Post0-30 to meet the increased CO Post0-30 (Renzi et al., 2010; Takano et al., 2005a & 2005b; Sumide et al., 2009). CO and CI; SV and SVI directly correlated to each other because the CI and SVI are CO and SV divided, respectively, by body surface area to ensure that individual variability in BSA did not affect results. The decreases in SVR could be due to the greater increase in CO vs MAP, but in this case the HDI/Pulswave uses algorithms to calculate some of these factors, and might not be exact. Oddly enough, SVR and TVI both decreased for Post0-20 and SVR for Post30, but SAE also decreased over baseline for Post0 and Post30, while LAE demonstrated no change over baseline. Prior research determined that in aged populations, that should demonstrate a decrease in arterial elasticity, there were only significant differences in central arterial elasticity, but not peripheral arterial elasticity, which was measured in this study (Tanaka et al., 1998; Hayashi et al., 2005; Fjeldstad & Bemben, 2007). Hayashi et al. (2005), also concluded that peripheral arterial stiffness is more difficult to change that central arterial stiffness.

Further research should focus on whether acute decreases in SAE, during resistance training, can lead to a chronic decrease and, if so, will the adaptations of this chronic decrease cause increased CVD risk. The differences between 50% intensity with and without BFR should be explored to determine if the BFR is the cause of the decrease in SAE and LAE or the intensity range.

Arterial Compliance and Elasticity

In the present study, arterial stiffness will refer to pulse wave velocity (PWV), specifically Carotid to Radial PWV (crPWV), Carotid to Femoral PWV (cfPWV), and Femoral to Distal PWV (fdPWV). There were no significant ($p>0.05$) condition effects, but time main effects were found in crPWV and fdPWV. For the average of all conditions, PWV decreased from Pre-to Post15 for crPWV. PWV also decreased for fdPWV from Pre-to Post5, 15, and 25. Arterial elasticity will be described by large and small arterial elasticity (LAE and SAE, respectively). BFR25 had a significantly greater LAE than BFR50 at Post10. T40 produced a significantly increased SAE over BFR50. At Post0, T40 and T80 elicited a greater SAE than BFR50, and T40 elicited a greater SAE than BFR35. At Post10, T40 maintained a greater SAE than BFR50, and T60 showed trends for significance with BFR50. The average of all conditions showed no difference between Pre-to Post LAE, but Post20 and 30 were markedly lower than Post0. The average of all conditions for SAE found a marked decrease ($p<0.05$) from Pre-to Post0 and Pre-to Post30.

Previous acute and training studies support the present finding that BFR leads to increase carotid arterial compliance or cause no change (Ozaki et al., 2011; Rakobowchuk et al., 2005; Casey et.al., 2007; Olson et al., 2006; Maeda et al., 2006; Fahs et al., 2011; Renzi et al., 2010). The present measurements are contrary to most studies that demonstrate that resistance training

both with and without BFR cause increases in arterial stiffness (DeVan et al., 2005; Fahs et al., 2009; Miyachi et al., 2003 & 2004; Fahs et al., 2014).

Acute studies have shown that traditional high intensity resistance exercise causes an acute decrease in arterial compliance (DeVan et al., 2005; Fahs et al., 2009) and training studies have shown a similar decrease (Miyachi et al., 2003 & 2004). The reason for the discrepancy in the literature is due to lack of standardized exercise prescription, which includes cuff pressure, exercise selection and duration, and intensity (Park, Kwak, Harveson, Weavil, & Seo, 2015). Fahs et al. (2014) found both BFR and non BFR to failure, to elicit increase in PWV after just six weeks of training. When volume is equal, positive increases for arterial compliance occur through enhanced post-occlusive calf blood flow and increased brachial artery diameter (Patterson and Ferguson, 2010 & 2011; Hunt et al., 2012).

