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From Zero to One Hundred: Assessing Discomfort in Different Cuff Widths Following Use of Blood Flow Restriction

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FROM ZERO TO ONE HUNDRED: ASSESSING DISCOMFORT IN DIFFERENT CUFF WIDTHS FOLLOWING USE OF BLOOD FLOW RESTRICTION

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ABSTRACT

Purpose: To examine the impact of cuff width, pressure, and sex on the perceptual response to blood flow restriction through a series of six experiments. **Methods:** Experiment One (n=50), Experiment Two (n=105), and Experiment Three (n=105) took place in the upper body, and Experiment Four (n=100), Experiment Five (n=100), and Experiment Six (n=100) took place in the lower body. Perceptual discomfort was measured following each condition. **Results:** Results are expressed as mean (± SD). In Experiment One, there were no differences in discomfort. In Experiment Two, the wide cuff resulted in more discomfort [43 (20) AU] compared to the narrow cuff [39 (20) AU]. In Experiment Three, the misapplied pressure resulted in more discomfort [44 (21) AU] compared to the correctly applied pressure [41 (20) AU]. In Experiment Four, the narrow cuff elicited greater discomfort [16 (14) AU] compared to the wide cuff [12 (11) AU]; but only in individuals with an estimated arterial occlusion pressure. In Experiment Five, males [Narrow= 59 (18) AU, Wide= 57 (19) AU] experienced greater discomfort compared to females [Narrow= 47 (18) AU, Wide= 50 (20) AU]; but only in those with an estimated arterial occlusion pressure. In Experiment Six, the discomfort from the misapplied pressure [74 (21) AU] exceeded that of the correctly applied pressure [52 (21) AU]. **Conclusion:** The width, pressure, and location of the cuff should all be considered when assessing perceptual responses to blood flow restricted exercise. There is no evidence that sex has a meaningful impact on discomfort.

LIST OF ABBREVIATIONS AND SYMBOLS

1-RM: One-repetition maximum

AOP: Arterial occlusion pressure

BF_{10}: Bayes Factor

AU: Arbitrary units

PAR-Q: Physical Activity Readiness Questionnaire

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CHAPTER I: INTRODUCTION

Exercise, a structured plan of physical activity, has been associated with lower risk of chronic disease, maintenance of a healthy body mass, and improved mood, amongst other benefits.[1] Aerobic exercise includes activities such as running, biking, or walking briskly, which can result in a lower resting heart rate and reduced risk of hypertension. Traditional resistance training is a form of exercise where skeletal muscles are moving against an external load to increase strength in different muscle groups.[2] Performing resistance training is most commonly prescribed for its benefits to skeletal muscle and bone, as well as protection against sarcopenia.[1,2]

The American College of Sports Medicine (ACSM) recommends that individuals perform 8-12 repetitions at 70% of his or her one-repetition maximum (1RM) in order to improve muscle strength and muscle size.[3] Unfortunately, there are many barriers to exercise that prevent certain populations from engaging in this activity. Physical barriers include lack of equipment or distance to the nearest facility, whereas physiological barriers include fitness level and exertion efforts. Some individuals view resistance exercise as tiring, fatiguing, unpleasant, or discomforting. Despite the benefits of resistance exercise, certain populations, such as the elderly or those who have been recently injured, may be advised to stray away from performing such protocols utilizing high loads. These populations are further advised to use low-load resistance training to maintain strength, but low-load protocols may be ineffective in providing the same preventative benefits as high-load resistance training.[4] Some may attempt to achieve such benefits by performing low-load resistance training to failure. However, this may require a large volume of exercise. Another method, blood flow restriction, would allow an individual to utilize these low loads while also minimizing the number of performed repetitions.

Blood flow restriction involves the placement of a cuff on the most proximal portion of the arm or leg in order to restrict blood flow into and out of the muscle. The pressure applied is often based on the arterial occlusion pressure, or the pressure needed to occlude venous outflow and attenuate arterial inflow.[5] A percentage of this arterial occlusion pressure is then applied during exercise, which allows the stimulus to be made relative to the cuff used and the individual to which the cuff is applied. Blood flow restriction in conjunction with low-load resistance training provides benefits, such as increases in muscle size and strength, over repetition matched low-load resistance training without blood flow restriction. These effects are observed with no known health or safety hazards, which could make this method of exercise more preferable to those who are unable to lift heavy weights.[6] Blood flow restriction exercise with low loads may be able to produce some of the same effects, especially for those individuals who are averse to lifting heavy weights. Therefore, in order to create a viable alternative, it is important to minimize the amount of discomfort that blood flow restricted exercise may introduce.

The majority of literature investigating exercise, including exercise with blood flow restriction, has been completed on men. In the studies including females, most did not make any comparisons solely on the differences between sexes. Studies without female participants have claimed that there are physiological reasons to exclude female representation.[7] It is possible that women respond differently to blood flow restriction, but it is also possible that women respond no differently than men. Given the general size difference between males and females, it is possible that cuff width could impact how females perceive blood flow restricted exercise. Since the perception of blood flow restriction between men and women exercising with relative pressures had not been compared, each of our research questions was also compared based on differences by sex.

The methods to individualize blood flow restriction involve altering the cuff material, cuff width, and pressure inflated into the cuff. The cuffs used in blood flow restriction application include non-pneumatic cuffs, elastic pneumatic cuffs, and nylon pneumatic cuffs. Non-pneumatic cuffs were used in early literature, as well as presently in practical blood flow restriction. There was not much difference during rest and exercise when applying blood flow restriction to the lower body using elastic cuffs and nylon cuffs of a similar width.[8] Elastic and nylon cuffs used in the upper body at the same relative arterial occlusion pressure produced similar muscular responses.[9] There have been numerous cuff sizes used all throughout the blood flow restriction literature. Participants found a wider cuff more discomforting than a narrow cuff when inflated to the same absolute pressure.[10] However, it is unknown whether cuff width truly impacts discomfort ratings when inflated to the same relative arterial occlusion pressure. By attenuating some of the cuff-induced discomfort, blood flow restricted exercise could become a viable alternative for traditional exercise. Furthermore, the increased discomforting feelings when using a narrow cuff could be due to the distinct decrease in the pressure required to occlude a vessel when using a wider cuff in comparison to the narrow cuff.[11] When taking arterial occlusion pressure, a wider cuff generally will require a lower absolute pressure to occlude the artery in comparison to a narrow cuff.

During blood-flow restricted exercise, a relative percentage of arterial occlusion pressure is applied to the cuff. In this instance, a narrower cuff will require a higher absolute pressure at a certain relative percentage compared to a wider cuff at the same relative percentage.[12] Due to this, it may become problematic when arterial occlusion pressure that is measured in a narrow cuff is applied to a larger cuff. Since a pressure measured in the original narrow cuff will be higher than the wide cuff, applying this pressure to a wide cuff would be synonymous to applying a higher relative percentage of pressure to the wide cuff. Therefore, when the applied pressure is individualized to the cuff and the participant at rest, we reasoned that there would be no difference between perceived discomfort in different cuff widths inflated to the same relative arterial occlusion pressure, which brings us to the purpose of the current study.

PURPOSE

The purpose of this research study was four-fold:

1) To examine the impact of cuff width on discomfort at rest and determine if there is a sex effect
2) To examine the impact of cuff width on discomfort following exercise and determine if there is a sex effect
3) To examine the impact a pressure intended for a narrow cuff had when inflated into a wide cuff and determine if there is a sex effect
4) To examine whether there is a preference between two different cuff conditions following exercise and determine if there is a sex effect

RESEARCH QUESTIONS

1. At rest, how does perceived discomfort vary with different sized cuffs inflated to the same relative arterial occlusion pressure in the upper body? Does this differ by sex?
2. How does perceived discomfort vary with different sized cuffs inflated to the same relative arterial occlusion pressure in the upper body following exercise? Does this differ by sex?
3. How does perceived discomfort vary when inflating a wide cuff with a pressure intended for a narrow cuff in the upper body following exercise? Does this differ by sex?
4. How do cuff width and pressure alter the preference of each condition in the upper body? Does this differ by sex?
5. At rest, how does perceived discomfort vary with different sized cuffs inflated to the same relative arterial occlusion pressure in the lower body?
6. How does perceived discomfort vary with different sized cuffs inflated to the same relative arterial occlusion pressure in the lower body following exercise? Does this differ by sex?
7. How does perceived discomfort vary when inflating a wide cuff with a pressure intended for a narrow cuff in the lower body following exercise? Does this differ by sex?
8. How does cuff width and pressure alter the preference of each condition in the lower body? Does this differ by sex?

These eight research questions are reflective of the overall purpose outlined in the study design. Through these questions, we were able to assess whether there were differences in perceived discomfort between the wide cuff and narrow cuffs when inflated to the same relative arterial occlusion pressure at rest, following exercise in the upper body, and following exercise in the lower body. We were also able to determine whether there were differences in perceived discomfort when a wide cuff is inflated to a pressure intended for a narrow cuff following exercise in the upper body and following exercise in the lower body. Lastly, we were able to determine cuff preference and whether there were sex differences between conditions.

SIGNIFICANCE

The preventative benefits, such as protection from sarcopenia and osteoporosis, of high load resistance exercise have not gone unnoticed, but much of the population is unable to adhere to a specific resistance training protocol to gain these benefits. The lack of adherence to resistance training programs may result from an inability to lift high loads due to old age or recent injury, the simple dislike for lifting heavy loads, or may even be the resulting discomfort (i.e. stress on joints, etc.) from lifting heavy weights. However, blood flow restriction has been proposed as an alternative to high-load resistance training to those individuals who are looking to heighten muscle growth. Although traditional high-load resistance training ultimately produces greater strength changes in comparison to blood flow restriction, this method allows individuals to lift lighter loads while seeing a similar muscle growth response as high-load resistance training. Many individuals exercise with different cuff widths inflated to different pressures, which may introduce other forms of discomfort. The potential discomfort that cuff width or pressure inflated into the cuff brings poses a limitation to blood flow restriction, as it would be simply replacing one discomfort with another. Therefore, discovering which cuff widths would be less discomforting and how cuff pressure can influence the discomforting rating can allow researchers and clinicians more information on ways to attenuate the discomfort in the cuff method of blood flow restriction to allow it to be a more widely-used method of exercise.

ASSUMPTIONS

1. Participants gave maximal effort during all testing procedures, specifically the 1-RM testing and the four sets of exercise to task failure.
2. Participants maintained all normal daily activities and dietary habits through the duration of the study.
3. Participants complied with food, caffeine, exercise, and alcohol restrictions prior to testing visits.
4. Participants answered all questions regarding to exclusion criteria truthfully.
5. Participants fully comprehended the 0-100 discomfort rating scale.

DELIMITATIONS

1. The results of this study are only applicable to healthy males and females between the ages of 18-35.
2. The participants were volunteers recruited from the University campus and may not represent a true random sample of the University population.

LIMITATIONS

1. During the exercise visits, the discomfort ratings were taken at two different time points since the exercise conditions were not performed concurrently.
2. Perceptual discomfort ratings were assessed immediately following exercise, rather than taking measurements while the participants were exercising.

3. The participants rated their feelings of discomfort on the single 0-100 discomfort scale with no other additional discomfort ratings.
4. The cuff inflation system had a maximum inflation pressure of 300 mmHg.

TERMINOLOGY

1. Arterial occlusion pressure (AOP)- the amount of pressure inflated into a cuff that occludes arterial inflow into a limb, measured in mmHg
2. Relative arterial occlusion pressure- an arterial occlusion pressure that accounts for both cuff width and the individual's limb circumference in the same measurement
3. Perceptual discomfort scale- the visual scale provided to all participants with values in increments of ten, from 0 to 100, that was used to rate discomfort immediately following four sets of exercise to failure
4. Blood flow restriction- application of a cuff to the proximal part of an appendicular limb with the purpose to decrease arterial inflow and occlude venous outflow
5. One-repetition maximum (1-RM)- the maximum load lifted for a single concentric muscle contraction

CHAPTER II: BACKGROUND

HISTORY OF BLOOD FLOW RESTRICTION

Over the past 20 years, the application of blood flow restriction during exercise has evolved from the traditional application of tourniquets to variations in cuff width, cuff material, and pressure inflated into the cuff. The physiological response to blood flow restricted exercise is ischemia, which is the full or partial restriction in blood supply. Although blood flow restricted exercise can be referred to as "KAATSU" training or "occlusion training", both will still achieve the same ischemic response. Our present reference to blood flow restricted exercise stems largely from a study published in 1998 which utilized tourniquet-induced ischemia in order to observe the resulting differences in strength training.[13] Both legs performed the same isometric knee extensions at 40% of their maximal voluntary contraction, except one leg performed the contractions with a tourniquet while the other did not. Over this four-week training period, the researchers noticed a significant increase in the maximal voluntary contraction produced in the leg that exercised under ischemic conditions. Due to the low force contraction used and the resulting increase in strength, the findings from this study and others[14] provide evidence that low-load resistance training could induce strength gains and muscle hypertrophy by restricting blood flow in a training limb.

METHODS OF APPLICATION

Much of the original literature utilized one pressure for all participants included in the blood flow restriction condition. This arbitrary pressure, which was not customized to the individual performing the exercise regimen, was used in both aerobic exercise protocols[15] and resistance exercise protocols.[16] Recognizing the variability of blood pressure and limb circumference values,[14,17] it is likely that this applied arbitrary pressure could have reached, exceeded, or fallen below the individuals' occlusion pressure during exercise. The application of blood flow restriction to these populations was done without considering the influence of external factors, such as the individual's limb circumference, the cuff width, or the type of cuff being used.[18]

Limb circumference is one physical feature of the individual that contributes to the application of blood flow restriction. A designated pressure can cause different outcomes, depending on the amount and composition of tissue around the blood vessels in that limb.[19] For example, someone with a greater amount of subcutaneous tissue may require a higher pressure to fully occlude blood flow in comparison to someone with more lean mass. The composition of the tissue contributing to the size of the limb is important to consider, but ultimately regardless of the cuff width used, a larger limb will result in a greater arterial occlusion pressure.[20]

In addition to taking into account individual factors, the type of cuff being used can also play a role in determining the arterial occlusion pressure. Three types of cuffs that have been used in previous blood flow restriction literature include non-pneumatic cuffs, elastic pneumatic cuffs, and nylon pneumatic cuffs.[21] Another method of "practical blood flow restriction" is using a non-pneumatic cuff with an adjustable strap. Initial blood flow restriction studies utilized tourniquets to occlude vessels during exercise, but these studies did not provide much indication of the pressure being applied to the occluded limb.[13] Since non-pneumatic cuffs are unable to provide information on the applied pressure, this introduces a benefit of using elastic or nylon pneumatic cuffs. In response to an acute bout of resistance exercise, elastic pneumatic cuffs do not differ from nylon pneumatic cuffs when used in the lower body,[8] and produce similar results when inflated to the same relative arterial occlusion pressure when measured in the upper body.[9] Although there were differences in resting pressures within the upper body, these differences become negligible during exercise.

Keeping in mind the previous notion that a limb with a larger circumference requires a greater pressure to fully occlude an artery, early work also showed that wider cuffs applied a greater percentage of pressure to a limb. This implies blood flow would be occluded at a lower pressure.[22] Using the principle from this study in another population, arterial occlusion pressure was measured in both a narrow and wide cuff on the same day.[11] The results indicated that the narrow cuff required an average pressure of about 235 mmHg to reach full occlusion, while the wide cuff required an average pressure of about 144 mmHg. These results provided further evidence that a wider cuff requires a lower pressure for full occlusion in comparison to a narrow cuff. We could more accurately compare individuals who are exercising with blood flow restriction if cuff width and limb circumference are accounted for during measurement and application.

Eventually, researchers began to consider the roles that cuff width and limb circumference play when applying pressure to a cuff. Arterial occlusion pressure is made relative to an individual when it is measured on that specific individual wearing the cuff that will be utilized. The need for relative arterial occlusion pressure was again emphasized when individuals exercised with a wide cuff and a narrow cuff inflated to the same absolute pressure. Of note, the relative pressure inflated into the wide cuff would have been much higher than the relative pressure inflated into the narrow cuff. Due to this relationship, the wide cuff produced greater cardiovascular changes, such as heart rate and blood pressure.[10] In another study, the researchers applied a relative occlusion pressure to a 5-cm, 10-cm, and 12-cm cuff.[12] With the same relative percentage of arterial occlusion pressure applied to all three cuffs, the researchers observed comparable decreases in blood flow between the three cuffs. This similar decrease provided further evidence towards utilizing a pressure relative to a cuff instead of a set absolute pressure. By applying relative arterial occlusion pressures which are individualized to both the person exercising and the cuff used, we can further ensure that a similar stimulus is being applied to all individuals equally.

