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Determining the Effect of Cuff Deflation on Post-Exercise Arterial Occlusion Pressure

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DETERMINING THE EFFECT OF CUFF DEFLATION ON POST-EXERCISE ARTERIAL OCCLUSION PRESSURE

by
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ABSTRACT

While it is recommended that blood flow restriction be applied relative to pre-exercise arterial occlusion pressure (AOP), no guidelines exist for an initial rest period prior to the measurement. Remeasuring AOP post-exercise can be used to estimate the cardiovascular response. When measuring post-exercise (pre-) AOP, different methods could be used. Some increase the cuff pressure from blood flow restriction exercise pressure (without deflation), or deflate the cuff prior to post-exercise (post-) AOP measurement. It is unknown if pre-AOP is affected by initial rest period, or if post- AOP is affected by cuff deflation. Thus, the purpose of this study was to: 1) compare pre- AOP across differing initial rest periods, and 2) compare post- changes in AOP measured either with or without cuff deflation following exercise.

20 participants completed three visits. Visit 1 consisted of paperwork, and measurements of height, weight, and 1 repetition maximum (1RM) bicep curl testing on the dominant arm, followed by familiarization. Upon entry into the lab on visits 2 and 3 (exercise testing days), AOP was measured immediately and 10min after initial measurement, with 10min serving as pre-AOP. Depending on condition, AOP was measured 5min after initial AOP on one of the two days. Three sets of elbow flexion exercise were performed at 30% 1RM to failure and 40% of pre- AOP with 30s rest between sets. 10s after the cessation of exercise, post-AOP was measured. Depending on condition, to assess post-exercise AOP, the pressure was increased from 40% AOP, or the cuff was deflated

and reinflated. A Bayesian one-way repeated measures ANOVA was used to compare differences in AOP across rest periods and a Bayesian t-test was used to compare differences in inflated versus deflated pre- to post- AOP changes. Results presented as mean (SD). **RESULTS**: The immediate [158.8 (21.6)], 5min [159.3 (20.3)], and 10min [159.4 (23.5)] AOP measures were similar (BF_{10} = .141). Differences between immediate-10min measures on days with a 5-min measure [0.65 (8.1)] and days without [1.65 (9.0)] were also similar (BF_{10} = .244). There was anecdotal evidence of a difference (BF_{10} = .815) in pre- to post- changes in AOP with the cuff remaining inflated [32.8 (25.6)] and deflated [21.6 (12.8)] shows. The number of total exercise repetitions completed was similar across days, days of cuff deflation 52.8(18.9) and those without 54.5(17.4) BF_{10} = .293). **CONCLUSION**: Our data shows similarity in these three initial rest periods. It is unclear if cuff deflation affects changes in pre- to post-AOP, therefore continued research is required.

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LIST OF ABBREVIATIONS

1RM	one repetition maximum
ACSM	American College of Sports Medicine
AOP	arterial occlusion pressure
BFR	blood flow restriction
Pre-	pre-exercise
Post-	post-exercise

INTRODUCTION

It is known that physical exercise improves musculoskeletal fitness, and resistance exercise recommendations from the American College of Sports Medicine call for 8-10 exercises with 8-12 repetitions each for at least 2-3 non-consecutive days a week and 60-70% of one repetition maximum (1RM) (American College of Sports Medicine, 2009). Due to a myriad of health complications, time restraints (real or perceived), and various restrictions, many are unable to perform exercise in this way. Several alternatives to these recommendations exist, one being low load exercise paired with blood flow restriction (BFR). Exercise with BFR is a common practice in exercise research and continues to be implemented in clinical and research settings. BFR is accomplished by wrapping a pneumatic cuff or tourniquet around the most proximal region of a limb followed by an inflation of the cuff from a tourniquet system as an increased external pressure(Patterson et al., 2019). This increase in cuff pressure serves to compress the vasculature beneath the cuff to slowly reduce arterial flow and fully occlude venous blood flow(Mouser, Dankel, et al., 2017). This alteration in normal blood flow leads to a decrease in available oxygen distal to the cuff as well as the creation of a venous blood pooling effect (Patterson et al., 2019).

When paired with low load exercise, BFR training is shown to be beneficial for a number of reasons. There are similar increases in muscle size with lower load BFR training and high load training(Wortman et al., 2021). It is also shown the potential to decrease muscle atrophy in patients who suffered injury or underwent major surgery (Hughes et al., 2017). It is also seen to decrease stress on muscles and joints in those recovering from injury or major surgery(Cognetti et al., 2022). Though BFR exercise leads to increased muscle size and decreased strain on muscles and joints, concerns do exist regarding the effect of BFR on cardiovascular health.

Spranger et al., (2015) states that BFR training can cause adverse effects in individuals with cardiovascular diseases or those suffering from hypertension and peripheral artery disease. Spranger et al., (2015) also states that even healthy individuals might suffer from deleterious cardiovascular events due to mechanically induced exercise pressor responses through BFR exercise (Spranger et al., 2015). Though concerns exist for the application of BFR with exercise, Spranger et al., (2016) states that when pressures are applied relative to an individual's arterial occlusion pressure, risk can be mitigated (Jessee et al., 2016). Arterial occlusion pressure (AOP) is simply the minimum pressure required to occlude blood flow distal to a cuff. Applying percentages of AOP (typically in the range of 40%-80%) ensures arterial blood flow during exercise and increases the chances that it can be carried out safely and effectively.

By utilizing AOP, researchers and clinicians can also measure AOP post-exercise to compare pre- and post-exercise AOP measurements. This comparison of pre- and post- AOP allows one to understand the cardiovascular response to BFR exercise without having to remove and change cuffs after exercise, potentially missing the true or immediate cardiovascular response (Jessee, Buckner, et al., 2018). Some have used a comparison of pre- and post- AOP to understand the cardiovascular response in exercising and non-exercising limbs (Jessee, Buckner, et al., 2018). This comparison has also been used to assess the cardiovascular response to very low, moderate, and high loads of BFR with exercise (Jessee, Mattocks, et al., 2018)(Mouser et al., 2019). In using AOP in this way it acts as a potential surrogate measurement for blood pressure, improving our understanding of cardiovascular responses to exercise with BFR (Jessee, Buckner, et al., 2018). (Bell et al., 2020) conducted a study in which systolic blood pressure measurement was compared to AOP measurement, finding that these two measures track similarly at rest and following exercise.