The lower measures of SAE and increased PWV for BFR50 may be due to BFR being applied at an intensity above the usual 20-30%1RM range. Suga et al. (2010) found a 40%1RM BFR condition to elicit greater decreases in PCr and pH and increases in $H_2PO_4^-$ than 20 and 65%1RM without BFR, 20 and 30%1RM with moderate BFR pressure, and 20%1RM with high pressure. This study performed 30 repetitions/min of plantar flexion for two minutes. This would lead to drastically different volume from 20 to 40%1RM BFR and 65%1RM. Despite 40%1RM BFR having a lower volume, it created greater intramuscular stress and recruited greater amounts of fast-twitch fibers, as represented by Pi splitting, similar to failure training (Suga et al., 2010; Park et al., 1987; Vandenborne et al., 1991). The mechanism by which the BFR50 had lower SAE than T80 and higher PWV than T60, could be caused by the release of epinephrine and norepinephrine increase above baseline and decreases in pH. These conditions lead to the constriction of vessels and an increase in release of free radicals that can interfere

with nitric oxide availability decreasing SAE (W. Kraemer et al., 1999; Stapleton et al., 2008; Di Francescomarino et al., 2009; Finaud, Lac, & Filaire, 2006). Little research exists on BFR resistance exercise's effects on SAE and LAE with moderate intensities (50%1RM) compared to different intensity traditional and BFR exercise.

Overall, when all condition averages are used, resistance training at differing intensities and modalities elicited no difference over baseline for LAE and cfPWV, but caused positive decreases in PWV for crPWV and fdPWV. The present study has found that arterial elasticity and PWV may not be negatively affected by resistance exercise, not to failure, and will produce similar effects in most volume-matched conditions. Future research, should focus on the effects of long term resistance training with varying intensities and modalities using volume matching and not reaching failure.

Respiratory Responses

In the present study, T40 and T60 had greater RER than BFR35 and BFR50, while only T40 had a greater RER than BFR25 during exercise. Over the course of the time points, RER was greater for traditional exercise protocols. This was true for Ex2 and Ex4, but only T80 had a greater RER than BFR in Ex6. Through the remainder of the exercise RER was similar. Postexercise was significantly greater for BFR25 over T60 and T80. At post 2, BFR25 started greater than all traditional groups, but by Post 14 all conditions elicited a similar RER. No condition main effects were found for relative or absolute VO_2 or VCO_2 consumption and EE during and post exercise.

The present study found RER to be elevated in traditional exercise conditions over BFR. RER for BFR25, 35, 50, T40, 60, and 80 were 0.988±0.012, 0.981±0.014, 0.983±0.012, 1.048±0.012, 1.021±0.014, and 1.016±0.011, respectively. RER acts as an indicator for the rate

of lipid oxidation, and these numbers would usually indicate a substrate utilization of 100% carbohydrates (Binzen, Swan, & Manore, 2001). Prior studies have observed RER of >1.00, and have concluded it is a result of non-respiratory changes (Gastin, 2001; Scott, 2014, Farinatti, et al., 2016). Elevated blood lactate concentration, decreased pH of blood, accumulation of CO_2 in tissues, or changes in buffering of acids can invalidate RER as a measure of substrate metabolism and EE during exercise (Binzen, Swan, & Manore, 2001; Pinto, Lupi, Bentano, 2010; Gaeser & Brooks, 1984, Braun et al., 2002). Other ways to take account for anaerobic EE are as follows: metabolic muscle biopsy in addition to VO_2; oxygen flow rate and VO_2 measurement; glycotic or lactate measurement in addition to VO_2 measurement. Indirect calorimetry only measures the aerobic component of EE, if lactate concentration is not taken in to account, as each millimole of lactate computes to a VO_2 increase of 3ml/kg (Pinto, Lupi, Bentano, 2010). Similarly, Scott and Kemp (2005) found lactate production to be independently associated with heat production. They remain separate and additive components to the measurement of total energy expenditure for exercise and recovery, but are usually not accounted for (Scott & Kemp, 2005).

A possible explanation for lack of significant differences in VO_2 or VCO_2, in the present study, could be due to the similar volume between conditions. Araujo (2015) performed a study, in which, high intensity exercise had almost twice the volume as the BFR condition. The high intensity resistance exercise was completed in less time which caused a 28% increase in rate of VO_2 L/min over the BFR condition. In Araujo (2015), ANCOVA found a significant effect of volume on the 23 and 29.5% increase in O_2 consumption and CO_2 production, respectively. Loenneke et al. (2011a) performed a walking study that utilized the same protocol for both BFR and nonBFR sessions, which elicited a greater VO_2 in the BFR session.