SAFETY

The safety of blood flow restriction has also been discussed in order to judge its efficacy as a suitable alternative to traditional resistance exercise. One concern includes the potential muscle damage after a bout of blood flow restricted exercise. This is posed as a concern since long-term ischemia, or reduced blood flow, typically leads to necrotic tissue.[23] The time window associated with these negative outcomes is between three to six hours of full occlusion followed by repurfusion.[24] Since blood flow restricted exercise is performed in periods of no more than 10-20 minutes at a partial occlusion pressure, the adverse effects of ischemia-reperfusion are not a serious threat in these situations. The only direct marker for muscle damage is through studying damage at the fiber level with a muscle biopsy, while indirect markers include prolonged decrements in torque, soreness, or prolonged swelling. Two other indirect markers that may indicate muscle damage include serum creatine kinase and myoglobin levels. These proteins are typically located within the muscle but are leaked into the blood when the muscle is damaged. When performing low-load resistance training with blood flow restriction[16] or light aerobic exercise with blood flow restriction,[15] there were not significant changes in the creatine kinase or myoglobin levels in the blood alluding to undamaged muscle.

Another concern of those who are skeptical of the safety of blood flow restricted exercise includes the cardiovascular effects while exercising with blood flow restriction. Part of the hemodynamic response when exercising with blood flow restriction is to reduce the amount of venous return in the occluded limb. The decrease in venous return results in a decrease in stroke volume while the cuff is inflated, which is counterbalanced by an increase in heart rate. While investigating this in a population of eleven untrained males performing bilateral leg extensions,[25] the researchers observed an increase in blood pressure. Although blood pressure does indeed increase, it is comparable to or less than the pressures associated with traditional resistance exercise.[6] Additionally, there is skepticism about the increased risk of blood clotting following blood flow restricted exercise. Lower intensity exercise typically does not initiate any sort of clotting response, while more vigorous exercise may increase the risk for thrombosis.[6] In a large-scale survey of over 12,000 participants, less than 0.1% of the individuals experienced some sort of side-effect, thrombosis response after using blood flow restriction.[26] This led the researchers to conclude that although the risk is present, the likelihood of blood flow restriction itself augmenting a thrombosis response is extremely low.

It is reasonable to expect some safety concerns since this physical activity is being performed with partial occlusion. Currently, the existing literature studying the safety of blood flow restriction unveils no new risks of blood flow restricted exercise that do not already apply to normal exercise. But in order to prevent any future issues or chronic effects, we must ensure that blood flow restricted exercise is individualized to the person exercising.

PHASES OF BLOOD FLOW RESTRICTION

The methodology and mechanisms of what we know as blood flow restricted exercise took off a little over two decades ago. It has now been applied in three phases, or conditions, to see changes in muscle size and strength: during bed rest, with light aerobic exercise, and in conjunction with resistance exercise.[27]

Following the initial studies utilizing tourniquet-styled occlusion stimuli,[13] researchers began applying blood flow restriction in clinical populations to determine the rehabilitative effects on muscle size and strength. A group of males and females experienced a compression-decompression stimulus from a pneumatic cuff for two weeks following ACL reconstructive surgery.[28] At the end of the recovery period, the researchers noticed an attenuation in muscle atrophy of the experimental group in comparison to the control group who received no occlusion stimulus. Since Takarada et al. utilized patients in a true rehabilitative setting, Kubota recreated a similar study by inducing muscle atrophy in a group of participants.[29] These participants were split into three different experimental groups to observe the effects of a blood flow restriction stimulus on recovery. After purposely immobilizing a limb by keeping it in a cast, the researchers found that a compression-decompression stimulus was more effective in preventing muscular weakness from disuse compared to a group that did not have the blood flow restriction stimulus. When compared to not adding any intervention, adding blood flow restriction to an immobile limb did reduce the decreases in muscle size. Although there was not much more work done in this “first phase” of blood flow restriction, these studies introduced the idea that muscle loss can be attenuated by including blood flow restriction during the recovery period.

Phase one of blood flow restriction utilizes either a reperfusion mechanism or a venous pooling response to reduce muscle loss during bedrest. The protein synthetic response has been shown to not increase when individuals are using blood flow restriction at rest.[30] This is expected since there is only data suggesting an attenuation in muscle loss; but there has not been any evidence to show any increase in muscle size. The mechanisms behind why this has worked in the previously mentioned studies have not been identified completely. One study showed an acute muscle swelling response following reperfusion and removal of a blood flow restriction cuff.[31] However, the certainty that the swelling response is responsible for producing any of the outcomes is still not confirmed. There needs to be further research to uncover whether this can be a useful rehabilitation strategy or whether the data is reproducible.[32]

The second phase of blood flow restriction utilizes the occlusion pressure from the cuffs to slightly increase muscle size and strength during light aerobic exercise. This was originally studied in a group of eighteen men walking on a treadmill for three weeks.[15] After using MRI to measure muscle hypertrophy and a one-repetition maximum test to assess strength, the researchers concluded that the group who walked on the treadmill with an elastic pneumatic cuff saw increases in muscle size and strength. These increases were small, but still more than what was seen in the control group. This study created an opportunity for those individuals who are unable to handle the intensity of resistance training to utilize blood flow restriction in slow-speed aerobic exercise and see some improvements.

Low intensity aerobic exercise with blood flow restriction can induce favorable changes in muscle size and strength. There are two commonly suggested reasons for muscle hypertrophy: increased signaling of the protein synthetic pathways via mechanotransduction[33] or through a cell swelling response.[30] Mechanotransduction is the process of converting the tension from contracting a muscle into chemical signals within the muscle to induce morphological adaptations.[35] Increases in muscle size can be induced regardless of the load that is being lifted given that the muscle is placed under enough tension while being contracted.[36] There are a number of signals stimulating anabolic signaling pathways, such as the mitogen-activated protein kinase (MAPK) and the mammalian target of rapamycin (mTOR) pathways. The number of signals increases as more of the muscle fibers are recruited to participate in the contraction. The second commonly suggested reason for muscle hypertrophy is due to an increase in fluid flowing into the cells following exercise.[37] The accumulation of metabolites following blood flow restricted exercise causes fluid to be pulled into the intracellular space of the muscle.[35,38] This increase of fluid inside the muscle cell may also result in an increase in anabolic signaling, which could lead to favorable changes in muscle protein synthesis.[33] Additionally, the extracellular or intracellular fluid shifts can be affected when the pressure applied to the limb is increased or decreased.[38] This increase in fluid concentration can cause the muscle cells to expand, and therefore increase muscle size by a small amount.

Once an individual is adjusted to performing light-intensity aerobic exercise, one can slowly transition to low-load resistance training with blood flow restriction. The majority of blood flow restriction literature comes from experiments concerning this final phase of blood flow restriction. The occlusion stimulus is applied during resistance training to see a noticeable increase in muscle size and strength. Most protocols perform some type of maximal muscle strength measurement, either through torque quantities or a one repetition-maximum test.[39–42] By utilizing a load that is set at a low percentage of this maximum strength, it is then termed as “low-load” exercise. Low-load exercise used in conjunction with blood flow restriction has been shown to produce similar muscle size increases as typical high-load resistance training.[43]

The third phase of blood flow restriction, which is used in conjunction with resistance training, is the primary area where researchers have seen a hypertrophic response. The growth of individual muscle fibers is achieved through the muscle protein synthesis response. The signaling protein that is predominantly responsible for the protein synthetic response is mTOR.[44] When performing low-load resistance exercise with blood flow restriction, there is an increase in activation of the mTOR pathway.[45] Because of the increased activation of the mTOR pathway and increase in protein synthesis, the individual muscle fibers are able to grow and increase the overall size of the muscle. This gene response to increase muscle size in low-load blood flow restricted exercise is similar to what is observed in a high-load resistance training protocol.[46] In essence, the protein synthetic and gene expression response appears to be similar once the fiber itself is activated, regardless of whether the mTOR pathway is stimulated by high load resistance training or low-load blood flow restriction exercise.

Early work showed that muscle strength was proportional to muscle cross-sectional area in a sample of healthy human subjects.[47] However, this proportionality does not guarantee a direct relationship between the two with exercise. Though increases in muscle size and strength often occur concurrently, the two do not necessarily have a causal relationship.[48] The original hypothesis from Moritani & DeVries stated that neural factors initiate the increases in muscle strength followed by muscle hypertrophy in the subsequent weeks.[49] Nonetheless, we cannot assume that muscle hypertrophy resulted in increases in muscle strength because muscle size was never directly measured. Since strength is both measured and often improved by performing a one-repetition maximum strength test, training close to that load will show increases in muscle strength without eliciting a hypertrophic response.[50,51] In one study, the researchers had one group of participants perform a one-repetition maximum test every day for three weeks while the other group of participants performed a much larger volume of exercise for every session.[52] Since the high-volume exercise group increased muscle size more than the one-repetition maximum group but the strength increases were similar; this provided support that the change in muscle size may not be contributing to the change in muscle strength. Even when a similar protocol was replicated over an eight-week period, the researchers concluded that the exercise volume and increases in muscle hypertrophy did not make any contribution to muscle strength.[53] In a between-subject comparison of a much larger population, one group performed one-repetition maximum elbow flexions and the other group performed elbow flexion repetitions to task failure.[41] Once again, the results indicate that the increases in muscle strength in the one-repetition maximum group occurred in the absence of muscle hypertrophy. The studies aforementioned give rise to the fact that changes in muscle growth are neither necessary nor contributory to increases in muscle strength.[54] Furthermore, the degree of muscle hypertrophy may not even be sufficient enough to increase muscle strength if a low-load resistance training protocol is used.[42,54]

There are two important components to increase muscle strength: the applied load and task specificity (i.e. repeatedly performing a maximal strength test). In other words, having an individual train at or close to their one-repetition maximum would seemingly result in maximal increases in muscle strength.[55] The question that then remains is how are increases in muscle strength mediated, if increases in muscle strength are not driven by muscle hypertrophy? Moritani & DeVries suggested neural factors followed by hypertrophy,[49] but it is possible that neural factors alone are driving increases in muscle strength without a preceding hypertrophic response.[54] Local changes at the fiber level could also play a role, such as the change in myosin isoform composition,[56] or variations in the way calcium is released into the muscle during a contraction.[57,58] The increases in muscle mass following blood flow restriction training are similar to high-load resistance training, but the magnitude of change in muscle strength is often less when using blood flow restriction with low-load resistance training.[41] This distinction provides another reason to challenge the relationship between muscle size and muscle strength. Even though there is still not much clarity on the mechanisms of muscle strength, it can be highly suggested that it does indeed follow different mechanisms from muscle hypertrophy.[58]

BLOOD FLOW RESTRICTION IN WOMEN AND MEN

The amount of research including female participants is lacking compared to their male counterparts. A narrative review published in 2016 revealed there were at least double, if not triple, the amount of male participants included in acute and chronic blood flow restriction studies in comparison to female participants.[7] Instead, the physiological differences between males and females should provide a precedence to study the sex differences associated with blood flow restriction.[7]

Many blood flow restriction studies tend to exclude females because the potential influence the menstrual cycle would have on changes in muscle size and the increased protein synthetic response. In a previous study, there were no differences in muscle protein synthesis across different phases of the menstrual cycle.[59] However, researchers who have excluded female participants have done so primarily based on the uncertainty of the menstrual cycle's effects on muscle growth during blood flow restricted exercise.[60] The limited number of females included in the blood flow restriction literature has not added much research to either corroborate the findings of this study or to look further into the muscle size changes in female populations. The existing blood flow restriction research that includes both males and females have not noticed obvious differences between the sexes, but there has not been any blood flow restriction research done, to date, where males and females were analyzed separately.[61] Instead of limiting females from blood flow restriction literature altogether, it would provide a greater benefit to observe the potential differences between males and females when using this type of training.

DISCOMFORT ASSOCIATED WITH BLOOD FLOW RESTRICTION RESISTANCE TRAINING

Although low-load resistance exercise with blood flow restriction can potentially serve as an alternative to traditional high-load resistance exercise, there is one key caveat that has limited its widespread use: the discomfort associated with blood flow restriction.

The mechanisms of what exactly produces discomfort are still uncertain, but the discomfort alone could be attributed to a number of factors. These factors include the designated exercise volume, cuff width, cuff material, application of pressure, and sex.

Variables that Affect Discomfort in Blood Flow Restricted Exercise

Exercise Volume

Researchers can either prescribe a fixed number of repetitions per set to maintain uniformity across the whole sample or have the participant train to failure to keep the fatiguing nature of the stimulus consistent on an individual level. Training to task failure does not meet the definition of training submaximally even though submaximal loads are typically used with blood flow restricted exercise.[27] Multiple sets of unilateral knee extensions with blood flow restriction result in a much higher degree of ischemic muscle pain when the sets were performed to complete exhaustion.[62] Different studies have shown that less discomfort is induced when all sets are not performed to task failure.[10,63] These findings were further corroborated when Sieljacks et al. observed that ratings of perceived exertion and ratings of discomfort were higher in the condition that performed to failure.[64] However, training to task failure does ensure that every individual is performing to their personal maximal level though this exercise prescription may result in inducing some discomfort.[65]

Cuff Width

There are a number of different cuff widths used throughout blood flow restriction literature, ranging from narrow 3-cm cuffs to wide 18-cm cuffs.[9–11,63] Wide cuffs elicit an elevated perceptual response during exercise when compared to narrow cuffs inflated to the same pressure, due to the increased amount of vasculature that is covered in both upper and lower limbs.[10] In fact, a greater feeling of discomfort is induced in wide cuffs compared to narrow cuffs when both cuffs are inflated to the same absolute pressure.[10] However, there appears to be a similar reduction in blood flow when narrow and wide cuffs are inflated to the same relative arterial occlusion pressure.[12] Furthermore, discomfort may be heightened if a pressure is misapplied to a narrow cuff, since wide cuffs require a lower pressure to occlude an artery when compared to a narrow cuff.[12] For this reason we believe we may be able to neutralize the difference in discomfort by making the pressure inflated into the cuff relative to both the participant and the cuff being used.[48]

Cuff Material

Blood flow restriction cuffs can either be non-pneumatic, such as tourniquets or elastic wraps, or pneumatic cuffs, which can be composed of either nylon or elastic. The arterial occlusion pressure measurements are similar in a nylon pneumatic cuff and an elastic pneumatic cuff of the same width.[66] For example, there were no differences in perceptual ratings of discomfort between elastic and nylon pneumatic cuffs of the same size after completing three sets of knee extensions with blood flow restriction.[8] However, there seemed to be a difference in perceptual discomfort in the latter sets of elbow flexion when comparing nylon and pneumatic cuffs of unequal sizes.[9] Due to conflicting findings with previous literature, there should be further research to evaluate whether this was a difference of cuff material or cuff width.

Application of Pressure

The discomfort associated with the physical application of the blood flow restriction stimulus can vary greatly based on the pressure inflated into the cuff and the cuff width. Using an arbitrary pressure can alter the perception of this stimulus.[67] Additionally, the pressure becomes increasingly important when measuring discomfort because the same cuff width with a different pressure application can augment higher feelings of discomfort.[40] In a low-load resistance training protocol by Rossow et al.,[10] the participants showed a heightened perceptual response after completing the exercise bout with a 13.5-cm cuff compared to a 5.0-cm cuff when both were inflated to the same pressure. However, the cuffs were inflated to the same absolute pressure. This indicates that the wide cuff was inflated to a higher relative pressure. Relative arterial occlusion pressure is a percentage of the arterial occlusion pressure that has been measured using the appropriate cuff on the participant's limb. When two different relative arterial occlusion pressures are inflated into a cuff, the higher relative arterial occlusion pressure tends to evoke a higher discomfort rating.[63,68] For this reason, researchers should account for the different perceptual responses that can arise if the inflated pressure is not as intended, even when using cuffs of the same size.

Sex

As mentioned previously, there are significantly less females included in blood flow restriction literature compared to males.[7] Some studies have analyzed data between sexes without finding any differences.[8] Other studies have observed differences in fatiguability when comparing males and females,[69] while some completely exclude females based on interference from the menstrual cycle.[60] To date, there is one study that has included both male and female subjects where discomfort ratings were compared following blood flow restricted exercise.[70] Following three sets of isotonic knee extensions with and without blood flow restriction, the participants rated cuff pain on the

Borg's category-ratio (CR) scale. The results showed that females had higher ratings of cuff pain following each set of exercise, compared to males. However, all of the participants' cuffs were inflated to the same absolute pressure. Given that the females had an overall smaller limb circumference, it is possible this heightened cuff pain is due to an issue with the application of pressure rather than sex differences alone.