In summary, the pre-exercise AOP measurement is largely important as exercise pressures (i.e., the BFR stimulus) are determined from this measurement, and when this pre-AOP is compared to post-AOP it can be used to quantify the cardiovascular response to BFR exercise. Several guidelines exist in the BFR exercise literature, guidelines for cuff pressures, cuff widths, BFR exercise pressures, and exercise bouts. However, no guidelines exist for an initial rest period prior to pre-exercise AOP measurement. Several studies have used 5min of initial rest (Stanford et al., 2020), some 10 min (Jessee et al., 2017), and several other studies are simply unclear on the initial rest period used (Hughes et al., 2018). Thus, one purpose of this study is to understand if differing initial rest periods (5 min and 10 min) affect pre-exercise AOP. It has also been shown that if the cuff remains inflated post-exercise, the hyperemic response to exercise is attenuated, causing a continuation in the blood pooling effect post-exercise (Mouser, Laurentino, et al., 2017). The literature differs, however, in whether or not the cuff is to be deflated post-exercise before AOP measurement. Some studies from our lab (unpublished) deflated the cuff before reinflating it for post-exercise AOP measurement in order to prioritize other measurements being taken. Others simply increase the pressure from the relative pressure applied during exercise to reach post-exercise AOP (Jessee et al., 2017). It is unknown whether cuff deflation prior to a post-exercise AOP measurement will affect the magnitude of the change in pre- to post-exercise AOP, and no standard protocols exist regarding cuff inflation versus deflation when assess AOP post-BFR exercise. Thus, a second purpose of this study is to compare differences in pre- to post-exercise AOP measurements when leaving the cuff inflated versus deflating and reinflating the cuff post-exercise.

CHAPTER I: LITERATURE REVIEW

Physical exercise improves musculoskeletal and cardiovascular health, decreases chances of chronic conditions or illnesses, and improves lifespan (Ruegsegger & Booth, 2018). To improve muscular fitness, decrease heart attack risk, and decrease blood pressure, the American College of Sports Medicine calls for resistance training of 8-10 exercises with 8-12 repetitions each for at least 2-3 non-consecutive days per week with 30-60% of 1RM (American College of Sports Medicine, 2009). However, several alternatives to traditional training exist. Low load exercise with blood flow restriction (BFR) is an alternative to these protocols and is currently used in research and clinical settings (Patterson et al., 2019). The objective of BFR is to increase cuff pressure, leading to the diminution of blood vessels and the creation a venous blood pooling effect. BFR is most often accomplished by wrapping a pneumatic cuff around the most proximal region of a limb followed by an increase in cuff pressure by a tourniquet system, which serves to decrease arterial blood flow and fully occlude venous flow.

When used in combination with low load exercise, BFR leads to several beneficial outcomes. BFR exercise has been shown to decrease muscle atrophy after an injury or major surgery, or in people suffering from chronic illnesses (Hughes et al., 2017). Conceição et al similarly found that in people with inflammatory myopathy, low load BFR exercise led to increased muscle size not seen with high load training (Conceição & Ugrinowitsch, 2019). BFR training has also been shown to improve quadricep function and decrease atrophy after ACL reconstruction (Kilgas et al., 2019). While BFR training is beneficial for combatting post-operative atrophy, low load BFR exercise also elicit similar muscular responses to high load training in healthy individuals(Martín-Hernández et al., 2013). We see decreased strain on muscles and joints while muscle size increases in the healthy elderly population as well (Conceição & Ugrinowitsch, 2019). It can even increase muscle strength and hypertrophy in well trained athletes that would not normally benefit from low load training (Wortman et al., 2021). Muscle size increases in healthy and untrained individuals due to BFR exercise in the upper and lower limbs(Counts et al., 2016)(Jessee et al., 2017). Though BFR exercise is proven to reduce muscle wasting and improve muscle size in several populations, safety concerns exist for the application of BFR during exercise. (Spranger et al., 2015)states that, in addition to the bodily mechanoreflex, the metaboreflex is engaged and exaggerated due to BFR exercise. The metaboreflex stimulates increased metabolite secretion in hypoxic muscle fibers. These responses can cause an increased risk for deleterious events in those with hypertension and peripheral artery disease, especially in the presence of BFR exercise. It is also stated that 1 in 3 Americans have hypertension and may be unaware of it, causing BFR to be unsafe in many populations (Spranger et al., 2015). Though BFR might cause exaggeration of the EPR, applying BFR relative to each participant can mitigate these risks (Jessee et al., 2016). Applying pressure based on percentages of an individual's arterial occlusion pressure (AOP) allows exercise pressures to be tailored to each participant. Arterial occlusion pressure is simply the minimum pressure required to fully occlude blood flow distal to the blood pressure cuff. Researchers and clinicians can increase cuff pressures until reaching AOP, then apply percentages of AOP (40%-80%) in conjunction with exercise. This can mitigate risk by allowing individuals to exercise with lower weight while still receiving beneficial muscular growth or decreased atrophy.

AOP is related to a variety of different characteristics including cuff width, cuff material, tourniquet shape, cuff length, size of an individual's limb, and an individual's blood pressure (Jessee et al., 2016). Bigger limbs typically require greater cuff pressures to occlude blood flow, even across varying cuff widths (Jessee et al., 2016). Wider cuffs require lesser cuff pressures to occlude flow than do narrower cuffs due to the greater vascular surface area covered by the wider cuff (Jessee et al., 2016). Though wider cuffs require lower absolute pressures, these cuffs might limit movement throughout the exercises (Patterson et al., 2019). Differing cuff materials seem to have an effect on upper body AOP as different cuff materials of the same size (3cm and 5cm) elicit very different AOP values (Patterson et al., 2019). When exercise pressures are percentages of each cuff's measured AOP, however, the muscular outcomes are similar. Individuals with larger limbs typically require increased pressures to occlude blood flow simply because the cuff must reach deeper to the vasculature (Mattocks et al., 2018). Additionally, individuals with higher blood pressure will require increased cuff pressure to reach their specific AOP value(Mattocks et al., 2018). Once the AOP value is reached for each individual participant, the cuff is typically deflated and percentages of AOP are selected to apply in conjunction with various exercise protocols. 40% to 80% of AOP is the typical range of pressures applied during exercise, having evidence to support effective muscle size increases (Dankel et al., 2016). Pressures below 40% of AOP might not provide proper diminution of the vasculature to elicit beneficial responses, and pairing exercise with pressures over 80% might augment the cardiovascular response and cause added discomfort, thus, 40 to 80% of AOP is commonly used (Patterson et al., 2019). However, (Counts et al., 2016) showed that relatively high pressures may not be needed to maximize the response to BFR exercise training and that similar muscular size and strength benefits were found between 40% and 90% of AOP. However, other studies have shown that at very low loads (≤20% 1RM) or for vascular benefit, greater pressures might be required (Mouser et al., 2019).