Conclusions

The purposes of this study were 1) to investigate the acute effects of traditional lower body resistance exercise sessions (T40, T60, and T80) and resistance exercise sessions using BFR (BFR25, BFR35, and BFR50) on LAE and SAE 2) to examine how these varying training modalities affect HR, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI, SVR and TVI in recreationally active male and female subjects 3) to determine how the varying training modalities affect HR, RPE, VO_2, VCO_2, and EE during and postexercise in recreationally active males and females.

The research questions were:

1) Would there be differences or similarities in small and large arterial elasticity and PWV following the resistance exercise protocol with varying intensities with and without BFR?

2) Would there be a change or similarity occurring in RPE, HR, SBP, DBP, MAP, CO, SV, SVR and TVI in recreationally active male and female subjects following a resistance exercise protocol with varying intensities with and without BFR?

3) Would there be a difference in energy expenditure during and after a volume-matched resistance exercise protocol with varying intensities with and without BFR?

Research Hypothesis 1. BFR25 would elicit statistically similar responses in HR, RPE, SBP, DBP, MAP, PP, CEJ, CO, CI, SV, SVI SVR and TVI compared to T40, BFR35 will elicit similar responses to T60, and BFR50 will elicit similar responses to T80.

The results of the present study did not fully support this hypothesis. It was hypothesized that BFR25 would mimic the responses of T40, BFR35 would mimic T60, and BFR50 would mimic T80. Prior literature had yet to show conditions of equal volume with varying intensities, BFR was previously found to enhance the effects of the same protocol and intensity. The assumption

was made that BFR25 could elicit similar responses to T40, BFR35 to T60, and BFR50 to T80 due to effects BFR. The hypothesis was correct for SBP, DBP, MAP, PP, CEJ, SV, SVI, CO, CI, and SVR as there were no conditions differences for these variables. Although, the hypothesis implied that BFR25/T40 would have lower response than BFR35/T60, and BFR35/T60 would have a lower response compared to BFR50/T80, which was not true as all conditions were statistically similar. The hypothesis was correct for SVI as BFR25/T40, BFR35/T60, and BFR50/T80 were statistically similar, but SVI for BFR25 was found to be significantly smaller than BFR35 and BFR50. The hypothesis was incorrect for HR as BFR25/T40, BFR35/T60, and BFR50/T80 did not elicit similar responses at each time point, but the peak HR (last set LE) was similar for BFR35/T60 and BFR50/T80 while BFR25 elicited a response greater than all other conditions, except BFR35. During postexercise, HR remained statistically similar for BFR25/T40, BFR35/T60, and BFR50/T80 at most time points.

Research Hypothesis 2. BFR conditions would elicit lower values of PWV and greater values of large and small arterial elasticity, when compared to their traditional resistance exercise counterpart

The results of the present study did not support the hypothesis. It was hypothesized that BFR conditions would elicit decreased PWV compared to the traditional resistance exercise group, but there were no significant differences between any of the BFR and traditional resistance exercise conditions with measures of PWV; crPWV, cfPWV, and fdPWV. No significant differences were elicited by any of the BFR conditions when compared to traditional resistance exercise. BFR25 elicited a greater response of LAE when compared to BFR50 for the Post10 measurement. No significant differences were found in SAE for BFR and traditional counterparts, but BFR50 elicited a lower SAE than T80 at Post0, opposite of the hypothesis.

Research Hypothesis 3. BFR conditions would elicit a significantly greater energy expenditure than their traditional resistance exercise counter parts.

The results of the present study did not support this hypothesis. It was hypothesized that due to the physiological differences of using BFR, it would elicit a greater EE during and postexercise than traditional resistance exercise as measured by indirect calorimetry. There were no significant differences between any of the conditions in EE during or postexercise. However, the current study did not account for lactate production. Previous studies concluded that glycolytic ATP and lactate oxidation, and lactate production are independently associated with heat production, thus represent separate and additive components for EE during and post resistance exercise, which cannot be measured by indirect calorimetry (Pinto, Lupi, & Bentano, 2010; Scott & Kemp, 2005). BFR exercise can lead to lower tissue oxygenation, and cause a disproportionate increase in anaerobic metabolites over traditional exercise modalities. Due to increased metabolites, accounting for lactate production would have favored the BFR modalities with increased EE, as previously shown in aerobic exercise protocols (Suga et al., 2010; Loenneke et al., 2011a; Karabulut et al., 2011 & 2017).