Mechanisms of Discomfort

There are currently no known studies about the exact mechanism for how discomfort or pain, which is a type of discomfort, arises during or following blood flow restricted exercise. Wernbom et al. conducted the first study observing blood flow restriction exercise-induced pain.[39] The participants performed dynamic knee extensions with and without blood flow restriction. The condition with blood flow restriction was associated with some discomfort, potentially due to an ischemic response from the body. Ischemic conditions result in an increase of metabolites coming from the muscle creating a surrounding hypoxic environment.[16,71] These metabolites can stimulate Group III and Group IV afferent neurons that relay information back to the brain about the different metabolic and mechanical stress on the muscle.[48,72] These stressors are potentially registered through the nervous system as a discomforting feeling.[72]

Methods to Measure Perception of Blood Flow Restriction and Discomfort

The two most common methods to assess a participant's perception of blood flow restriction, either in pain or discomfort, is through a visual analog scale (VAS) or a variation of the Borg Criterion-Ratio (CR) scale. Visual analog scales are commonly used to measure muscle soreness, which quantifies muscle damage rather than being a representation of discomfort.[39,64] However, it has also been used as a scale where participants are able to rate pain, which is a form of discomfort, on a continuum.[73] Furthermore, two versions of the Borg CR scale can be used to measure discomfort: Borg's CR-10 scale and Borg's CR-10+ scale. Some studies have utilized the Borg's CR-10 scale to keep discomfort ratings within a set magnitude,[39,70,71] while other studies have employed the Borg's CR-10+ scale to allow participants to quantify their discomfort above the set maximum rating.[40,74]

CHAPTER III: METHODOLOGY

This study consisted of six experiments: (Experiment One, n=50) comparison between a 12-cm nylon cuff (i.e. wide cuff) and a 5-cm nylon cuff (i.e. narrow cuff) inflated to the same relative arterial occlusion pressure at rest in the upper body; (Experiment Two, n=105) comparison between a 12-cm nylon cuff and a 5-cm nylon cuff inflated to the same relative arterial occlusion pressure following exercise in the upper body; (Experiment Three, n=105) comparison between two 12-cm nylon cuffs, with one cuff inflated to a pressure intended for a 12-cm cuff and one cuff inflated to a pressure intended for a 5-cm cuff, following exercise in the upper body; (Experiment Four, n=100) comparison of between a 12-cm nylon cuff and a 5-cm nylon cuff inflated to the same relative arterial occlusion pressure at rest in the lower body; (Experiment 5, n=100) comparison between a 12-cm nylon cuff and a 5-cm nylon cuff inflated to the same relative arterial occlusion pressure following exercise in the lower body; and (Experiment Six, n=100) comparison between two 12-cm nylon cuffs, with one cuff inflated to a pressure intended for a 12-cm cuff and one cuff inflated to a pressure intended for a 5-cm cuff, following exercise in the lower body.

The exclusion criteria for all six experiments included regular tobacco use in the previous six months, any orthopedic injury preventing exercise, or any two of the following risk factors for thromboembolism: (1) body mass index (BMI) $\geq$ 30, (2) using birth control pills, (3) medical diagnosis of Crohn's Disease, (4) previous fracture of hip, pelvis, or femur, (5) any major surgery within the past six months, (6) medically diagnosed varicose veins, (7) a personal or family history of deep vein thrombosis, or (8) a personal or family history of pulmonary embolism. The researchers explained the entirety of the study prior to the participant signing an informed consent form, which detailed his or her intent to participate in the research study. Following the review of the exclusion criteria and experimental details, the participants also completed a Physical Activity Readiness Questionnaire (PAR-Q). This allowed the researchers to continue forward with exercise protocols without any further medical clearance from a physician. The participants were instructed to abstain from exercise and alcohol 24 hours prior, caffeine eight hours prior, and food two hours prior to any of the experimental visits. The Institutional Review Board (IRB) at the University of Mississippi reviewed and accepted all protocols before the investigators commenced any experiments.

Upper Body

Experiment One

Following a period of 10-minute seated rest and in a randomized fashion, arterial occlusion pressure was measured with a 5-cm nylon cuff or 12-cm nylon cuff while the participant remained in a seated position. The cuffs were then simultaneously inflated to 40% of arterial occlusion pressure for a period of four minutes while the participant kept their arms hanging freely at his or her sides. The discomfort scale was explained prior to both of the cuffs being inflated and at the three-minute mark. Four minutes represented the estimated amount of time the cuffs would be inflated if the participant was engaging in four sets of exercise with thirty seconds of rest between each set. At four minutes, the participant provided a discomfort rating in the arm where the first arterial occlusion pressure measurement was taken. Using the first discomfort rating as an anchor, the participant then provided a numerical value for the second discomfort rating, either rating the other arm as higher, lower, or the same, accordingly. Both of the cuffs were deflated and removed.

Experiment Two

Experiment Two consisted of two exercise conditions, either using a 5-cm nylon cuff or a 12-cm nylon cuff, completed in a randomized order. Upon arrival to the lab, the researchers explained the discomfort scale that would be used to rate perceived discomfort following the exercise bout. Once the participant completed a ten-minute seated rest to allow blood pressure and heart rate to return to baseline; one of the researchers measured standing arterial occlusion pressure with the appropriate cuff in the arm randomized to complete the first exercise condition. Once again, the researchers clarified to the participant that the exercise bout began once the cuff was inflated. The cuff was then inflated to 40% of arterial occlusion pressure. The participant completed four sets of unilateral elbow flexions to task failure with a 30-second rest between each set. The discomfort rating was provided upon completion of the final set of exercise and then the cuff was deflated. Additionally, this discomfort rating was written down on a whiteboard. After another 10-minute seated rest period, the entire exercise protocol was repeated in the opposite arm with the remaining condition. Following the completion of the second bout of exercise, the participant was reminded of their discomfort rating from the first condition when the researcher held up the whiteboard. Using the first discomfort rating as an anchor, the participant then rated the discomfort in the second arm as higher, lower, or the same, accordingly. The participant then chose whether he or she would prefer to use the first or second condition on a regular basis, or whether there was no difference between the two (i.e. condition preference).

Experiment Three

Experiment Three followed a similar procedure as Experiment Two, with the only exception being the applied cuff width and applied cuff pressure. Both conditions utilized a 12-cm nylon cuff. However, the cuff in one condition was inflated to a pressure intended for a 12-cm cuff (Wide cuff 12-cm 40% AOP), while the cuff in the remaining condition was inflated to a pressure intended for a 5-cm cuff (Wide cuff 5-cm 40% AOP).

Lower Body

Experiment Four

Experiment Four began with the researchers explaining the 0-100 discomfort scale, with which the participant would rate their feelings of discomfort following deflation of the cuffs. Once the participant verbally affirmed their understanding of the scale, the cuffs were both inflated to 40% of the arterial occlusion pressure that was just measured previously. The participant remained in a seated position with both cuffs inflated for a period of four minutes. Once the four minutes was completed, the researchers asked the participant to rate their feelings of discomfort in one leg that was selected via a randomized fashion. The researchers then asked the participant to rate the discomfort in the second leg using the discomfort rating in the first leg as anchor; by rating the second condition as higher, lower, or the same, accordingly. The cuffs were deflated following the second discomfort rating.

Experiment Five

Experiment Five began with ten minutes of supine rest upon the participant's arrival to the lab. Either a 5-cm or a 12-cm nylon cuff, chosen through randomization, was placed around the most proximal portion of the upper thigh before the participant transitioned to the leg extension machine. Prior to the beginning of exercise, the cuff was inflated to 40% of the participant's arterial occlusion pressure that was measured just before Experiment Four began. The participant then performed four sets of unilateral leg extensions to task failure with a load of 30% of their one-repetition maximum. The participant provided a discomfort rating following the fourth set of exercise. The cuff was immediately deflated, and the discomfort rating was written on a whiteboard. The participant completed an additional ten minutes of supine rest before repeating the same exercise bout on the other leg with the remaining cuff condition. Following completion of the second bout of exercise, the researcher held up the whiteboard to remind the participant of his or her discomfort rating from the first condition. The researchers then asked the participant to rate the discomfort in the second leg using the discomfort rating from the first leg as anchor; by rating the second condition as higher, lower, or the same, accordingly. The participant then chose whether he or she would prefer to use the first or second condition on a regular basis, or whether there was no difference between the two (i.e. condition preference).

Experiment Six

The sequence of events for Experiment Six were identical to those of Experiment Five with the exception of the applied cuffs and applied pressure. In Experiment Six, a 12-cm nylon cuff was used in both conditions. One condition consisted of the 12-cm cuff inflated to the measured arterial occlusion pressure that was determined during the first visit (Wide cuff 12-cm 40% AOP). The remaining condition consisted of the 12-cm cuff inflated to an arterial occlusion pressure intended for a 5-cm narrow cuff (Wide cuff 5-cm 40% AOP). The conditions were assigned to a designated limb via randomization.

Anthropometric measurements

Upon completion of paperwork and informed consent, the participants' height was measured to the nearest 0.1 cm on a standard stadiometer (Seca, Chino, USA). Additionally, his or her body mass was measured to the nearest 0.1 kg with a digital scale (Seca, Chino, USA).

One-Repetition Maximum Testing and Familiarization

The load for each of the exercise visits was set at a percentage of each participant's one-repetition maximum for a unilateral elbow flexion in the upper body or a unilateral leg extension in the lower body. In the upper body, the researchers handed the dumbbell to the participant at full extension, and the participant completed only the concentric motion with the shoulders and heels against the wall. The researchers incrementally added weight to the dumbbell until the participant was unable to lift the load through the full range of motion or could not maintain proper form. A 90-second rest period was allotted between a unilateral elbow flexion repetition on each arm. The one-repetition maximum was quantified as the maximum load the participant was able to lift to the nearest 0.5 lbs. A similar protocol was implemented in the lower body while the participant performed a unilateral leg extension one-repetition maximum strength test. An attempt was marked as "completed" once the participant was able to extend far enough to touch the bar that was pre-set at the same place for all participants, in an effort to ensure uniformity in all attempts. Similar to the upper body, a 90-second rest period was allotted between each unilateral leg extension repetition on each leg. The one-repetition maximum was quantified as the maximum load the participant was able to lift to the nearest 0.25 kg. Following completion of the strength testing, the participant completed a short familiarization session. In the upper body, the participant performed 5-10 unloaded unilateral repetitions to the 30 repetitions per minute (1-second concentric, 1-second eccentric) cadence. In the lower body, the participant performed two sets of eight repetitions on each leg with a load of 30% of their one-repetition maximum at the same cadence.

Arterial Occlusion Pressure Measurements

Arterial occlusion pressure measurements were taken in the upper body just prior to cuff inflation. Arterial occlusion pressure measurements were taken in both arms following a ten-minute seated rest period in Experiment One. However, in Experiment Two and Three, arterial occlusion pressure was measured twice during each experiment—immediately before each arm completed the exercise bout. Arterial occlusion pressure measurements in the lower body for Experiments Four, Five, and Six were all taken prior to the start of Experiment Four.

In Experiment One, the participant remained sitting while the researchers measured the arterial occlusion pressure with the appropriate randomized cuff condition on each arm. As the participant's arms were relaxed by his or her sides, a researcher set a hand-held Doppler probe (MD6, Hokanson, Bellevue, WA) covered in ultrasound transmission gel over the radial artery. Once an auditory signal was located, the cuff pressure was increased using an E20 Rapid Cuff Inflator (Hokanson, Bellevue, WA) beginning at 50 mmHg. The pressure was increased in small increments until the auditory signal disappeared, which indicated a lack of blood flow. This pressure resulting in the cessation of blood flow was deemed the arterial occlusion pressure relative to the participant and the cuff being used. Following the exercise bout and an additional ten minutes of seated rest, the entire procedure was repeated on the second arm with the remaining cuff condition. In Experiments Two and Three, arterial occlusion pressure was measured just before the exercise bout was completed on each arm. The randomized cuff was placed at the most proximal portion of the upper arm and the participant rose to a standing position. The researchers measured standing arterial occlusion pressure as the participants' arms hung freely at their sides, since the participant would be performing the exercise bout in this position.

Just prior to the beginning of Experiment Four, arterial occlusion pressure measurements were taken in the lower body with a 5-cm nylon cuff and 12-cm nylon cuff. The cuffs were placed on the most proximal portion of the upper thigh. The participant then rested in the supine position for ten minutes before the first set of arterial occlusion pressure measurements was taken on both legs. The researcher covered the Doppler probe (MD6, Hokanson, Bellevue, WA) in ultrasound transmission gel and placed it over the tibial artery to measure arterial occlusion pressure while the participant remained in the supine position. The researchers then removed the first set of cuffs and applied the remaining cuffs. The participant completed an additional five minutes of supine rest before the second set of arterial occlusion pressure measurements was completed. One limitation of the Hokanson rapid cuff inflator is the maximum inflation pressure of 300 mmHg. Some individuals had detectable blood flow in the tibial artery even after the pressure was set maximally at 300 mmHg. In this case, the researchers had to estimate those individuals' arterial occlusion pressure in the lower body if complete occlusion was not reached at 300 mmHg. The researchers estimated the arterial occlusion pressure to be 350 mmHg if the auditory signal at 300 mmHg seemed fainter than when the cuff was beginning to be inflated. The researchers estimated the arterial occlusion pressure to be 400 mmHg if the auditory signal at 300 mmHg seemed just as pronounced when the cuff was beginning to be inflated.

Discomfort Scale

The discomfort scale was explained numerous times during all six experiments to ensure the participants' full understanding. The scale was explained just prior to cuff inflation and between the third and fourth minute of cuff inflation during Experiment One in the upper body and Experiment Four in the lower body. To ensure an objective, equal explanation to all of the participants, the following script was used to verbally explain the discomfort scale: "The scale begins at zero which is described as no perceivable discomfort. This can be likened to a perception of discomfort at a time where you feel no noticeable sensations. The scale ends at 100 which is described as maximal perceivable discomfort. This can be likened to a perception of discomfort at a time where you could not imagine the sensations being any more intense." This scale was modified from the original to serve the purpose of gauging discomfort ratings during rest.[75]

The same discomfort scale was used during Experiment Two and Experiment Three in the upper body and Experiment Five and Experiment Six in the lower body, with a slightly varied standardized explanation: "The scale begins at zero which is described as no perceivable discomfort. This can be likened to a perception of discomfort where you feel no noticeable sensations relating to physical activity. The scale ends at 100 which is described as the maximal perceivable discomfort. This can be likened to a perception of discomfort at a time where you could not imagine the sensations relating to physical activity being any more intense." This variation allowed the participant to adjust their discomfort rating according to the feeling of discomfort associated with completing a bout of exercise. The explanation of the scale and the scale itself were presented prior to cuff inflation and between the third and fourth set of exercise, in both the upper and lower body.

Condition Preference

Condition preference was recorded immediately following the exercise bout during the four experimental visits that required exercise (i.e. Experiments Two, Three, Five, and Six). The participants were presented with a sign that stated, "Of the two conditions completed today, which condition would you prefer to use?" There were three answer choices listed below: the first condition, the second condition, or no difference.

Statistics

The data for all six experiments was analyzed initially through a Bayesian repeated measures ANOVA using JASP (Version 0.11.1, Netherlands). The repeated measures included discomfort and repetitions for the two conditions, with a between subject factor of sex to assess the differences between perceived discomfort between males and females. Bayes Factors (BF_{10}) were used to detect probability in favor or against the null hypothesis. The interaction model (condition + sex + condition x sex) was divided by the main effects model (condition + sex) to determine whether there was a condition x sex interaction.

Condition preference (i.e. first condition, second condition, no preference) was also analyzed using JASP. A Bayesian contingency table was used to retrieve the number of males and females that chose each condition. The Bayes Factor (BF_{10}) in a joint multinomial sample was used to see if cuff preference differed by sex. Secondly, a

Bayesian binomial test was used to determine the total number of individuals that preferred each condition. A test value of 0.333 was used to split the likelihood of each condition being chosen equally, since there was no prior knowledge about condition preference.