When applying BFR to exercise, several variable manipulations might lead to differing musculoskeletal and cardiovascular responses. By experimentally manipulating cuff pressure and material, exercise percentage of AOP, exercise load, and set/repetition protocols, researchers can better understand how these variables affect acute and chronic responses. The most common protocol calls for an exercise total of 75 repetitions, 30 repetitions in the first set and 3 sets of 15 repetitions following. Another common protocol calls for 3-5 sets of exercise until the participant reaches concentric failure (Patterson et al., 2019). These protocols are thought to bring a participant to adequate muscle fatigue, thus, allowing for greatest muscle adaptation. In those that have recently suffered injury or undergone major surgery, the 30, 15, 15, 15 protocol may offer healthy adaptations in a safer manner. Rest periods between exercise sets are usually short and the cuff remains inflated at exercise percentages of AOP while resting. Differing rest periods (30s and 60s) have been compared, and no significant strength adaptations or increased metabolic stress was found between rest periods (Loenneke et al., 2012). Exercise weight is typically based on percentages of a participant's 1 repetition maximum (1RM) of the chosen exercise. For most BFR studies, 1RM is achieved by a participant completing multiple repetitions of the exercise at lower percentages of the 1RM. Exercise with BFR is usually performed at 20-40% of 1RM because these weight percentages, in conjunction with 40-80% AOP, have been most commonly seen to elicit muscle adaptation. Individuals exercising with ≤20% 1RM may require higher percentages of AOP (80%) to benefit from this protocol, when using an arbitrary repetition protocol. Though the literature differs in exercise pressures used, exercise protocols, %1RM, and several other variables, the musculoskeletal adaptations to BFR exercise continue to be supported.

As previously mentioned, measuring an individual's AOP prior to exercise (pre-AOP) allows researchers and clinicians to determine safe and effective individual exercise pressures (40-80%). A secondary purpose or utility of the AOP measurement involves a post-exercise AOP measure (post-AOP). This post-AOP measure allows for AOP comparison from pre- to post-offering a reliable way to understand the cardiovascular response to BFR exercise. Using a pre- to post- AOP comparison allows researchers and clinicians to capture the immediate cardiovascular response without having to remove and change from exercise cuff to blood pressure cuff, possibly missing the true or immediate cardiovascular response. This specific technique has been explored in the literature as a potential surrogate measure of blood pressure (Jessee, Buckner, et al., 2018), a universally important measurement in understanding cardiovascular health and responses. (Bell et al., 2020) conducted a study in which brachial systolic blood pressure and AOP were compared, finding that the two methods of measurement tracked similar measurements at rest and after exercise. This comparison of AOP values has been seen to quantify the cardiovascular response in many studies, and evidence exists that this method is reliable. Previous studies used a pre- to post- comparison to quantify the cardiovascular response to very low, low, moderate, and high levels of BFR with exercise (Jessee et al., 2017). It has also been used to measure the cardiovascular response in exercising and non-exercising limbs (Jessee, Buckner, et al., 2018). AOP was used to compare responses to unilateral, bilateral, and alternating resistance exercises with BFR (Stanford et al., 2020). Though we continually see the utility of the post-AOP measurement in understanding the cardiovascular system, no protocol exists concerning the measurement of post-AOP. Several studies simply increase the pressure in the inflated cuff from exercise percentage of AOP to reach post-AOP following the last repetition of the final set of exercise (Jessee et al., 2017). However, some recent (unpublished) studies from our lab deflate the cuff before post-exercise AOP in order to measure several different responses. This deflation potentially causes a hyperemic response and loss of the blood pooling effect created by BFR. The buildup of metabolites distal to the cuff via the metaboreflex could cause a flushing of metabolites back to the heart causing a potential effect on AOP. Also, the loss in the blood pooling effect itself could cause a change due to a large amount of blood rushing back immediately following cuff deflation. This could increase stroke volume and pressure, causing an increase in AOP. However, this effect of cuff deflation has not been examined to date, therefore, it is unclear whether post-exercise cuff deflation has an effect on post-AOP, a measure being used in BFR exercise research to quantify the cardiovascular response to various protocols. Thus, the primary purpose of this study is to determine the effect of a cuff deflation on post-exercise arterial occlusion pressure. Additionally, since no standardized initial rest period exists for pre-AOP measurement, a secondary purpose of this study is to understand if differing initial rest periods (5min and 10min) affect the pre-AOP measure.

CHAPTER II: METHODS

Participants: Twenty participants (10 male and 10 female) volunteered to participate in the study. All participants had resistance trained the upper body at least twice a week for the last two months and were familiar with the elbow flexion exercise (biceps curl). Participants were eligible for inclusion in the study if they: were resistance trained, within the age range of 18-35 years, did not regularly use tobacco or nicotine products in the last 6 months, had a BMI <30, taking no medications that affect blood pressure, abstained from upper body exercise for 48 hours prior to each visit, abstained from food and caffeine for 2 hours prior to each visit, and abstained from alcohol consumption 24 hours before each visit. Additionally, each participant had to meet less than two of the following risk factors for thromboembolism: currently taking birth control, diagnosed with Crohn's or inflammatory bowel disease, diagnosed with varicose veins, past fracture of hip, pelvis, of femur, or have personal or family history of deep vein thrombosis or pulmonary embolism. All participants were informed of laboratory techniques and procedures as well as risks before giving written consent. The University of Mississippi Institutional Review Board approved this study, and it meets all ethical requirements.

Experimental Design: Each participant made three visits to the lab, each visit separated by at least 2 days. Visit 1 consisted of paperwork, including informed consent and PAR-Q, followed by measurements of height, weight, and elbow flexion (biceps curl) 1 repetition maximum (1RM). Participants were then familiarized with BFR exercise. For visits 2 and 3 (testing days), one of four random conditions was tested. Each condition was a different combination of initial rest period (0min, 5min, and 10min or 0min and 10min) and the presence or absence of cuff deflation before post-exercise AOP measurement. The exercise protocol, including relative pressure and load was the same across days 2 and 3. Participants completed 3 sets of biceps curls to concentric failure at 30% 1RM and 40% AOP. For both testing days, upon entry into the lab, standing AOP was measured using a 5cm cuff on the upper dominant arm and a handheld doppler probe on the radial artery at the wrist. On one of two days, depending on condition, AOP was measured again at 5min and 10min after the initial AOP measure. On the other day, AOP was only measured 10min after the initial AOP measure. The 10 min measures served as the pre-exercise AOP for which exercise pressure was determined. Participants then completed the exercise protocol as stated. Following the final repetition of the third exercise set, post-exercise AOP was measured. Depending on condition and on one of two days, the cuff remained at exercising % of AOP and the cuff was inflated to find post-AOP starting 10 seconds after the final set of exercise. On the other day, the cuff was deflated immediately after exercise and was reinflated after the same 10 second interval. A 10 second timer allowed the AOP measures to begin at precisely the same time post-exercise on both days, and allowed the researcher enough time to locate the pulse with the doppler probe. Post-AOP measurement concluded the testing day protocol.