This study is the first to have investigated the acute effects of varying intensities of BFR and traditional resistance exercise while volume matched. The literature did not show previous studies with BFR using ≥50%1RM and comparing it to traditional protocols. This investigation demonstrated, the physiological responses cause by increase in metabolites from resistance exercises in both BFR and traditional exercise. It elicited greater increases in HR for BFR25 over other traditional conditions, as previously seen in literature for similar volume protocols that did not reach failure.

In conclusion, this study found no significant differences in EE responses during or postexercise in volume matched resistance protocols of varying intensities and modalities (BFR vs traditional). BFR25 was found to cause significantly greater responses in HR and RPE than other conditions. Of the traditional conditions T80 created the greatest responses in RPE and HR. BFR and Traditional conditions did not elicit increases in PWV from baseline and found no differences between conditions. Similarly, no decreases were elicited in LAE from Pre-to Post by the average of all conditions, but at Post10 BFR25 produced greater LAE than BFR35. SAE was significantly decreased from Pre-to Post0 and 30. BFR50 had significantly lower SAE compared to T40 and 80 at Post0 and T40 greater than BFR35. Demonstrating that BFR resistance exercise at moderate intensities might not be as favorable for promoting arterial health as low intensity BFR. In the present study, BFR25 was able to elicit positive increases in LAE and may be a possible route for attenuating long term negative arterial responses, while eliciting similar increases in muscle strength and size to traditional resistance exercise, as shown in previous literature.

The present study implemented resistance exercise protocols with differing intensities of BFR and traditional protocols that matched volume and time spent exercising without reaching failure, which has not been done in prior literature. Further studies should continue to implement volume-matched protocols with different intensities to control for work done with all other variables, and possibly this procedure should be reimplemented in a training protocol to determine long term effects of these exercise protocols on vascular function and muscular strength. Energy expenditure and respiratory responses did not display conclusive data, but statistically similar RER during exercise between BFR25 and T60&80 and increased RER postexercise for BFR25 than T60&T80 could be indicative of increased energy production

related to lactic acid. Further studies should measure lactic acid to determine the correct energy expenditure of non-failure volume-matched resistance exercise with and without BFR.

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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 five 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

USG -Urine Specific Gravity

VI -Vascular Impedance

VR -Vascular Resistance

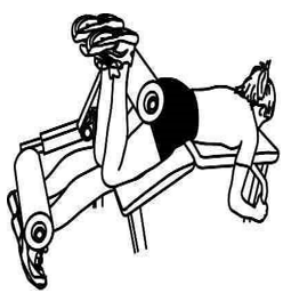
APPENDIX-FORMS

APPENDIX-FORMS

1. RECRUITMENT FLYER

PARTICIPANTS NEEDED

You are invited to participate in an IRB approved research training study at the Health and Human Performance Department at the University of Texas Rio Grande Valley at Brownsville. The purpose of the study is to assess the acute differences in energy expenditure and arterial compliance responses to different resistance training intensities and protocols in untrained males and females (18-50 years old). Total time required for completion of the study is 7 visits for a total of about 8-10 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 Resistance Training with Blood Flow Restriction Cuffs versus Traditional Resistance Training on Arterial Compliance and Energy Expenditure in Recreationally Active Males and Females

Principal Investigator: Dr. Murat Karabulut
Co-Investigators: Danny Dominguez, Patrick Murphy, and Brittany Esparza

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 energy expenditure during different modalities and intensities of resistance exercise 2) to examine the acute effects on arterial elasticity of varying resistance training intensities with and without blood flow restriction cuffs when compared to traditional resistance training without blood flow restriction

Number of Participants

80 sedentary to recreationally active, untrained male and/or female participants will take part of this study.

Procedures

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

On the first day, you will be evaluated to determine if you qualify for the study. You will be asked to fill out questionnaires and will be familiarized with the study procedures before starting the exercise sessions. 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. Following initial

screening (PAR-Q and health questionnaire, a copy of both forms will be provided) and familiarization, anthropometric measurements will include, resting heart rate, blood pressure, height, weight, body composition, and thigh circumference. Weight and body fat percentage will be measured using the BodPod (gold standard body composition based on air displacement). Inflation of the blood flow restriction cuffs (elastic cuffs that are tightened and filled with air to restrict blood flow) will be determined by following a set protocol. Participants will also perform a one-rep max (highest load that can be lifted only once with a proper technique, 1RM) test to determine future training weight, and using SphygmoCor, HDI, and BodPod. This session will last approximately 75 minutes.