CHAPTER IV: RESULTS

Experiment One

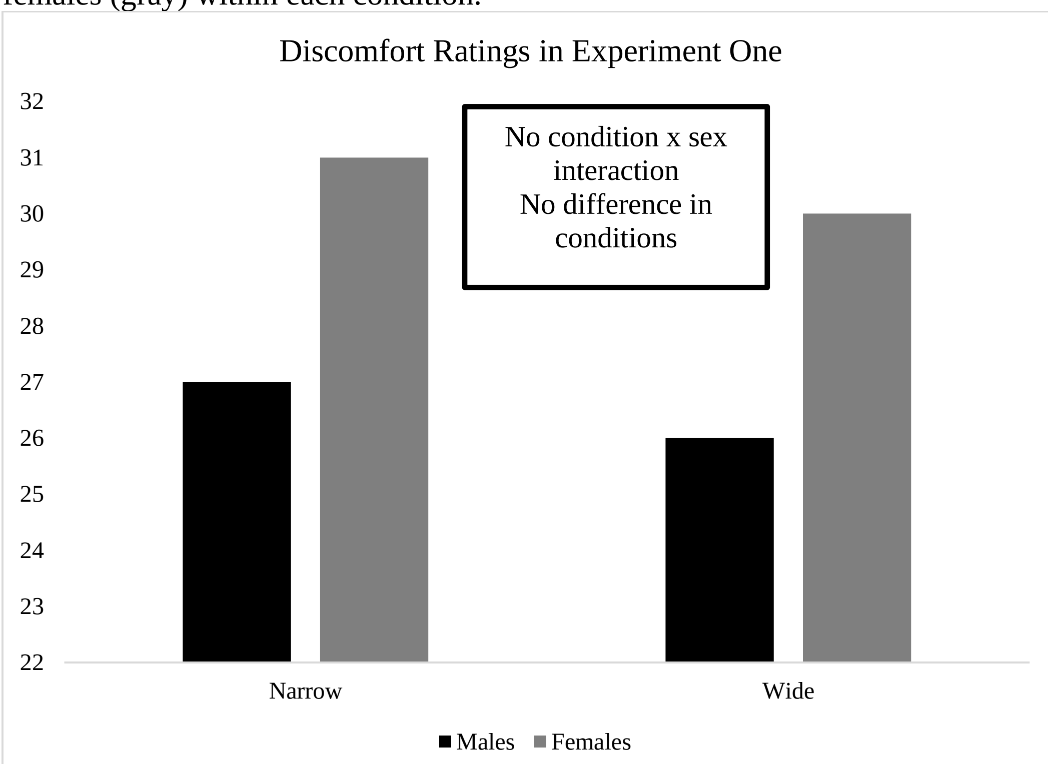
A total of 50 participants [Males (n=25): Age: 22 years (3), Height: 175.4 cm (9.1), Body Mass: 80.2 kg (9); Females (n=25): Age: 20 years (1), Height: 164.3 cm (5.3), Body Mass: 67.6 kg (17.6)] completed this experiment. The mean pressure inflated into the wide cuff [Males: 50.8 mmHg (4.4); Females: 48.8 mmHg (5.7)] was lower than the mean pressure inflated into the narrow cuff [Males: 62.6 mmHg (5.9); Females: 59.2 (7.0)] when both cuffs were inflated to 40% of the relative arterial occlusion pressure.

For discomfort (Table 1 and Figure 1), there was evidence for the null with the condition x sex interaction (BF_{10} 0.275). This indicated that the discomfort did not change differently across levels of sex. There was also evidence for the null with respect to condition (BF_{10} 0.242). This indicated that the discomfort did not differ between exercising with a narrow cuff and exercising with a wide cuff. There was no evidence for or against the null with respect to the sex effect (BF_{10} 0.521). This indicates that there is not enough information to definitively state that men and women experience different levels of discomfort.

Table 1. Ratings of discomfort for Experiment One. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects.

	Discomfort (0-100)	
	Men (n=25)	Women (n=25)
Narrow cuff (5 cm)	27 (21)	31 (21)
Wide cuff (12 cm)	26 (18)	30 (18)
	Bayes Factor (BF_{10})	
Condition	0.242	
Sex	0.521	
Condition * Sex	0.275	

Figure 1. Discomfort ratings for Experiment One separated by condition and sex. The discomfort ratings separated by condition, with the mean discomfort ratings in the narrow cuff condition on the left and the mean discomfort ratings in the wide cuff condition on the right. Discomfort ratings were also separated between males (black) and females (gray) within each condition.



Experiment Two

A total of 96 participants [Males (n=48): Age: 22 years (3), Height: 177.0 cm (7.5), Body Mass: 81.9 kg (14.9); Females (n=48): Age: 21 years (2), Height: 163.0 cm (6.7), Body Mass: 66.0 kg (14.2)] completed this experiment. The average pressure inflated into the wide cuff [Males: 50.8 mmHg (4.4); Females: 48.8 mmHg (5.7)] was lower than the average pressure inflated into the narrow cuff [Males: 62.6 mmHg (5.9); Females: 59.2 (7.0)], when both cuffs were inflated to 40% of arterial occlusion pressure.

For discomfort (Table 2 and Figure 2), there was no evidence for or against the null with the condition x sex interaction (BF_{10} 0.854). This indicated that there was insufficient evidence to conclude that discomfort changed differently across level of sex. There was, however, evidence for the alternative hypothesis with respect to condition (BF_{10} 5.868). This suggested that the discomfort did differ between conditions with the narrow cuff producing less discomfort compared to the wider cuff. There was no evidence for or against the null with respect to the sex effect (BF_{10} 0.658). This suggests that there is not enough information to definitively state that men and women have different levels of discomfort.

For repetitions (Table 2 and Figure 3), there was no evidence for or against the null with the condition x sex interaction (BF_{10} 0.854). This indicated that there was insufficient evidence to conclude that the number of repetitions completed was different across levels of sex. There was, however, evidence for the alternative hypothesis with respect to condition (BF_{10} 237421). This suggested that the number of repetitions completed did differ between conditions with the narrow cuff condition completing more repetitions compared to the wider cuff condition. In addition, there was evidence for the alternative hypothesis with respect to sex (BF_{10} 7.714). This suggests that women completed more repetitions than men.

Table 2. Discomfort ratings and number of repetitions for Experiment Two separated by condition and sex. Discomfort ratings (mean $\pm$ SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean $\pm$ SD) performed during four sets of unilateral elbow flexions is located at the bottom of this table, also separated by condition and sex with the associated Bayes Factor for condition and sex effects.

	Discomfort (0-100)	
	Men (n=48)	Women (n=48)
Narrow cuff (5 cm)	41 (21)	38 (19)
Wide cuff (12 cm)	46 (21)	39 (18)
	Bayes Factor (BF_{10})	
Condition	5.868	
Sex	0.658	
Condition * Sex	0.854	
	Repetitions	
	Men (n=48)	Women (n=48)
Narrow cuff (5 cm)	63 (19)	75 (26)
Wide cuff (12 cm)	55 (15)	62 (15)
	Bayes Factor (BF_{10})	
Condition	237421	
Sex	7.714	
Condition * Sex	0.854	

Figure 2. Discomfort ratings for Experiment Two separated by condition and sex. The discomfort ratings separated by condition are displayed below with the mean discomfort ratings in the narrow cuff condition on the left and the mean discomfort ratings in the wide cuff condition on the right. Discomfort ratings were further separated between males (black) and females (gray) within each condition.

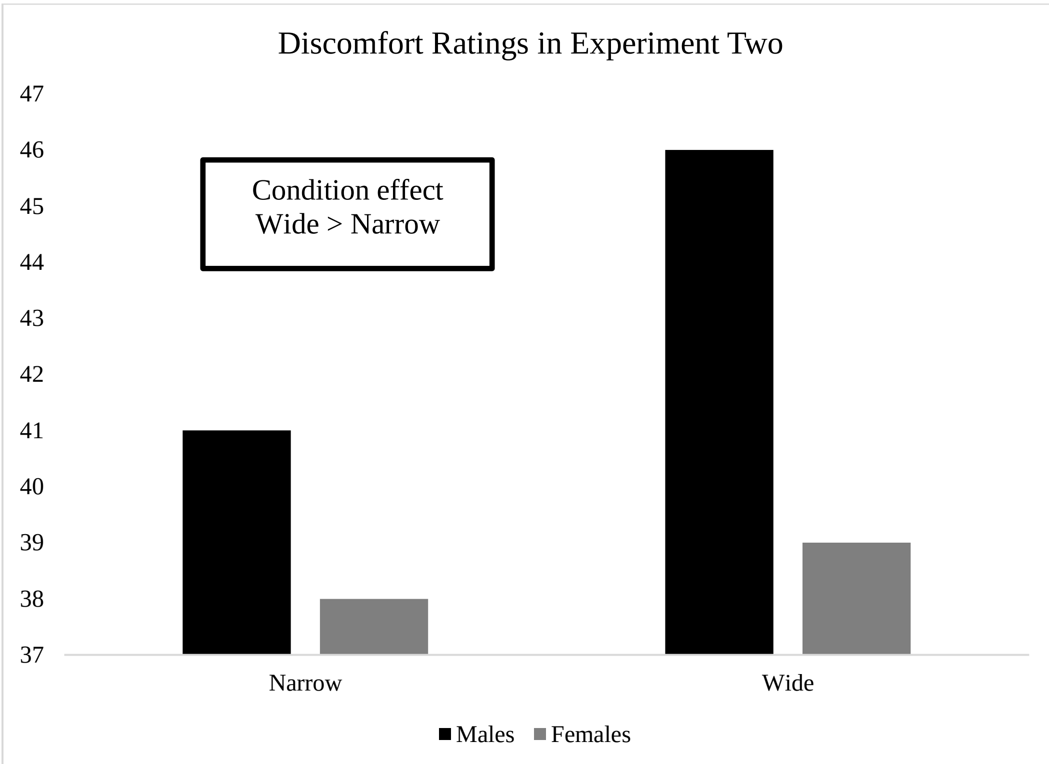
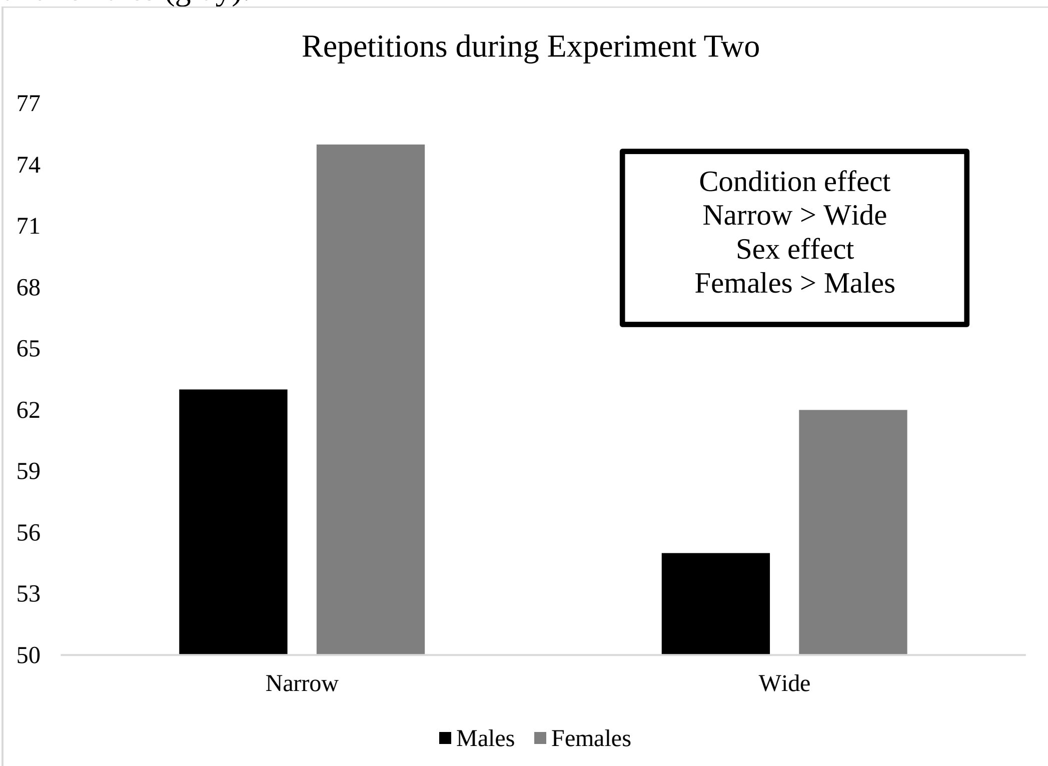


Figure 3. Number of repetitions completed during Experiment Two separated by cuff width and sex. The average number of repetitions completed during four sets of unilateral elbow flexions separated by condition with the narrow cuff condition on the left and the wide cuff condition on the right. Additionally, the average number of repetitions completed in each condition was further broken down between males (black) and females (gray).



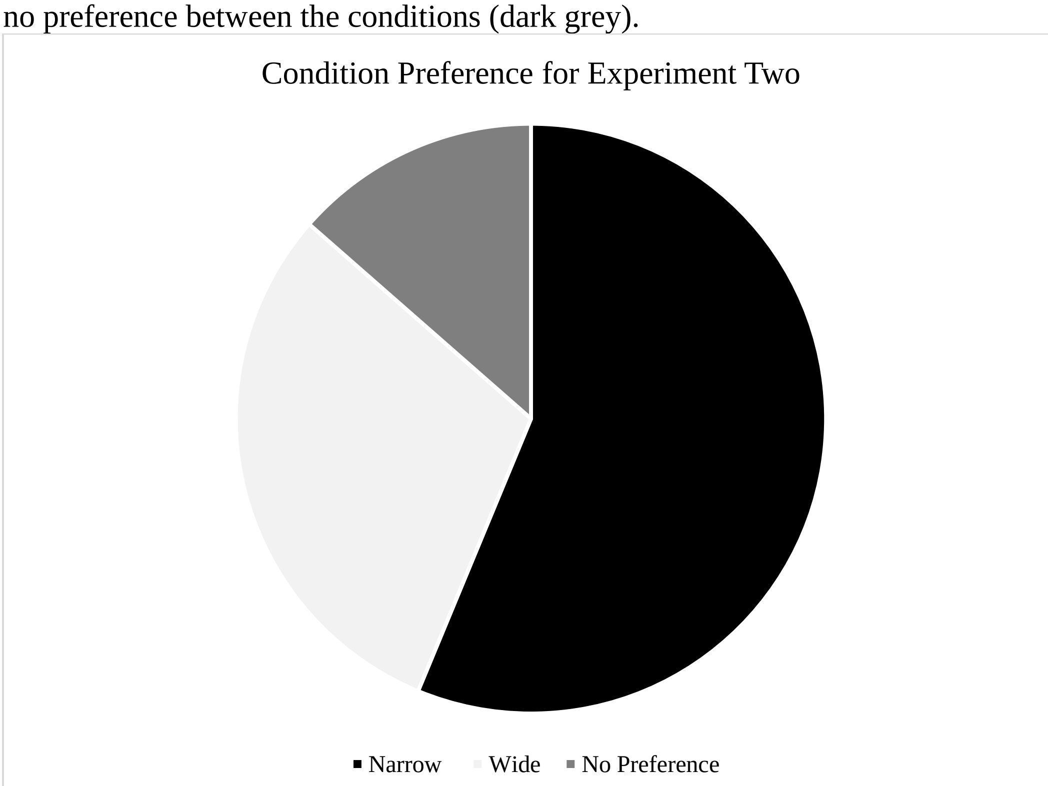
For condition preference and sex (Table 3 and Figure 4) there was evidence for the null to determine if condition preference differed by sex (BF_{10} 0.171). This implied that cuff preference did not differ by sex. When collapsing the condition preference values together, there was evidence for the null for the wide cuff condition (BF_{10} 0.138). This suggested that the proportion of individuals who selected the wide cuff condition did not differ from the test value. However, there was evidence for the alternative hypothesis in respect to the narrow cuff condition (BF_{10} 6807.057) and those with no preference between conditions (BF_{10} 1265.764). The greatest proportion of individuals preferred to use the narrow cuff condition (0.563).

Table 3. Condition preference for Experiment Two separated by sex. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differed from the test value of 0.333.

	Men	Women	Total
Narrow cuff	28	26	54
Wide cuff	13	16	29
No Preference	7	6	13
Total	48	48	96
Bayes Factor	0.171		

	Counts	Total	Proportion	Bayes Factor
Narrow cuff	54	96	0.563	6807.057
Wide cuff	29	96	0.302	0.138
No Preference	13	96	0.135	1265.764

Figure 4. Condition preference for Experiment Two. The proportion of individuals who selected the narrow cuff condition (black), wide cuff condition (light grey) and had no preference between the conditions (dark grey).