Condition Assignment: Conditions were assigned as combinations of initial rest periods with and without 5min measure, and the presence of absence cuff deflation prior to post-exercise AOP measure. These combinations formed 4 conditions. Given that we had 4 conditions, we took a counterbalanced approach giving us 5 participants in each of the 4 conditions.

Arterial Occlusion Pressure: Standing arterial occlusion pressure was measured in the most proximal region of the dominant arm before and after each exercising bout with a 5cm wide, nylon cuff (SC5 Hokanson, Bellevue, WA). A handheld doppler probe (MD6, Hokanson, Bellevue, WA) was placed over the radial artery of the wrist until an auditory signal of blood flow was perceived. The cuff was slowly inflated using an E20 rapid cuff inflator (Hokanson, Bellevue, WA) until no signal of blood flow was perceived. The lowest cuff pressure at which the signal was lost was considered to be the arterial occlusion pressure. Once arterial occlusion pressure was determined, the cuff was immediately deflated.

One Repetition Maximum: Unilateral elbow flexion one repetition maximum was determined on visit one of the study in order to determine appropriate exercise loads. Determination began with a warm up of 5-10 repetitions using 30% of an assumed maximum. Each repetition was completed with feet shoulder width apart with back and heels against a wall. When in proper position, participants were handed a loaded dumbbell with their arm fully extended and were encouraged to complete elbow flexion through a full range of motion while remaining upright. Testing attempts began with completing one repetition at 60-75% of an estimated maximum, and the load steadily increased until the participant was unable to lift the load with proper form. After each attempt participants were given 90 seconds rest. An attempt was considered unsuccessful if the participant could not complete the full range of motion or they were unable to maintain strict form. One repetition maximum was determined as the greatest load a participant could lift with proper form.

Blood flow restriction exercise protocol: BFR protocol was performed by placing a 5cm wide nylon cuff (Hokanson, Bellevue, WA) on the most proximal region of the dominant arm and inflating it to 40% of pre-exercise AOP. This pressure is common in BFR exercise research and has been shown to elicit muscle adaptation. After inflation, participants completed 3 sets of biceps curls to concentric failure. This exercise protocol is common in exercise research. Each repetition was completed to a metronome cadence of 45 beats per minute for both exercise testing days.

Statistical Analyses: To compare pre-exercise AOP measurements across different rest periods, we compared the mean values of walk-in, 5min, and 10min AOP measurements using a one-way Bayesian repeated measures ANOVA. To determine if there was any effect of the 5min AOP measure on subsequent 10 min measures, we also compared the difference in means from walk-in to 10min on the 5min measure day and compared that difference to the walk-in and 10min AOP measure on the other day using a Bayesian paired t-test. To assess the effect of cuff deflation before post-exercise AOP, we compared change scores from pre to post on days when the cuff was deflated and when the cuff remained inflated before post-AOP using a Bayesian paired t-test. Results are reported as mean (SD) unless otherwise noted.

CHAPTER III: RESULTS

Participant Characteristics: 20 participants (female = 10, male = 10) had a mean age of 21.5 (1.2) years, weight of 76.9 (16.9) kg, height of 179.9 (23.0) cm, bicep curl 1RM of 18.3 (6.4) kg, and 30% 1RM of 5.6 (1.9) kg. Arm dominance was 18/20 right-handed.

Pre-Exercise AOP: On days consisting of all three pre-exercise measurements of AOP, the walk-in AOP measurement [158.8 (21.6) mmHg], the 5min measurement [159.3 (20.3)], and the 10min measurement [159.4 (23.5)] were similar (BF_{10} = 0.141, Figure 1). The Bayes Factor indicates that the Null hypothesis was 7 times more likely than the Alternative. For the comparison of differences between walk-in to 10min AOP on the day with [0.65 (8.1)] and without 5min measure [1.65 (9.0)], the differences were similar as well, with the null being 4 times more likely than the alternative (BF_{10} = .244, Figure 2).

Figure 1: Comparison of pre-exercise arterial occlusion pressure at three different time periods.