Sessions 2-7 session will take approximately 75 minutes each.

They will include resistance exercise sessions separated by at least 48 hours. Each session the participant will come fasted for at least 8 hours and be tested for hydration using the urine refractometer. You will be asked to provide, in writing, a food journal of what you have consumed in the past 24 hours and will be asked to maintain similar eating habits 24 hours before each exercise session. If hydrated, the subject will have their arterial profile measured using the SphygmoCor and HDI. When performing measurements using SphygmoCor you will lie down in the supine position for a minimum of 10 minutes and baseline arterial elasticity and hemodynamics will be measured using Hypertension diagnostic (noninvasive equipment conducts measurements of arterial stiffness via placing a sensor on the radial artery 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). Then a mobile metabolic cart, a small vest and mask, will be placed on the subject and they will perform the specified routine in the exercise science lab using the resistance training machines. Upon completion of the resistance training protocol the subject will be asked to lie down in the supine position and measures will be taken by the HDI at 0,10, 20, and 30 minutes post exercise. SphygmoCor will readings will be taken at 5, 15, and 25 minutes post workout. Throughout this period, the metabolic cart will remain on the subject to measure their excessive post oxygen consumption (EPOC). Heart rate (via Polar chest strap and watch) will be monitored continuously during the whole session.

This study will consist of 6 different exercise types:

Three different resistance exercise sessions without blood flow restriction using 40%, 60% and 80% of their 1RM.

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

Three different BFR resistance exercise sessions using 20%, 30-40%, and ~50% of their 1RM.

All sessions will be performed in the exercise lab using 2 different machines, the leg curl and leg extensions, and dumbbells for split squat.

All training sessions will include a 5-minute warm-up on a cycle ergometer at 1.5 kP and 50 rpm.

Minimal Risk: The minimal risk includes discomfort using blood flow restriction cuff and performing the one-rep max test (the subject may feel tired right after the test and feel sore a day after the test). They will be screened in detail before being allowed to participate. If at any time they are unable to complete any task they will be allowed to stop.
The research team is required to calibrate all the equipment (which will be performed regularly according to instructions provided by the manufacture) 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.

Length of Participation

You will be required to visit the research labs in the Department of Health and Human Performance on 7 separate days for a total time commitment of approximately 8-10 hours (depending on which research group you are placed in).

Risks

The study has the following risks:

There are minimal risks to healthy individuals when performing any of the requirements for this project. 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: The minimal risks include discomfort using BFR cuff and performing one-rep max testing.

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 cardiovascular health and strength when performing exercise, and arterial health from Pulse Wave Analysis assessment. There is a possibility that you may be eligible for extra credit, dependent on your professor. If extra credit is offered by

your professor there will be alternatives to students who do not wish to participate. The individual can acquire extra credit by means of a written report that is relevant to the class material.

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 in locked cabinets and encrypted computers after completion of the study and only approved researchers will have access to the records.

Costs

There is no cost for participation.

Compensation

You will not be monetarily 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.

Waivers of Elements of Confidentiality

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

_____ I consent to being quoted directly.

_____ I do not consent to being quoted directly.

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.

Contacts and Questions

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 Dr. Murat Karabulut, Ph.D., at (956) 882-7236 or e-mail co-Investigator Patrick.Murphy01@utrgv.edu or the research assistants: Brittany Esparza at Brittany.Esparza01@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.

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

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

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

November 22, 2016

To: Murat Karabulut

From: Institutional Review Board

Subject: Approval of a New Human Research Protocol

IRBNet ID: 984870-1

IRB# 2016-209-11

Project Title: Neuromuscular and Arterial Compliance Responses to Different Resistance Training Intensities and Protocols

Dear Researcher,

The IRB protocol referenced above has been reviewed and **APPROVED ON November 21, 2016**.