Experiment Three

A total of 87 participants [Males (n=45): Age: 22 years (3), Height: 177.0 cm (7.8), Body Mass: 81.9 kg (15.3); Females (n=42): Age: 21 years (2), Height: 162.9 cm (6.3), Body Mass: 66.6 kg (14.8)] completed this experiment. The average arterial occlusion pressure for the Wide cuff 5-cm 40% AOP condition [Males: 62.6 mmHg (8.8); Females: 57.9 mmHg (8.5)] was higher than the average arterial occlusion pressure for the Wide cuff 12-cm 40% AOP condition [Males: 51.5 mmHg (5.0); Females: 47.7 mmHg (4.9)].

For discomfort (Table 4 and Figure 5), there was evidence for the null with the condition x sex interaction (BF_{10} 0.270). This indicated that there was evidence that discomfort did not change differently across sexes. However, there was evidence supporting the alternative hypothesis with respect to condition (BF_{10} 8.213). This suggested that there was a difference in discomfort between conditions, with the Wide cuff 12-cm 40% AOP condition resulting in less discomfort when compared to the Wide cuff 5-cm 40% AOP condition. There was no evidence for or against the null hypothesis with respect to the sex effect (BF_{10} 0.588). This suggests that there is insufficient information to conclusively state that men and women perceived different levels of discomfort.

For repetitions (Table 4 and Figure 6), there was evidence for the null with a condition x sex interaction (BF_{10} 0.270). This indicated that the number of repetitions completed during the different conditions did not vary across sex. There was no evidence for or against the alternative hypothesis with respect to the condition effect (BF_{10} 1.820). This indicated that the number of repetitions completed did not differ between the two wide cuff conditions. Furthermore, there was no evidence for or against the null hypothesis with respect to sex (BF_{10} 0.564). This indicated that there was no difference in the number of repetitions completed between sexes.

Table 4. Ratings of discomfort and number of repetitions for Experiment Three separated by condition and sex. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean ± SD) performed over four sets of unilateral elbow flexions is located at the bottom of this table, also separated by condition and sex with the associated Bayes Factor for condition and sex effects.

	Discomfort (0-100)	
	Men (n=45)	Women (n=42)
Wide cuff (5-cm 40% AOP)	45 (21)	43 (20)
Wide cuff (12-cm 40% AOP)	43 (20)	39 (21)
	Bayes Factor (BF_{10})	
Condition	8.213	
Sex	0.588	
Condition * Sex	0.270	
	Repetitions	
	Men (n=45)	Women (n=42)
Wide cuff (5-cm 40% AOP)	52 (11)	56 (16)
Wide cuff (12-cm 40% AOP)	55 (13)	58 (21)
	Bayes Factor (BF_{10})	
Condition	1.820	
Sex	0.564	
Condition * Sex	0.270	

Figure 5. Ratings of discomfort for Experiment Three separated by condition and sex. The discomfort ratings separated by condition with the mean discomfort ratings in the Wide cuff 5-cm 40% AOP condition on the left side and the discomfort ratings in the Wide cuff 12-cm 40% AOP condition on the right side. Additionally, discomfort ratings are separated between males (black) and females (gray) in both conditions.

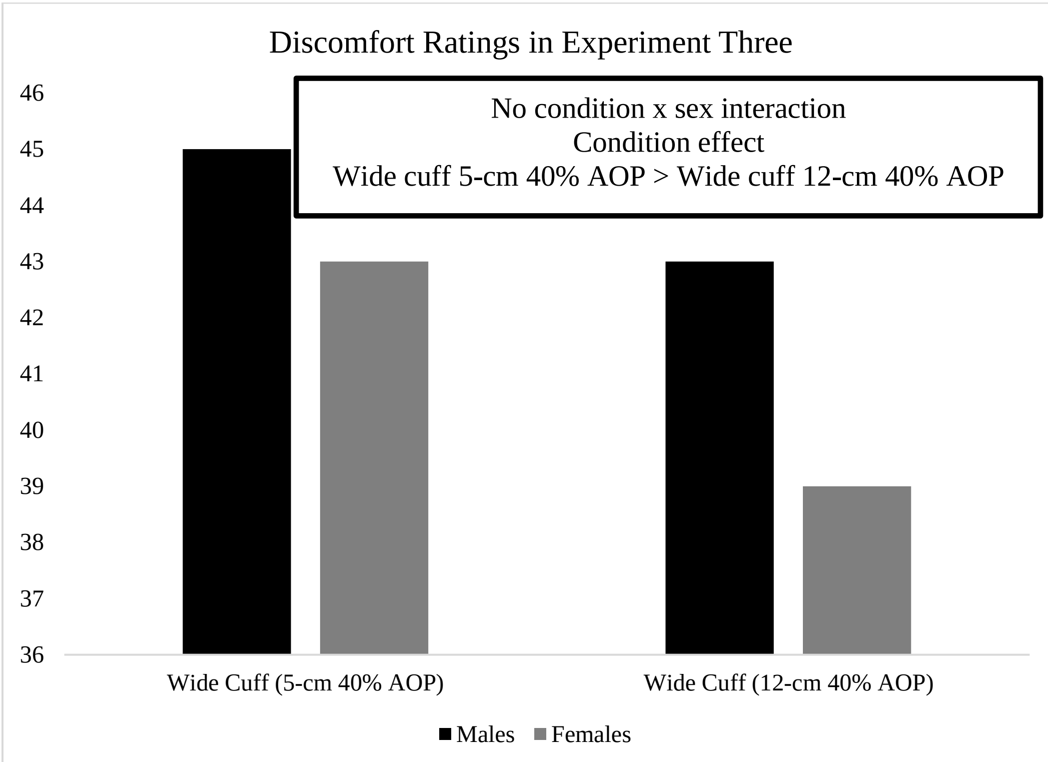
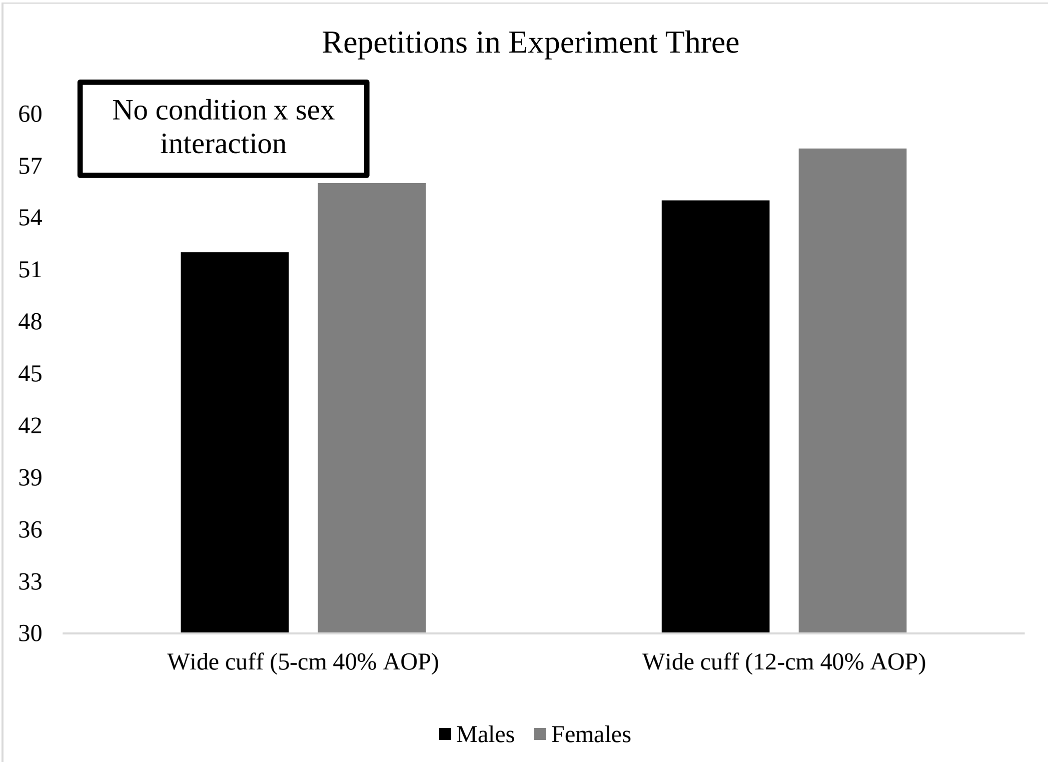


Figure 6. Number of repetitions completed during Experiment Three separated by condition and sex. The average number of repetitions completed over four sets of unilateral elbow flexions separated by condition with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. The total number of repetitions were also separated between males (black) and females (gray) in both conditions.



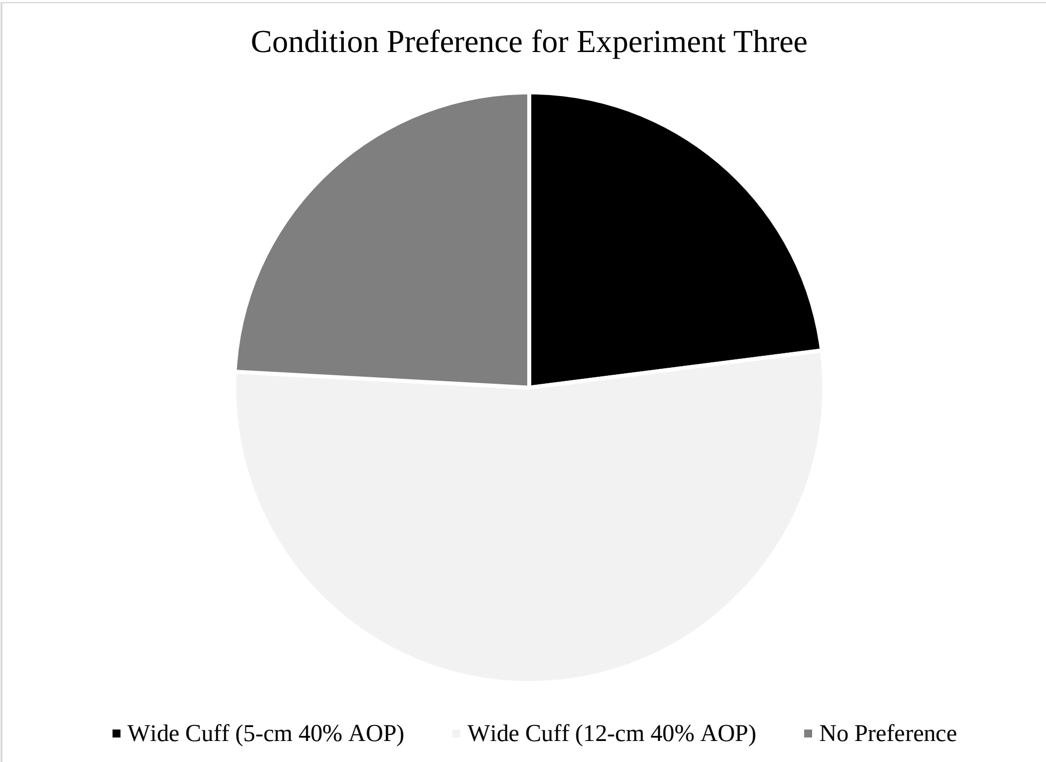
For condition preference and sex (Table 5 and Figure 7) there was no evidence for or against the null to determine if condition preference differed by sex (BF_{10} 0.370). This implied that there was insufficient information to determine whether condition preference differed between sexes. When collapsing the condition preference values together, there was no evidence for or against the null that showed any difference in proportions from the test value in the Wide cuff 5-cm 40% AOP condition (BF_{10} 0.917) and those who had no preference between the two conditions (BF_{10} 0.584). However, there was evidence for the alternative hypothesis with respect to the Wide cuff 12-cm 40% AOP condition (BF_{10} 188.794). This implied that the proportion of individuals who selected the Wide cuff 12-cm 40% AOP condition differed from the test value of 0.333. Additionally, the greatest proportion of individuals preferred to use the Wide cuff 12-cm 40% AOP condition (0.529).

Table 5. Condition preference for Experiment Three separated by sex. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differed from the test value of 0.333.

	Men	Women	Total
Wide cuff (5-cm 40% AOP)	11	9	20
Wide cuff (12-cm 40% AOP)	21	25	46
No Preference	13	8	21
Total	45	42	87
Bayes Factor	0.370		

	Counts	Total	Proportion	Bayes Factor
Wide cuff (5-cm 40% AOP)	20	87	0.230	0.917
Wide cuff (12-cm 40% AOP)	46	87	0.529	188.794
No Preference	21	87	0.241	0.584

Figure 7. Condition preference for Experiment Three. The proportion of individuals who selected the Wide cuff 5-cm 40% AOP condition (black), the Wide cuff 12-cm 50% AOP condition (light grey) and had no preference between the conditions (dark grey).



Experiment Four

Total

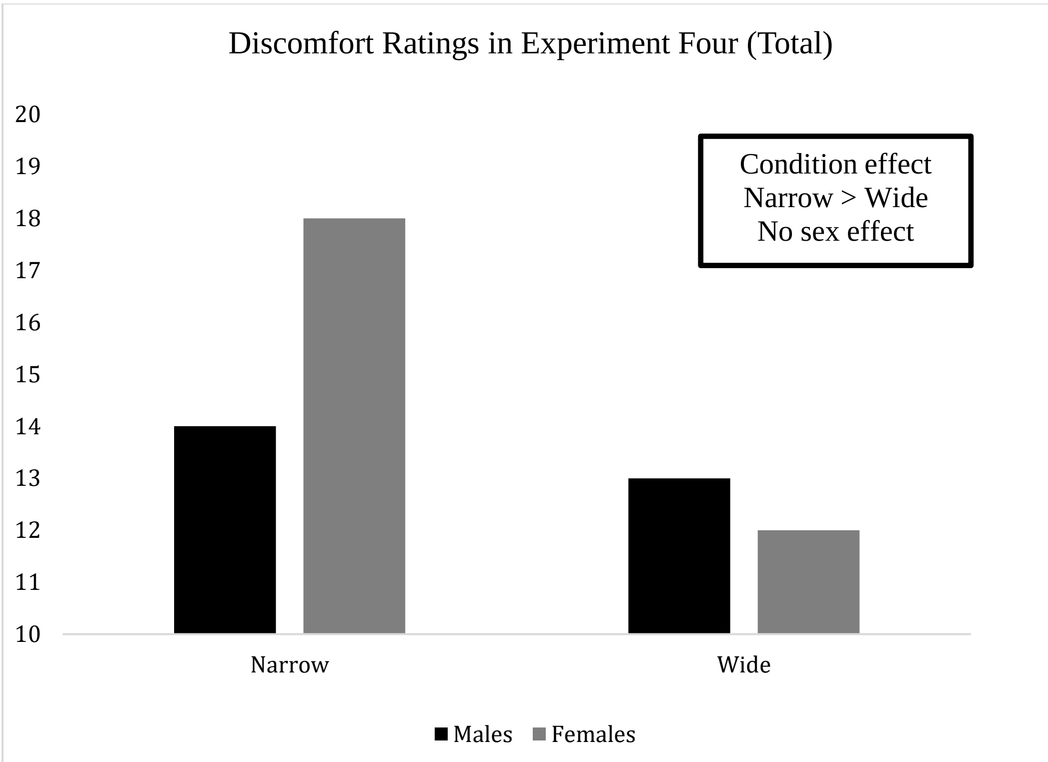
A total of 99 participants [Males (n=44): Age: 23 years (3), Height: 176.8 cm (8.0), Body Mass: 80.9 kg (11); Females (n=55): Age: 21 years (2), Height: 163.1 cm (6), Body Mass: 64.6 kg (13)] completed this experiment. The mean pressure inflated into the wide cuff [Males: 63.3 mmHg (9); Females: 60.4 mmHg (11)] was lower than the mean pressure inflated into the narrow cuff [Males: 145.9 mmHg (25); Females: 142.5 mmHg (28)] when both cuffs were inflated to 40% of arterial occlusion pressure.

For discomfort (Table 6 and Figure 8), there was no evidence for or against the alternative hypothesis for the condition x sex interaction (BF_{10} 1.478). This indicated that there was insufficient evidence to conclude that discomfort changed differently across level of sex. However, there was evidence for the alternative hypothesis with respect to condition (BF_{10} 34.209). This suggested that there was a difference in discomfort between conditions, with the narrow cuff condition resulting in greater discomfort compared to the wide cuff condition. There was evidence for the null with respect to sex (BF_{10} 0.306). This suggests that men and women had similar levels of discomfort.

Table 6. Discomfort ratings for Experiment Four for the total sample. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects for the total sample (i.e. those who had a measurable arterial occlusion pressure and those whose arterial occlusion pressure was estimated).