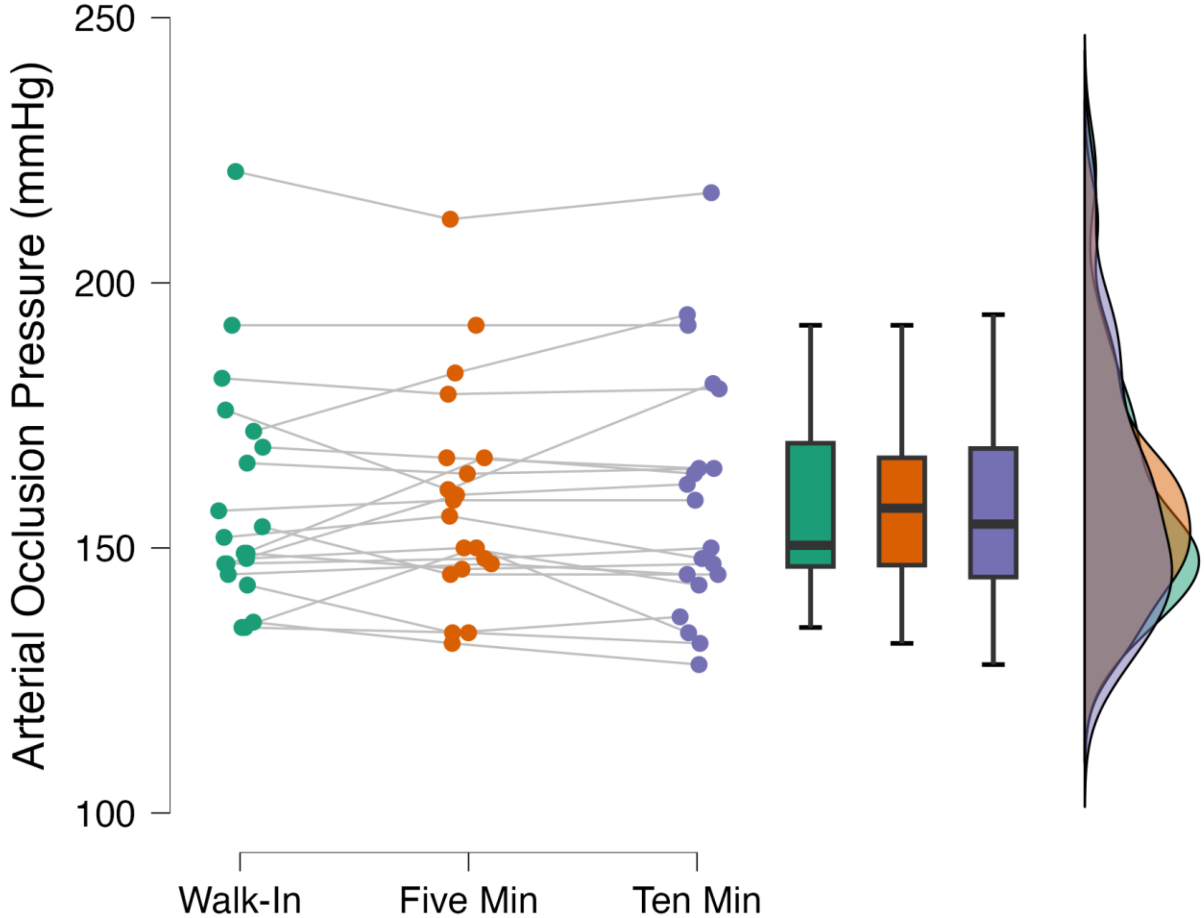

Figure 1: Comparison of pre-exercise arterial occlusion pressure across three different initial rest periods. Statistical comparisons between time points are not shown because the null hypothesis was more probable ($BF_{10} = 0.141$). Dots indicate individual measurements; lines indicate individual change across rest periods. Box plots represent the 25th to 75th percentile as dashed lines represent medians and whiskers indicate 1.5x the interquartile range of the data set. Raincloud plots show relative distribution and overlap of data points.

Figure 2: AOP difference from walk-in to 10min across exercise days

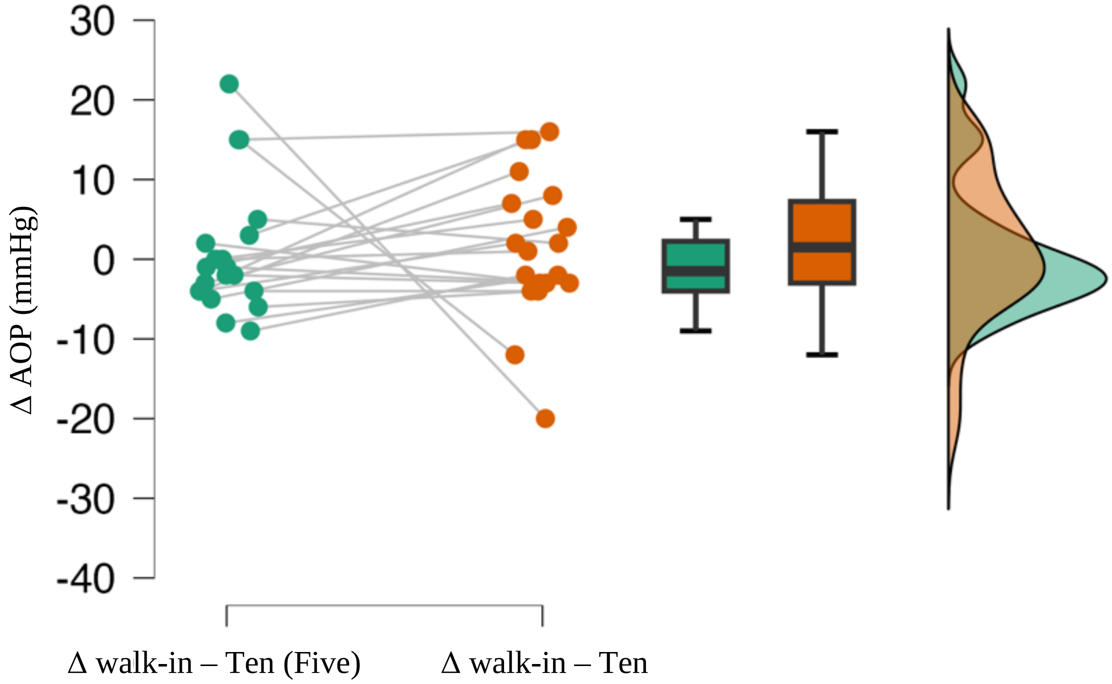

Figure 2: Comparison of initial AOP to 10min AOP measurements across days. We see evidence for the null indicating these two measures are similar (BF_{10} = .244). Dots indicate individual data points. Lines indicate connection of data points across days. Box plots represent the 25th to 75th percentile as dashed lines represent medians and whiskers indicate 1.5x the interquartile range of the data set. Raincloud plots show relative distribution and overlap of data points.

Subsequent Data Analysis: Being that two of twenty participants had unusually large changes in walk-in to 10min AOP measure on days with and without a 5min measure, we ran data again without these two participants. On days with a 5min measure, this yielded a mean of -1.33(5.44). For days without a 5min measure, this yielded a mean of 3.61(7.0) with BF_{10} = 11.46.