Basis for approval: Expedited #3; Expedited #4; Expedited #7

Approval expiration date: November 20, 2017

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 to the IRB for approval. Changes should 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 submit a continuing review request for approval. Failure to submit this request 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 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: Wendy A. Lawrence Fowler

Dr. Wendy Lawrence Fowler
Vice Chair/Acting Chair, Institutional Review Board

APPENDIX-FORMS

5. HEALTH STATUS QUESTIONNAIRE

HEALTH STATUS QUESTIONNAIRE

SECTION ONE - GENERAL INFORMATION

1. Date____________________
2. Name____
3. Mailing Address____________________________________ Phone (H)_______________

   ____________________________________ Phone (W)_______________

   Email ____________________________________
4. *EI* Personal Physician__________________________________ Phone_________________

   Physician Address__________________________________ Fax___________________

   ____
5. *EI* Person to contact in case of emergency__________________ Phone_________________
6. Gender (circle one): Female ◯ Male *RF* ◯
7. *RF* Date of birth____________/__________/_____________
8. Height ____________________ Weight _______________________
9. Number of hours worked per week: Less than 20 ◯ 20-40 ◯ 41-60 over 60 ◯
10. *SLA* More than 25% of the time at your job is spent (circle all that apply)

    ◯ Sitting at desk ◯ Lifting loads ◯ Standing ◯ Walking ◯ Driving

SECTION TWO - CURRENT MEDICAL INFORMATION

11. Date of last medical physical exam:______________
12. Circle all medicine taken of prescribed in last 6 months:

    ☐ Blood thinner *MC*
    ☐ Diabetic *MC*
    ☐ Digitalis *MC*
    ☐ Diuretic *MC*
    ☐ Epilepsy medication *SEP*
    ☐ Heart rhythm medication *MC*
    ☐ High blood pressure medication *MC*
    ☐ Insulin *MC*
    ☐ Nitroglycerin *MC*
    Other___________________
13. Please list any orthopedic conditions. Include any injuries in the last six months

    ____

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

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

Other____

SECTION THREE - MEDICAL HISTORY

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

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

16. Circle any operations that you have had:

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

☐ Ears *SLA* ☐ Hernia *SLA* ☐ Lung *SLA* Other________________________________

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

☐ Father ☐ Brother ☐ Son

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

☐ Mother ☐ Sister ☐ Daughter

SECTION FOUR - HEALTH-RELATED BEHAVIORS

19. Have you ever smoked? Yes ◯ No ◯

20. *RF* Do you now smoke? Yes ◯ No ◯

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

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

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

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

23.. Last physical fitness test:___________________

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

0 1 2 3 4 5 6 7 days per week

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

0 1 2 3 4 5 6 7 days per week

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

____

27. Weight now:___________lb. One year ago:__________ Age 21:__________

SECTION FIVE - HEALTH-RELATED ATTITUDES

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

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

Circle the number that best describes how you feel:

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

SECTION FOUR - HEALTH-RELATED BEHAVIORS

19. Have you ever smoked? Yes ◯ No ◯

20. *RF* Do you now smoke? Yes ◯ No ◯

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

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

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

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

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

____

27. Weight now:___________lb. One year ago:__________ Age 21:__________

SECTION FIVE - HEALTH-RELATED ATTITUDES

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

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Circle the number that best describes how you feel:

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

APPENDIX-FORMS

6. 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

7. DATA COLLECTION SHEET 2

Familiarization Day

Name: ______________________________ Date: ____________

Height: ________cm ________ in

Tanita: ________kg ________ lbs ________% Body Fat

Leg Curl			Knee Extension	
Bike Height			Back Adjustment	
Leg Adjustment			Knee Angle Adjustment	
Leg Curl Start/Stop			Limb Length Adjustment	

Repetition Maximums

Leg Curl	Leg Curl
________lbs X ________reps	________lbs X ________Reps
________lbs X ________reps	________lbs X ________Reps
________lbs X ________reps	________lbs X ________Reps
________lbs X ________reps	________lbs X ________Reps