	Discomfort (0-100)	
	Men (n=44)	Women (n=55)
Narrow cuff (5 cm)	14 (13)	18 (14)
Wide cuff (12 cm)	13 (12)	12 (11)
	Bayes Factor (BF_{10})	
Condition	34.209	
Sex	0.306	
Condition * Sex	1.478	

Figure 8. Discomfort ratings for Experiment Four separated by condition and sex. The discomfort ratings for the total sample, with the narrow cuff condition on the left and the wide cuff condition on the right. The average discomfort ratings were further broken down between males (black) and females (gray).



Measured Arterial Occlusion Pressure

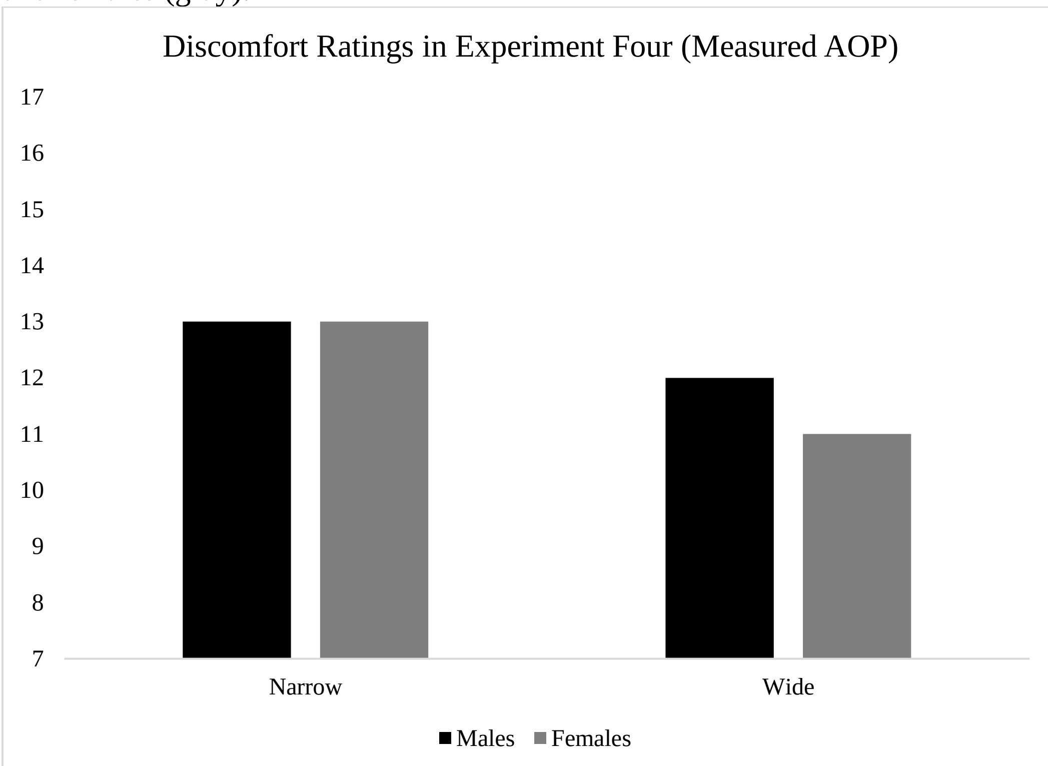
Of the 99 participants who completed Experiment Four, 21 participants [Males (n=8), Females (n=13)] had an arterial occlusion pressure that was measurable with the cuff inflation system used. The average pressure inflated into the wide cuff [Males: 54.8 mmHg (5); Females: 52.2 mmHg (5)] was lower than the average pressure inflated into the narrow cuff [Males: 97.5 mmHg (15); Females: 96.7 mmHg (16)] when both cuffs were inflated to 40% of arterial occlusion pressure.

For discomfort ratings in the sample of Experiment Four with a measurable arterial occlusion pressure (Table 7 and Figure 9), there was no evidence for or against the null with respect to the condition x sex interaction (BF_{10} 0.482). This indicated that there is not enough information to state whether discomfort changed differently across sex. There was also no evidence for or against the null with respect to condition (BF_{10} 0.405). This suggested that there is insufficient information to state whether discomfort differed between the narrow cuff and wide cuff conditions. Furthermore, there was no evidence for or against the null with respect to sex (BF_{10} 0.554). This suggests that there is not enough information to definitively state that males and females have different levels of discomfort.

Table 7. Discomfort ratings for Experiment Four in the sample with a measurable arterial occlusion pressure. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects for the sample whose arterial occlusion pressure was measurable with the cuff inflation system.

	Discomfort (0-100)	
	Men (n=8)	Women (n=13)
Narrow cuff (5 cm)	13 (11)	13 (10)
Wide cuff (12 cm)	12 (16)	11 (10)
	Bayes Factor (BF_{10})	
Condition	0.405	
Sex	0.554	
Condition * Sex	0.482	

Figure 9. Discomfort ratings for Experiment Four separated by condition and sex for the sample with a measurable arterial occlusion pressure. The discomfort ratings for the sample whose arterial occlusion pressure was measurable with the cuff inflation system, with the narrow cuff condition on the left and the wide cuff condition on the right. The average discomfort ratings were further broken down between males (black) and females (gray).



Estimated Arterial Occlusion Pressure

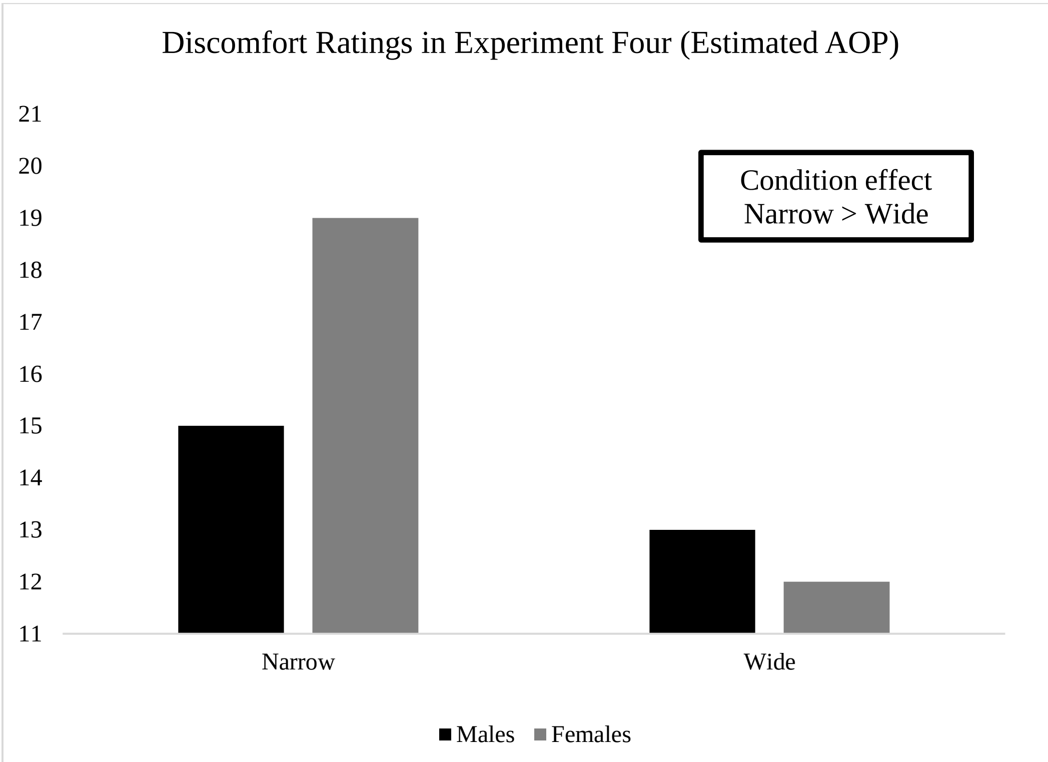
Of the 99 participants who completed Experiment Four, 78 participants [Males (n=36), Females (n=42)] had an arterial occlusion pressure that was not measurable with the cuff inflation system used. When both cuffs were inflated to 40% of arterial occlusion pressure, the mean pressure inflated into the wide cuff [Males: 65.2 mmHg (8); Females: 63.0 mmHg (12)] was lower than the mean pressure inflated into the narrow cuff [Males: 156.7 mmHg (9); Females: 156.7 mmHg (8)].

For discomfort ratings in the individuals with an estimated arterial occlusion pressure (Table 8 and Figure 10), there was no evidence for or against the alternative hypothesis for the condition x sex interaction (BF_{10} 1.666). This indicated that there was insufficient evidence to conclude that discomfort changed differently across sex. However, there was strong evidence for the alternative hypothesis with respect to condition (BF_{10} 25.947). This suggested that discomfort differed between the narrow cuff and wide cuff conditions, with the narrow cuff producing greater discomfort. There was no evidence for or against the null with respect to sex (BF_{10} 0.351). This suggests that there was not enough information to state whether men and women experience different levels of discomfort.

Table 8. Discomfort ratings for Experiment Four for the sample with an estimated arterial occlusion pressure. Discomfort ratings (mean $\pm$ SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects for the sample whose arterial occlusion pressure was not measurable with the cuff inflation system.

	Discomfort (0-100)	
	Men (n=36)	Women (n=42)
Narrow cuff (5 cm)	15 (14)	19 (15)
Wide cuff (12 cm)	13 (11)	12 (11)
	Bayes Factor (BF_{10})	
Condition	25.947	
Sex	0.351	
Condition * Sex	1.666	

Figure 10. Discomfort ratings for Experiment Four separated by cuff size and sex for the sample with an estimated arterial occlusion pressure. Discomfort ratings (mean ± SD) for the sample whose arterial occlusion pressure was not measurable with the cuff inflation system, with the narrow cuff condition on the left and the wide cuff condition on the right. The mean discomfort ratings were further separated between males (black) and females (gray).



Experiment Five

Total

A total of 96 participants [Males (n=43): Age: 23 years (3), Height: 176.8 cm (8), Body Mass: 81.3 kg (11); Females (n=53): Age: 21 years (2), Height: 163.3 cm (6), Body Mass: 64.5 kg (13)] completed Experiment Five. The average pressure inflated into the wide cuff [Males: 62.6 mmHg (9); Females: 60.6 mmHg (12)] was lower than the average pressure inflated into the narrow cuff [Males: 147.3 mmHg (25); Females: 142.9 mmHg (26)], when both cuffs were inflated to 40% of arterial occlusion pressure.

The discomfort ratings of all individuals who completed Experiment Five (Table 9 and Figure 11) showed no evidence for or against the null for the condition x sex interaction (BF_{10} 0.886). This indicated that there was inadequate evidence to specify whether discomfort changed differently across level of sex. There was evidence for the null with respect to condition (BF_{10} 0.170). This suggested that the discomfort did not differ between the narrow and wide cuff conditions. There was evidence for the alternative hypothesis with respect to sex (BF_{10} 4.733). This suggests that men and women experienced different levels of discomfort.

For the number of repetitions in all individuals who completed Experiment Five (Table 9 and Figure 12), there was no evidence for or against the null with the condition x sex interaction (BF_{10} 0.886). This indicated that there was insufficient evidence to conclude that the number of repetitions differed across levels of sex. However, there was evidence for the alternative hypothesis with respect to condition (BF_{10} 2802.494). This suggested that the number of repetitions was different with respect to condition, with the narrow cuff producing a greater number of repetitions compared to the wide cuff. There was no evidence for or against the null in regard to sex (BF_{10} 0.351). This suggests that there was insufficient evidence to state whether the number of repetitions completed differs between men and women.

Table 9. Discomfort ratings and number of repetitions for Experiment Five separated by condition and sex for the total sample. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean ± SD) performed during four sets of unilateral leg extensions is located at the bottom of this table, separated by sex and cuff size with the associated Bayes Factor for condition and sex effects. Values for average discomfort ratings and number of repetitions are analyzed based on the total sample (i.e. those who had a measurable arterial occlusion pressure and those whose arterial occlusion pressure was estimated).

	Discomfort (0-100)	
	Men (n=43)	Women (n=53)
Narrow cuff (5 cm)	59 (20)	47 (18)
Wide cuff (12 cm)	57 (19)	50 (20)
	Bayes Factor (BF_{10})	
Condition	0.170	
Sex	4.733	
Condition * Sex	0.886	
	Repetitions	
	Men (n=43)	Women (n=53)
Narrow cuff (5 cm)	61 (15)	61 (13)
Wide cuff (12 cm)	59 (14)	56 (11)
	Bayes Factor (BF_{10})	
Condition	2802.494	
Sex	0.351	
Condition * Sex	0.886	

Figure 11. Discomfort ratings for Experiment Five separated by condition and sex in the total sample. The discomfort ratings for the total sample are separated by condition, with the narrow cuff condition on the left and the wide cuff condition on the right. The mean discomfort ratings were further broken down between males (black) and females (gray).

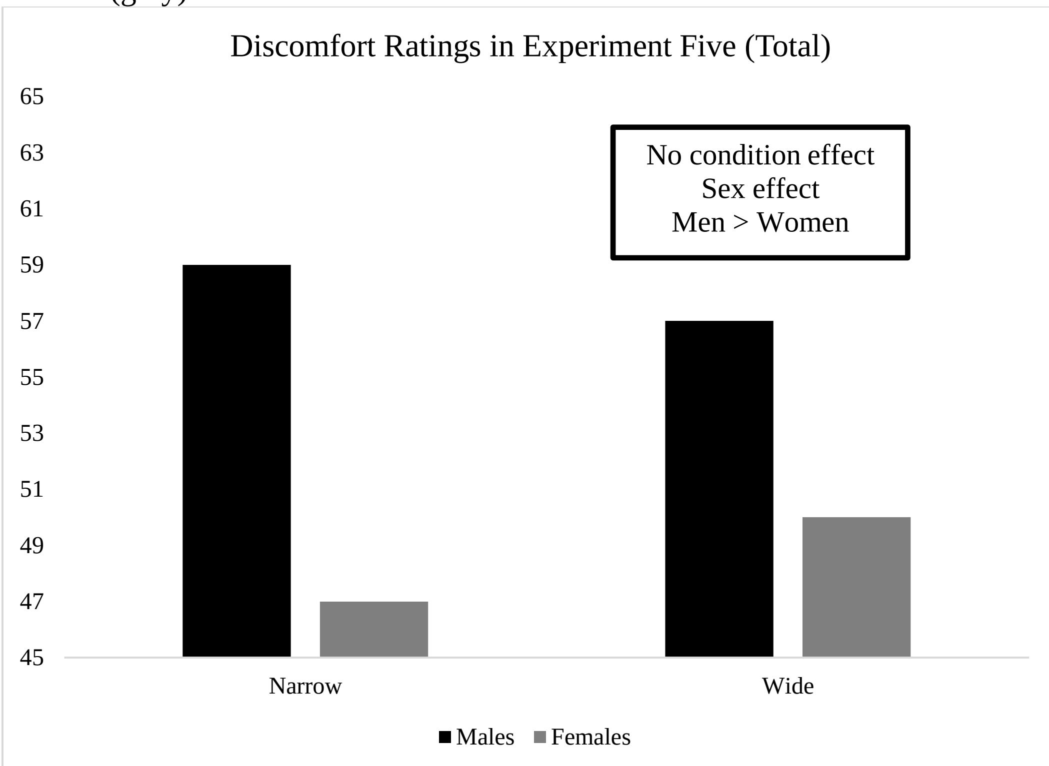
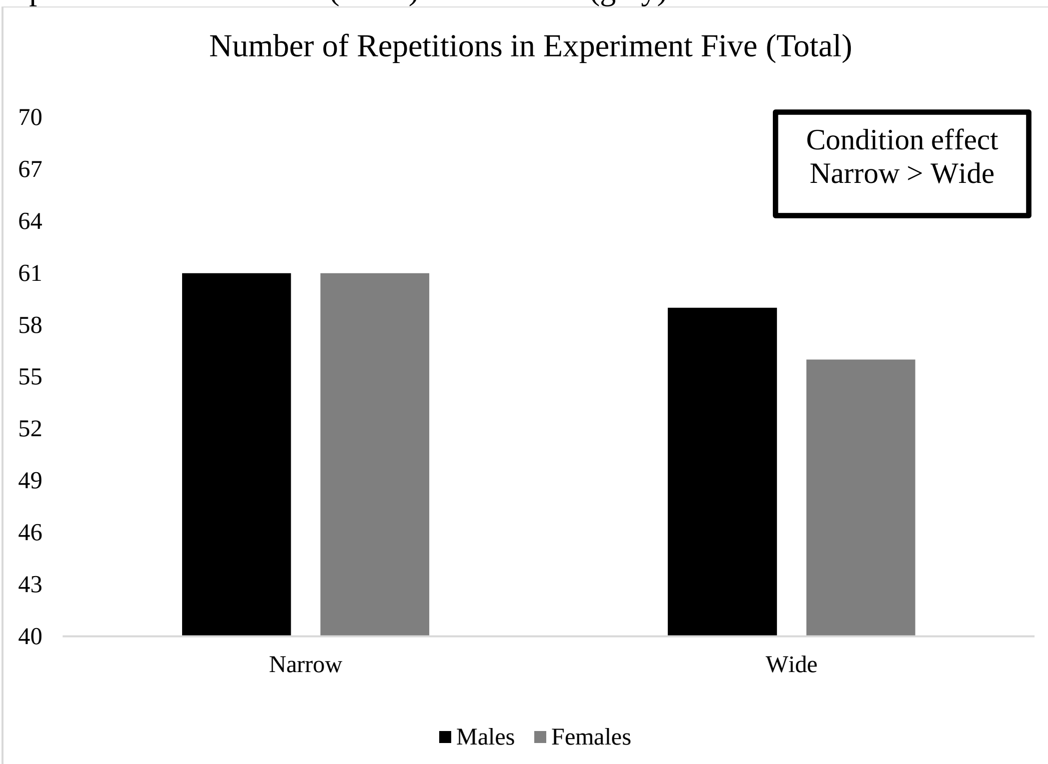


Figure 12. Number of repetitions for Experiment Five separated by condition and sex in the total sample. The average number of repetitions performed during four sets of unilateral leg extensions separated by condition, with the narrow cuff condition on the left and the wide cuff condition on the right. The mean number of repetitions are further separated between males (black) and females (gray).