Figure 3: AOP difference from walk-in to 10min across exercise days

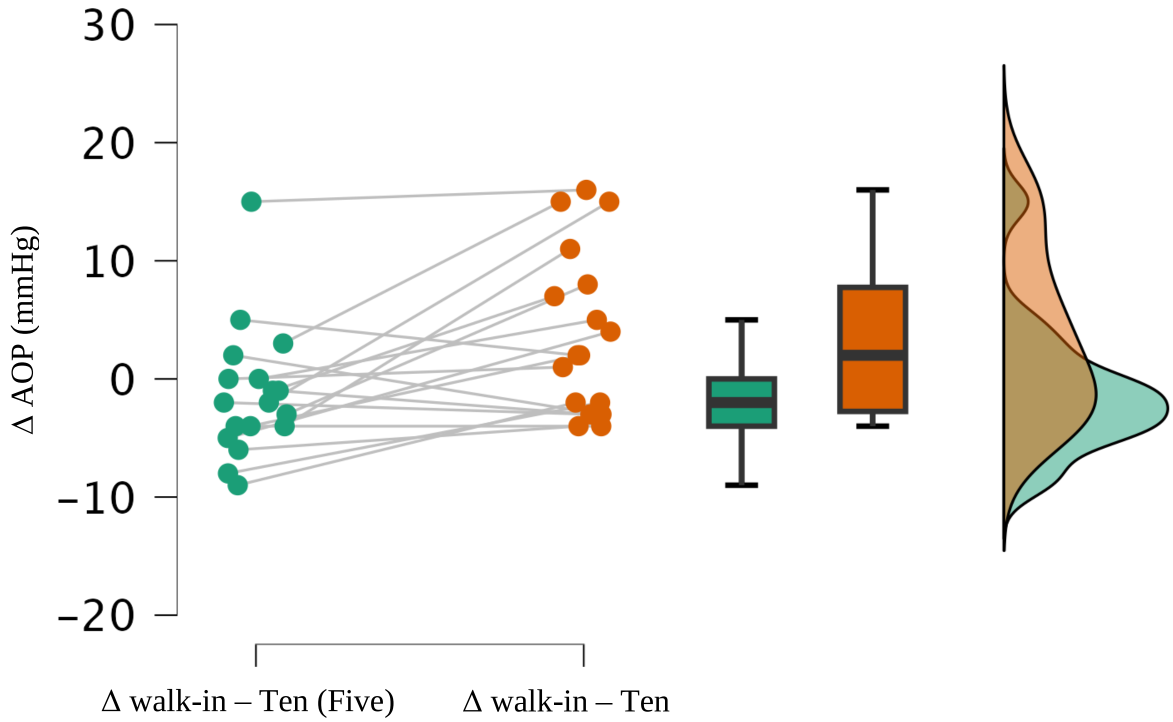

Figure 3: Comparison of initial AOP to 10min AOP measurements across days. We see evidence for the null indicating these two measures are similar (BF_{10} = .244). Dots indicate individual data points. Lines indicate connection of data points across days. Box plots represent the 25th to 75th percentile as dashed lines represent medians and whiskers indicate 1.5x the interquartile range of the data set. Raincloud plots show relative distribution and overlap of data points.

Post-Exercise AOP: There was anecdotal evidence of a difference (BF_{10} = .815, Figure 3) between the change score from pre- to post-AOP measurements on the day of inflation [32.8 (25.6)] and the change score from pre- to post-AOP measurements on the day of deflation [21.6 (12.8)]. This suggests that more data is needed to come to a more definitive conclusion.

Figure 4: Change in AOP from pre- to post-exercise on days with and without cuff deflation

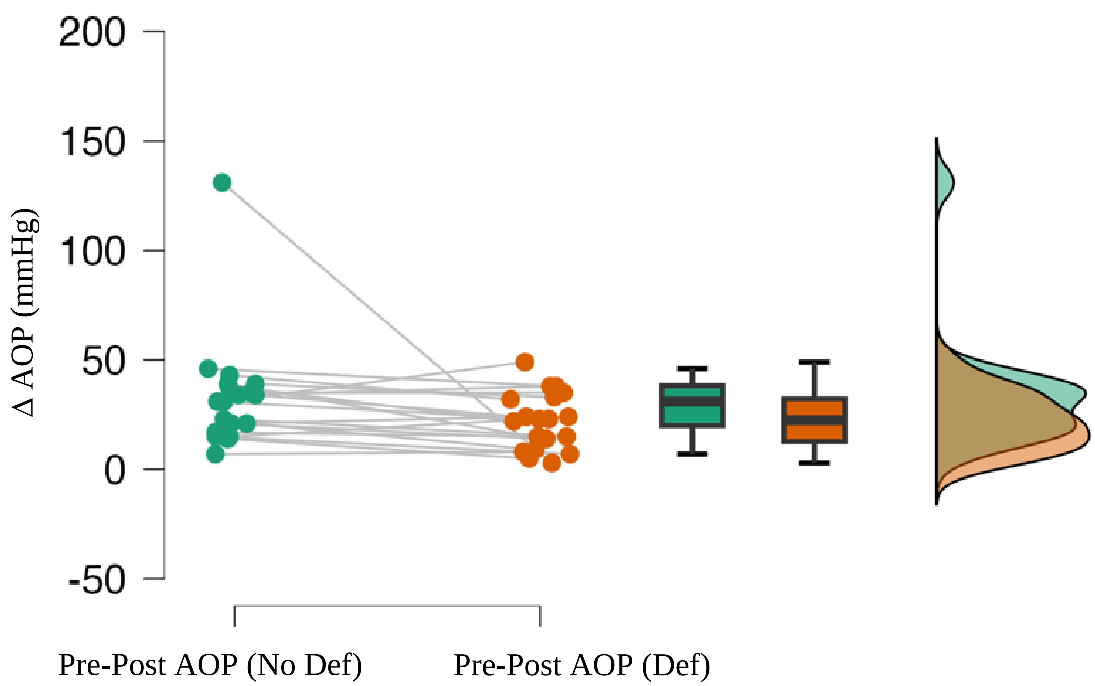

Figure 4: Change in AOP from pre- to post-exercise on days with and without cuff deflation. Dots indicate individual data points. Lines indicate connection of data points across days. Box plots represent the 25th to 75th percentile as dashed lines represent medians and whiskers indicate 1.5x the interquartile range of the data set. Raincloud plots show relative distribution and overlap of data points.

Exercise Repetitions: Total exercise repetitions completed on inflation [54.5 (17.4)] and deflation [52.8 (18.9)] days were similar (BF_{10} = .293, Figure 4).