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday

APPENDIX-FORMS

8. DATA COLLECTION SHEET 3

Subject ______________________ DOB: 1/1/00

Time & Date: 11/30/2017

Session: **BFR 25%**

USG: ________

	S.I.	Metric
Height	1	1
Weight	1	1
Cuff Pressure		1
Time Total		

Warm-Up

HR	RPE

Height: 1

Carotid ________

Radial ________

Femoral ________

Distal ________

EXERCISE

Leg Curl

Set	Reps	Complete	HR	RPE	Rest (s)	Weight
1	1	◯			1	1
2	1	◯				
3	1	◯				
4	1	◯				

Pad: 1

Adj: 1

Stop: 1

Leg Extension

Set	Reps	Complete	HR	RPE	Rest (s)	Weight
1	1	◯			1	1
2	1	◯				
3	1	◯				
4	1	◯				

KAA: 1

BA: 1

LLA: 1

APPENDIX-FORMS

9. DATA COLLECTION SHEET 4

Subject ______________________________

BFR 25%			
Time	C-R	C-F	F-D
Pre			
5			
15			
25			

T 40%			
Time	C-R	C-F	F-D
Pre			
5			
15			
25			

BFR 35%			
Time	C-R	C-F	F-D
Pre			
5			
15			
25			

T 60%			
Time	C-R	C-F	F-D
Pre			
5			
15			
25			

BFR 50%			
Time	C-R	C-F	F-D
Pre			
5			
15			
25			

T 80%			
Time	C-R	C-F	F-D
Pre			
5			
15			
25			

APPENDIX-FORMS

10. PROFESSOR PERMISSION SCRIPT

The University of Texas Rio Grande Valley
Professor Permission Script

My name is Danny Dominguez/Patrick Murphy/Brittany Esparza; I am a graduate student from the Department of Health and Human Performance at the University of Texas Rio Grande Valley (UTRGV). I would like to ask permission to enter your classroom to invite your students to participate in my research study. My study is about the acute effects of resistance training with blood flow restriction cuffs versus traditional resistance training on arterial compliance and energy expenditure in recreationally active males and females.

As a participant, students will be asked to perform 7 sessions, which will include: A preliminary session in which the student will be asked to come in hydrated (which will be tested via urine sample) and fasted. This session will include body composition testing, anthropometric measuring, hemodynamics, and one-rep max testing, and large and small arterial elasticity. Students will then come to the lab for 6 resistance exercise sessions with and without blood flow restriction at different intensities. Each of these sessions will last approximately 75 minutes. The total time commitment is 8-10 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 Danny Dominguez, Brittany Esparza, Patrick Murphy, and Murat Karabulut, and later stored in a locked file cabinet for 3 years.

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

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

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

If you have questions about the research, please feel free to contact any of us at Danny Dominguez at danny.dominguez01@utrgv.edu; Patrick Murphy at Patrick.murphy01@utrgv.edu, Brittany Esparza at Brittany.esparza01@utrgv.edu; and/ or the principal investigator Murat Karabulut murat.karabulut@utrgv.edu. Or, if you have any questions regarding your students' rights as participants in the study, please call the IRB at (956) 665-2889 or email at irb@utrgv.edu.

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

APPENDIX-FORMS

11. RECRUITMENT SCRIPT IN PERSON

The University of Texas Rio Grande Valley
Recruitment Script

My name is Danny Dominguez/Brittany Esparza/Gage Murphy; I am a graduate student from the Department of Health and Human Performance at the University of Texas Rio Grande Valley (UTRGV). I would like to invite you to participate in my research study: **The Acute Effects of Resistance Training with Blood Flow Restriction Cuffs versus Traditional Resistance Training on Arterial Compliance and Energy Expenditure in 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).

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

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

As a participant, you will be asked to perform 7 sessions, which will include: A preliminary session in which the student will be asked to come in hydrated (which will be tested via urine sample) and fasted. This session will include body composition testing, anthropometric measuring, hemodynamics, and one-rep max testing, and large and small arterial elasticity. Students will then come to the lab for 6 resistance exercise sessions with and without blood flow restriction at different intensities. Each of these sessions will last approximately 75 minutes. The total time commitment is 8-10 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 Patrick Murphy, Brittany Esparza, Danny Dominguez, and Murat Karabulut, and later stored in a locked file cabinet for 3 years.

If you would like to participate in this research study, please e-mail principal investigator Murat Karabulut at murat.karabulut@utrgv.edu, or research assistants Danny Dominguez at danny.dominguez01@utrgv.edu, Brittany Esparza at Brittany.esparza01@utrgv.edu, and Patrick Murphy at Patrick.murphy01@utrgv.edu.

Do you have any questions now? If you have questions later, please contact me by email at Danny.Dominguez01@utrgv.edu

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

BIOGRAPHICAL SKETCH

Danny D Dominguez, Bachelor's degree in Exercise Science August 2014 acquired from the University of Texas at Brownsville, Master's degree in Exercise Science December 2017 acquired from the University of Texas Rio Grande Valley, National Academy of Sports Medicine Certified Personal Trainer (CPT) October 2017; 1970 Westminster Road, Brownsville, Texas 78521