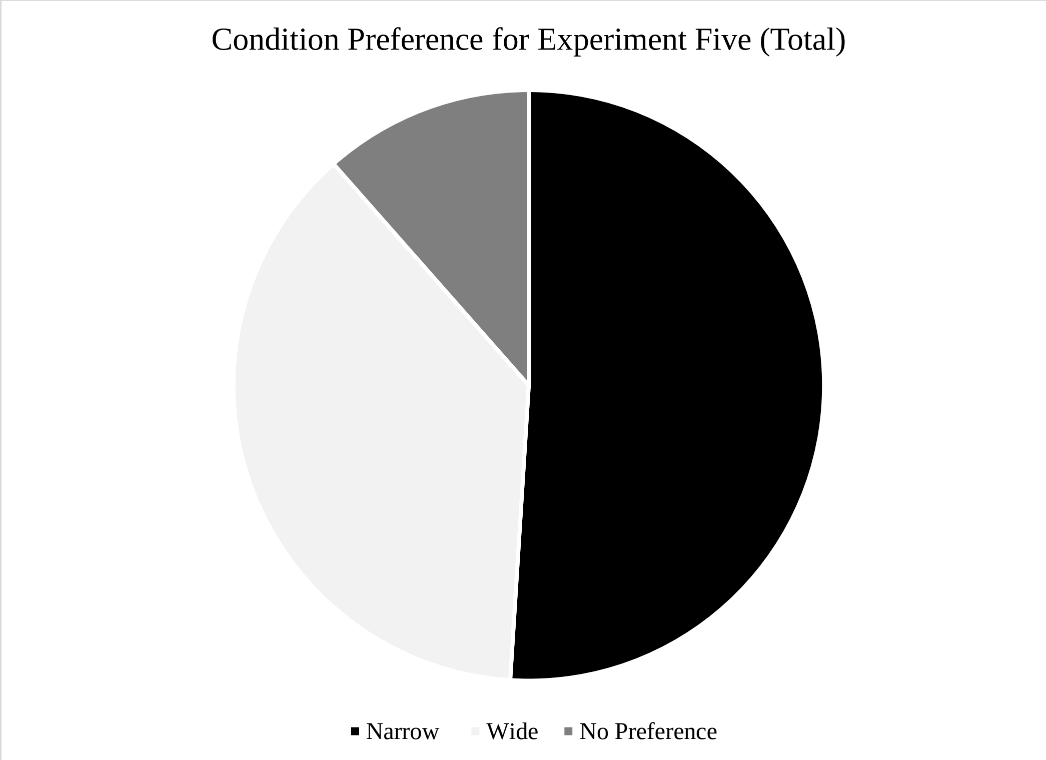
For condition preference and sex (Table 10 and Figure 13) there was no evidence for or against the alternative hypothesis to determine if condition preference differed by sex (BF_{10} 1.783). This suggested that there was insufficient evidence to claim whether condition preference differed between sexes. When collapsing the condition preference values together, there was evidence for the null for the wide cuff condition (BF_{10} 0.189). This implied that the proportion of individuals who selected the wide cuff condition did not differ from the initial test value. However, there was evidence for the alternative hypothesis in respect to the narrow cuff condition (BF_{10} 95.704) and those individuals who had no preference between the conditions (BF_{10} 14054.153). These values imply that the proportion of individuals who selected those conditions did indeed differ from the test value of 0.333. In addition, the greatest proportion if individuals preferred to use the narrow cuff condition (0.510).

Table 10. Condition preference for Experiment Five separated by sex for the total sample. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differed from the test value of 0.333.

	Men	Women	Total
Narrow cuff	25	24	49
Wide cuff	11	25	36
No Preference	7	4	11
Total	43	53	96
Bayes Factor	1.783		

	Counts	Total	Proportion	Bayes Factor
Narrow cuff	49	96	0.510	95.704
Wide cuff	36	96	0.375	0.189
No Preference	11	96	0.115	14054.153

Figure 13. Condition preference for Experiment Five for the total sample. The proportion of individuals who selected the narrow cuff condition (black), wide cuff condition (light grey) and had no preference between the conditions (dark grey).



Measured Arterial Occlusion Pressure

Of the 96 participants who completed Experiment Five, 19 participants [Males (n=7), Females (n=12)] had an arterial occlusion pressure that was measurable with the cuff inflation system used. The average pressure inflated into the wide cuff [Males: 53.0 mmHg (5); Females: 50.6 mmHg (6)] was lower than the average pressure inflated into the narrow cuff [Males: 96.1 mmHg (14); Females: 99.5 mmHg (15)] when both cuffs were inflated to 40% of arterial occlusion pressure.

For discomfort ratings in the sample of Experiment Five whose arterial occlusion pressure was measurable with the cuff inflation system (Table 11 and Figure 14), there was no evidence for or against the null with respect to the condition x sex interaction (BF_{10} 0.434). This indicated that there was not enough information to state whether discomfort changed differently across sex. There was no evidence for or against the alternative hypothesis with respect to condition (BF_{10} 2.076). This implied that there was insufficient information to make a definitive claim about a condition effect between the narrow cuff and wide cuff conditions. Furthermore, there is no evidence for or against the null hypothesis in regard to sex (BF_{10} 0.649). This suggests that there is not enough information to conclusively state that men and women experience different levels of discomfort.

The total number of repetitions in the sample of Experiment Five whose arterial occlusion pressure was measurable with the cuff inflation system (Table 11 and Figure 15) showed no evidence for or against the null with respect to the condition x sex interaction (BF_{10} 0.434). This indicated that there is not enough information to state that the number of repetitions changed differently across sexes. There was, however, evidence for the alternative hypothesis with respect to condition (BF_{10} 4.127). This suggested that the number of repetitions completed did differ between conditions with narrow cuff condition resulting in a greater number of repetitions compared to the wide cuff condition. There was no evidence for or against the null hypothesis with respect to sex (0.654). This suggests that there is insufficient information to state that the number of repetitions differs between men and women.

Table 11. Discomfort ratings and number of repetitions for Experiment Five separated by condition and sex for the sample with a measurable arterial occlusion pressure. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean ± SD) performed during four sets of unilateral leg extensions is located at the bottom of this table, separated by condition and sex with the associated Bayes Factor for condition and sex effects. Values for average discomfort ratings and the number of repetitions is analyzed based on the individuals whose arterial occlusion pressure was measurable with the cuff inflation system.

	Discomfort (0-100)	
	Men (n=7)	Women (n=12)
Narrow cuff (5 cm)	55 (20)	49 (16)
Wide cuff (12 cm)	55 (23)	56 (16)
	Bayes Factor (BF_{10})	
Condition	2.076	
Sex	0.649	
Condition * Sex	0.434	
	Repetitions	
	Men (n=7)	Women (n=12)
Narrow cuff (5 cm)	66 (17)	64 (17)
Wide cuff (12 cm)	61 (18)	58 (14)
	Bayes Factor (BF_{10})	
Condition	4.127	
Sex	0.654	
Condition * Sex	0.434	

Figure 14. Discomfort ratings for Experiment Five separated by condition and sex in the sample with a measurable arterial occlusion pressure. The mean discomfort ratings for the sample whose arterial occlusion pressure was measurable with the cuff inflation system separated by condition, with the narrow cuff condition on the left and the wide cuff condition on the right. The discomfort ratings were further divided between males (black) and females (gray).

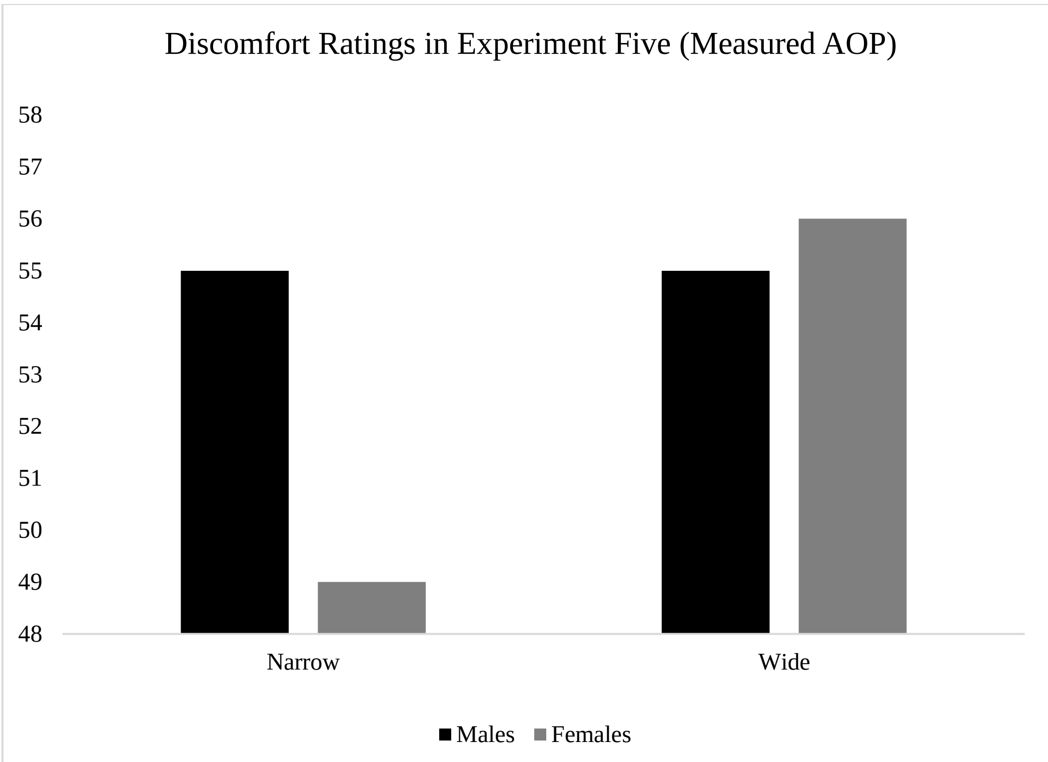
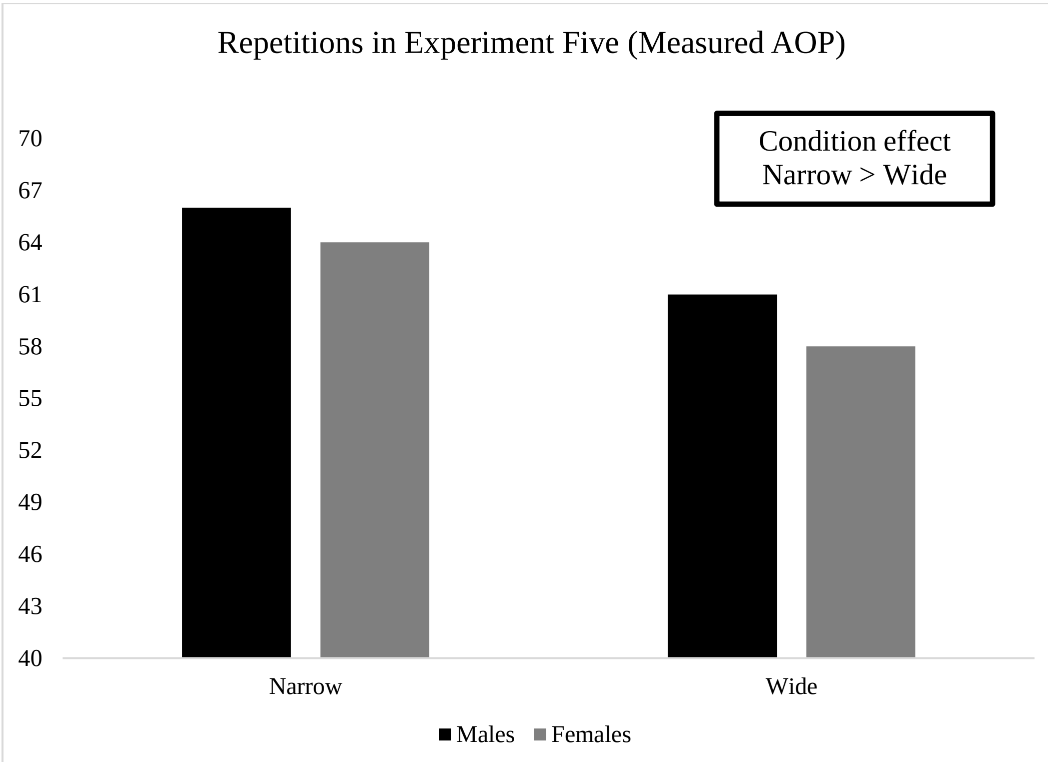


Figure 15. Number of repetitions for Experiment Five separated by condition and sex in the sample with a measurable arterial occlusion pressure. The average number of repetitions performed across four sets of unilateral leg extensions in the individuals whose arterial occlusion pressure was measurable with the cuff inflation system, with the narrow cuff condition on the left and the wide cuff condition on the right. The total number of repetitions is further broken down between males (black) and females (gray).



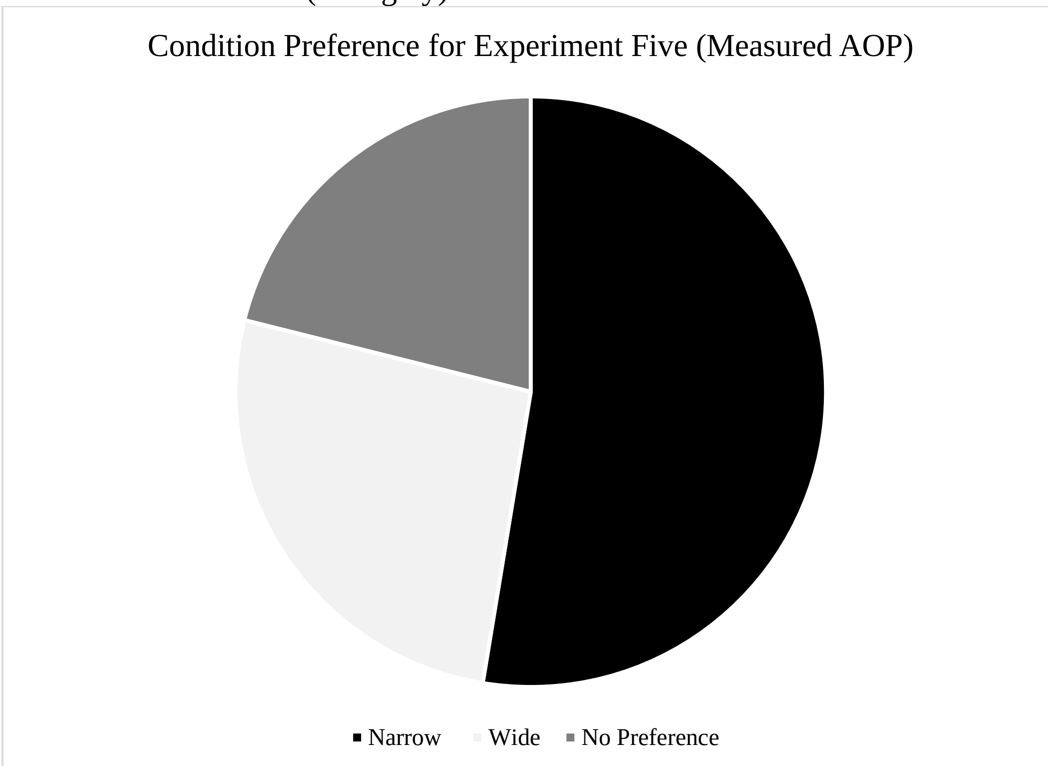
For condition preference and sex (Table 12 and Figure 16) there was no evidence for or against the null to determine if condition preference differed by sex (BF_{10} 0.692). This suggested that there was not enough information to determine whether condition preference differed between sexes. After collapsing the values for male and female condition preferences together, there was no evidence for or against the alternative hypothesis for the narrow cuff condition (BF_{10} 1.299). This indicated that there was insufficient information to suggest whether the proportion of the individuals who preferred to use the narrow cuff condition differed from the test value. There was evidence for the null with respect to the wide cuff condition (BF_{10} 0.299). This suggested that the proportion of individuals who chose to use the wide cuff condition did not differ from what was expected of the test value. There was no evidence for or against the null with respect to the individuals who did not prefer either condition (BF_{10} 0.442). This implied that there was insufficient information to determine whether the proportion of individuals who had no preference differed from the test value. Of the three condition preference options, the greatest proportion of individuals preferred to use the narrow cuff condition (0.526).