Figure 5: Total Number of Completed Repetitions

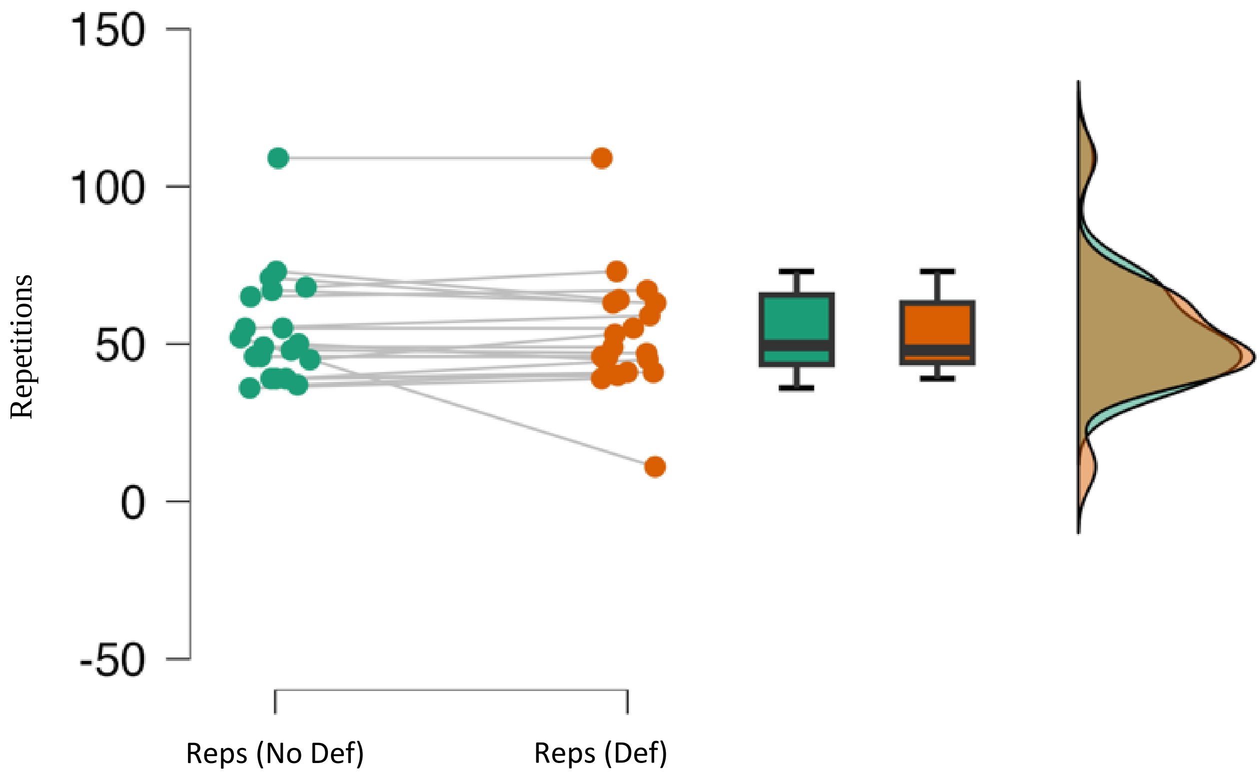

Figure 5: Total number of completed repetitions across exercise days. Dots indicate individual data points. Lines indicate connection of data points across days. Box plots represent the 25th to 75th percentile as dashed lines represent medians and whiskers indicate 1.5x the interquartile range of the data set. Raincloud plots show relative distribution and overlap of data points.

Subsequent Data Exploration: Upon analyzing experimental data, we noticed one participant whose pre- to post-exercise AOP measurements were unusually large in comparison to all other participants. Therefore, we re-analyzed all data without this participant to determine the potential influence of this unusual response on the results. All data that changed when removing this participant is reported below. With this participant removed, we have anecdotal evidence favoring a difference (BF_{10} = 1.96) between the change score from pre- to post-AOP measurements on the day of inflation [27.6 (11.3)] and days of cuff deflation [22.5 (12.3)].

Figure 6: Change in AOP from pre- to post-exercise on days with and without a cuff deflation

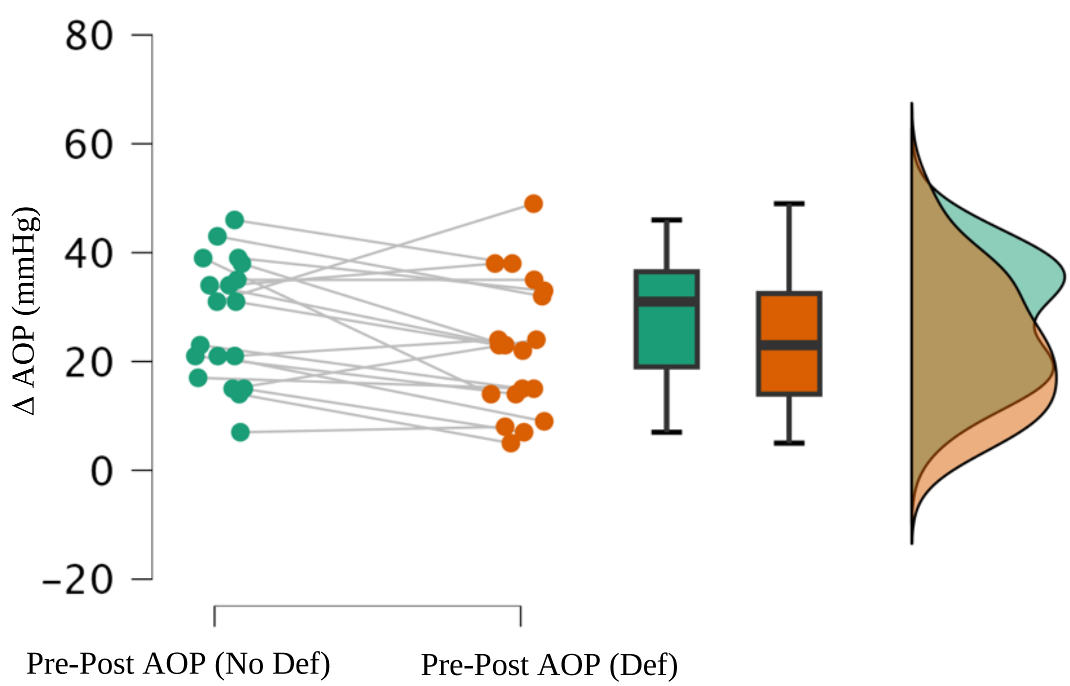

Figure 6: Change in AOP from pre- to post-exercise on days with and without a cuff deflation. Dots indicate individual data points. Lines indicate connections in data points across days. Box plots represent the 25th to 75th percentile as dashed lines represent medians and whiskers indicate 1.5x the interquartile range of the data set. Raincloud plots show relative distribution and overlap of data points.

CHAPTER IV: DISCUSSION

Physical exercise is proven to be beneficial to the musculoskeletal and cardiovascular system. Due to various time constraints and/or health restrictions, many do not exercise according to guidelines set forth by the ACSM. Low load exercise with BFR is an alternative to high load exercise and is being used in exercise research and clinical settings. Low load exercise with BFR involves inflation of a cuff relative to someone's arterial occlusion pressure, and exercising with lower relative percentages of maximum strength. There are several common protocols or suggestions set forth by researchers concerning many variables, but we sought to study an area in which no guidelines exist. There are no guidelines concerning initial rest period before the pre-exercise AOP measurement, a measure that is important, as exercise pressures and post-exercise AOP comparisons rely on this measure. Additionally, no recommended protocol exists concerning cuff deflation prior to the post-exercise AOP measure. It is thought that doing so would potentially result in a hyperemic response, altering the post-exercise AOP measure. In this study, we compared immediate, 5min, and 10min initial rest periods prior to pre-exercise AOP and found that all initial rest periods are similar. We also compared changes in pre- to post-exercise AOP measurements on a day with a cuff deflation prior to post-exercise AOP measurement and day without cuff deflation. We found anecdotal evidence suggesting a difference between the two measures.

Pre-Exercise AOP: In the comparison of 5min and 10min initial rest periods prior to pre-exercise AOP measurement, we found evidence for the null (similarity of measurements) as it was 7 times more likely than the alternative (BF_{10}=.141). Additionally, comparison of immediate to 10min

AOP measurements across both days were similar as well. When removing two participants in our analysis of immediate to 10min AOP measure, we see that this 5min measure could have an effect on the walk-in to 10min measure (BF_{10} = 11.46). However, because two out of twenty participants had a similar response, we believe these two participants should remain included in our results and analysis. Therefore, pre-exercise AOP could be reliably measured upon entry into a lab or clinic, after 5min, or after 10min, assuming the participant or patient didn't run or rush into the lab or clinic. For those applying BFR with exercise, waiting up to 10min before pre-exercise AOP may not be necessary. Our data suggests these rest periods are similar across 20 participants. The American Heart Association similarly states that shorter initial rest periods yield blood pressure measurements that aren't significantly different (<2mmHg) than 5min initial rest periods that were previously recommended (Brady et al., 2021). Johns Hopkins Medicine also states that less than even 3 minutes rest yields accurate blood pressure measurement in those without hypertension. For those with hypertension, blood pressure values were significantly different (>2mmHg) between 0min, 2min, and 5min before exercise (Brady et al., 2021). Concerning our measurement of pre-exercise AOP, measures were similar to previous studies as Jessee et al., 2016 found similar pre-exercise AOP values [145 (19) mmHg] in the standing position with a similar cuff width (5cm). (Barnett et al., 2016) also found similar pre-exercise AOP values [137 (15) mmHg], further validating our data. Though researchers and clinicians use differing initial rest periods, these pre-exercise AOP values are unaffected by initial rest. The results found within this study can serve to save researchers and clinicians, participants and patients valuable time that many of them lack. This finding serves to further shorten the time to create healthy muscular adaptations and provide an even more practical BFR protocols.

Post-exercise AOP: For the comparison of post-exercise AOP with and without cuff deflation, we found anecdotal evidence. For those seeking to use pre- to post- comparison of AOP to quantify the cardiovascular response to BFR exercise, more evidence is needed to come to a definitive conclusion on potential differences in AOP caused by the presence or absence of cuff deflation prior to post-exercise measurement. The inconclusive data we found could likely be due to a small sample size, and/or potentially due to variability in individual participants' cardiovascular response to exercise day to day. Responses to cuff deflation could also vary between participants, another potential reason for inconclusive data.

There are a few previous studies that have used post-exercise AOP to quantify the cardiovascular response to BFR exercise in the upper arm, and the majority did not deflate the cuff at exercise cessation before measurement. This is a key difference between one of our conditions and some of these others. (Barnett et al., 2016) measured AOP pre- and post-exercise using similar equipment, load (30% 1RM) and pressure (40% AOP) without deflating the cuff post-exercise. They found a change of 22 mmHg, which is similar to our data. This suggests that the change in AOP we observed is in line with others. In another study, (Bell et al., 2018) similarly used 40% AOP and measured AOP pre- and post-exercise. Though exercise protocols were different and they used 15% 1RM, they observed a change of 43mmHg. However, we wouldn't know what could have happened had these researchers deflated the cuff prior to post-exercise AOP measurement. Previous (unpublished) research from our lab deflated the cuff prior to post exercise AOP measurement in order to take other measures, and we do not know what effect that could have on the measure. As previously mentioned, post-exercise cuff deflation could cause a hyperemic response and flushing of built-up metabolites back to the heart. This deflation could cause an increase in stroke volume, blood pressure, and AOP. Additionally, one of our twenty participants had unusually large differences in pre- to post-exercise AOP measurements compared to their other exercise visit and to other participants across both exercise visits. Though analyzing the data with and without this participant didn't change the outcome or level of evidence for a hypothesis, it might shed some light on the potential variability between participants and the pre- to post- measurement with and without cuff deflation. More data is needed to come to a definitive conclusion on this comparison, and future research is needed to understand if a difference exists in pre- to post- changes in AOP with the presence of absence of cuff deflation. This work could be used by our lab to continue collecting data or the mean differences could be used by others to study the same thing.

Exercise Repetitions: We found that total number of exercise repetitions were similar across both days with and without cuff deflation prior to post-exercise measurement. The reason for summing total exercise repetitions each day rather than studying decreasing repetitions with increasing sets was to seek to understand if on one day of exercise, participants completed more repetitions. If a participant completed more repetitions on a certain day and therefore had a higher post-exercise AOP that same day, we could potentially attribute a higher post-exercise AOP with a participant simply completing more repetitions. Repetitions did decrease as sets increased, in line with much BFR exercise literature. (Mouser, Laurentino, et al., 2017)We also attempted to control for any potential order effect created by participants completing more repetitions on their second day of exercise as the conditions of inflation or deflation were randomized and counterbalanced in this study. Using a commonly prescribed BFR exercise protocol leads us to believe our participants did complete reasonable exercise to elicit the cardiovascular responses also seen in other studies (Patterson et al., 2019).

Limitations: No study is without limitations. This study had very small age variation with a small standard deviation, having one participant being 25 years old and one participant being 19. All other participants were 20, 21, or 22 years old. We don't know if the effect of cuff deflation could be different for older trained individuals, or individuals with injury or illness. Our participants were all resistance trained in the upper body; these effects are unknown for the untrained population. None of our participants had high blood pressure, which is seen to have an effect on initial rest periods prior to blood pressure measurement (Brady et al., 2021). We do not know if high blood pressure could have an effect on initial rest prior to AOP measurement. Future research could be conducted to test these rest periods in those with high blood pressure. A future study could also test even longer initial rest periods prior to exercise (15min). For the comparison of post-exercise AOP with and without cuff deflation, more research is needed to come to a definitive conclusion. Our research was potentially limited by a smaller sample size, and future research could incorporate more participants in order to draw more definitive conclusions.

CHAPTER V: CONCLUSION

Though differing initial rest periods are used in the BFR exercise literature, our data shows that waiting up to 5min or 10min is not necessary for a reliable pre-exercise AOP measurement. Measuring AOP upon entry into a lab or clinic is similar to these 5min and 10min measures in a young, healthy, and trained sample. Additionally, more data is needed to determine if post-exercise AOP is affected by cuff deflation prior to the measurement.

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