Table 12. Condition preference for Experiment Five separated by sex in the sample with a measurable arterial occlusion pressure. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differs from the test value of 0.333.

	Men	Women	Total
Narrow cuff	3	7	10
Wide cuff	2	3	5
No Preference	2	2	4
Total	7	12	19
Bayes Factor	0.692		

	Counts	Total	Proportion	Bayes Factor
Narrow cuff	10	19	0.526	1.299
Wide cuff	5	19	0.263	0.299
No Preference	4	19	0.211	0.442

Figure 16. Condition preference for Experiment Five in the sample with a measurable arterial occlusion pressure. The proportion of individuals who selected the narrow cuff condition (black), wide cuff condition (light grey) and had no preference between the conditions (dark grey).



Estimated Arterial Occlusion Pressure

Of the 96 participants who completed Experiment Five, 77 participants [Males (n=36), Females (n=41)] had an arterial occlusion pressure that was not measurable with the cuff inflation system used. The average pressure inflated into the wide cuff [Males: 64.4 mmHg (8); Females: 63.6 mmHg (12)] exceeded the average pressure inflated into the narrow cuff [Males: 157.2 mmHg (8); Females: 155.6 mmHg (10)] when both cuffs were inflated to 40% of arterial occlusion pressure.

For discomfort ratings in the individuals with an estimated arterial occlusion pressure (Table 13 and Figure 17), there was no evidence for or against the null for the condition x sex interaction (BF_{10} 0.898). This indicated that there was insufficient evidence to conclude that discomfort changed differently across sex. There was evidence for the null hypothesis with respect to condition (BF_{10} 0.178). This suggested that discomfort did not differ between the wide cuff condition and the narrow cuff condition. On the other hand, there was evidence for the alternative hypothesis with respect to sex (BF_{10} 6.301). This suggests that women experienced discomfort less than men.

For repetitions in the individuals with an estimated arterial occlusion pressure (Table 13 and Figure 18), there was no evidence for or against the null for the condition x sex interaction (BF_{10} 0.898). This indicated that there was not enough evidence to conclude that there is a difference in the number of repetitions completed across level of sex. There was strong evidence for the alternative hypothesis with respect to a condition effect (BF_{10} 219.558). This suggested that the number of repetitions differed between conditions, with the narrow cuff condition producing a greater number of repetitions when compared to the wide cuff condition. There was no evidence for or against the null hypothesis in regard to sex (BF_{10} 0.349). This suggests that there was not enough evidence to state that the number of repetitions completed differs between men and women.

Table 13. Discomfort ratings and number of repetitions for Experiment Five separated by condition and sex for the sample with an estimated arterial occlusion pressure. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean ± SD) completed during four sets of unilateral leg extensions is located at the bottom of this table, separated by condition and sex with the associated Bayes Factor for condition and sex effects. Values for average discomfort ratings and the number of repetitions is analyzed based on the individuals whose arterial occlusion pressure was not measurable by the cuff inflation system.

	Discomfort (0-100)	
	Men (n=36)	Women (n=41)
Narrow cuff (5 cm)	60 (21)	47 (19)
Wide cuff (12 cm)	58 (18)	48 (20)
	Bayes Factor (BF_{10})	
Condition	0.178	
Sex	6.301	
Condition * Sex	0.898	
	Repetitions	
	Men (n=36)	Women (n=41)
Narrow cuff (5 cm)	61 (15)	62 (13)
Wide cuff (12 cm)	58 (14)	55 (11)
	Bayes Factor (BF_{10})	
Condition	219.558	
Sex	0.349	
Condition * Sex	0.898	

Figure 17. Discomfort ratings for Experiment Five separated by condition and sex in the sample with an estimated arterial occlusion pressure. The average discomfort ratings for the sample whose arterial occlusion pressure was not measurable by the cuff inflation system separated by condition, with the narrow cuff condition on the left and the wide cuff condition on the right. The discomfort ratings were further divided between males (black) and females (gray).

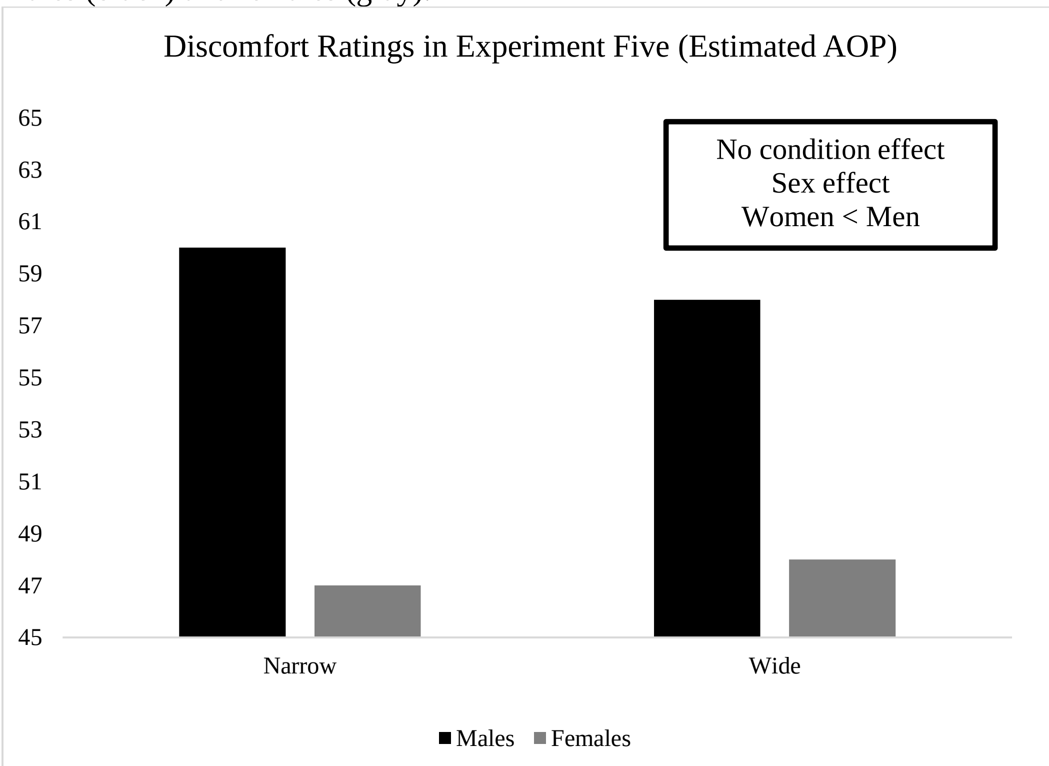
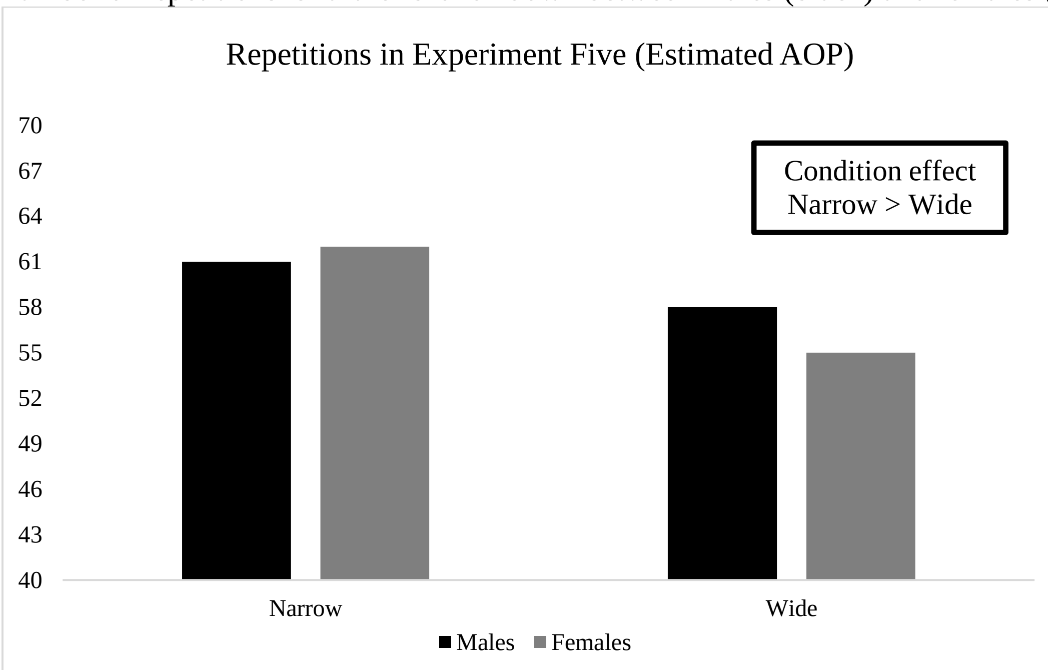


Figure 18. Number of repetitions for Experiment Five separated by condition and sex in the sample with an estimated arterial occlusion pressure. The average number of repetitions performed across four sets of unilateral leg extensions in the individuals whose arterial occlusion pressure was not measurable with the cuff inflation system, with the narrow cuff condition on the left and the wide cuff condition on the right. The total number of repetitions is further broken down between males (black) and females (gray).



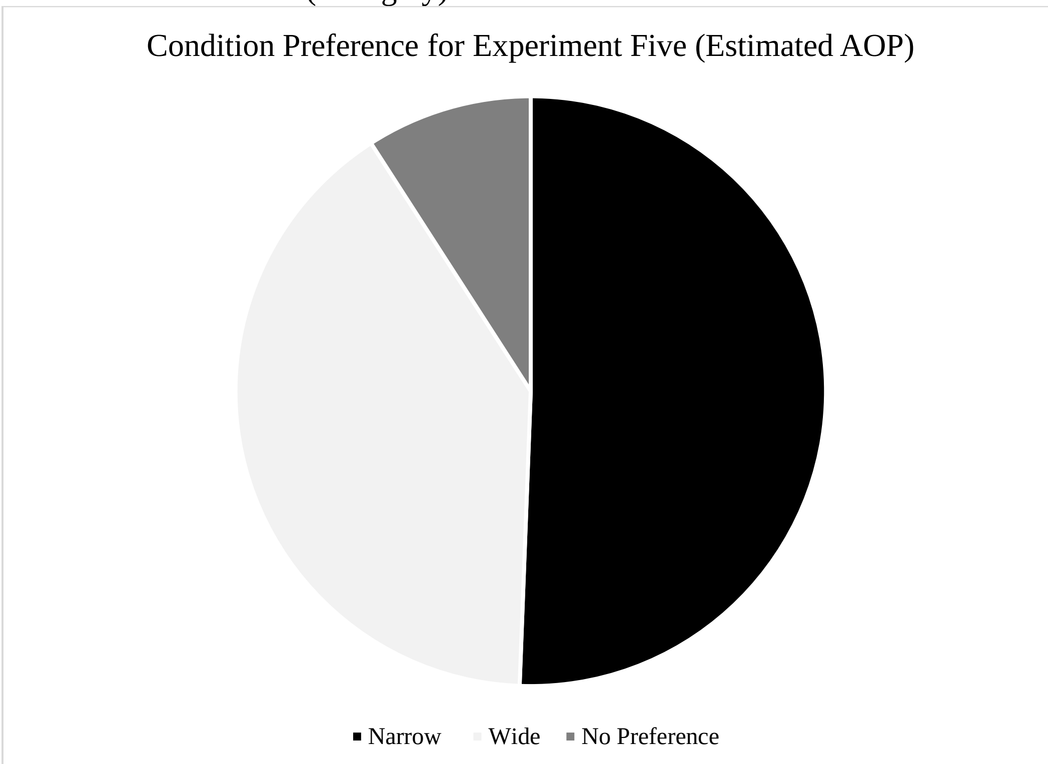
For condition preference and sex (Table 14 and Figure 19) there was evidence for the alternative hypothesis that condition preference differed by sex (BF_{10} 4.757). This indicated that men preferred to use the narrow cuff condition while women preferred to use the wide cuff condition. Once all of the condition preference values were collapsed, there was evidence for the alternative hypothesis for the narrow cuff condition (BF_{10} 22.973) and those who had no preference between conditions (BF_{10} 18706.441). This indicated that the proportion of individuals who chose the narrow cuff condition or had no preference did differ from the test values. On the other hand, there was no evidence for or against the null for the wide cuff condition (BF_{10} 0.337). This indicated that there is not enough information to suggest whether the proportion of individuals who selected the wide cuff condition differed from the test value. Of the three choices, the greatest proportion of individuals preferred to use the narrow cuff condition (0.506).

Table 14. Condition preference for Experiment Five separated by sex in those with an estimated arterial occlusion pressure. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differed from the test value of 0.333.

	Men	Women	Total
Narrow cuff	22	17	39
Wide cuff	9	22	31
No Preference	5	2	7
Total	36	41	77
Bayes Factor	4.757		

	Counts	Total	Proportion	Bayes Factor
Narrow cuff	39	77	0.506	22.973
Wide cuff	31	77	0.403	0.337
No Preference	7	77	0.091	18706.441

Figure 19. Condition preference for Experiment Five in the sample with an estimated arterial occlusion pressure. The proportion of individuals who selected the narrow cuff condition (black), wide cuff condition (light grey) and had no preference between the conditions (dark grey).



Experiment Six

Total

A total of 95 participants [Males (n=42): Age: 23 years (3), Height: 176.7 cm (8), Body Mass: 81.3 kg (11); Females (n=53): Age: 21 years (2), Height: 163.3 cm (6), Body Mass: 64.5 kg (13)] completed Experiment Six. The average pressure inflated into the Wide cuff 5-cm 40% AOP condition [Males: 145.00 mmHg (24); Females: 141.3 mmHg (28)] was higher than the average pressure inflated into the Wide cuff 12-cm 40% AOP condition [Males: 62.5 mmHg (9); Females: 59.7 mmHg (11)].

For discomfort in all of the individuals who completed Experiment Six (Table 15 and Figure 20), there was no evidence for or against the null for the condition x sex interaction (BF_{10} 0.353). This indicated that there was not enough evidence to conclude whether discomfort changed differently across sexes. There was, however, strong evidence towards the alternative hypothesis with respect to condition (BF_{10} 5.219 * 10^{22}). This implied that the discomfort did differ between conditions, with the Wide cuff 5-cm 40% AOP condition producing more discomfort compared to the Wide cuff 12-cm 40% AOP condition. There was evidence for the null hypothesis with respect to the sex effect (BF_{10} 0.296). This suggests that there is no difference in the discomfort between men and women.

The number of repetitions in all of the individuals who completed Experiment Six (Table 15 and Figure 21) showed no evidence of the condition x sex interaction (BF_{10} 0.413). This indicated that there was insufficient evidence to definitively state that the number of repetitions changed differently across sex. There was strong evidence favoring the alternative hypothesis for a condition effect (BF_{10} 5.528 * 10^{19}). This denotes that condition impacts the number of repetitions performed, with Wide cuff 5-cm 40% AOP condition resulting in a fewer number of repetitions when compared to the Wide cuff 12-cm 40% AOP condition. There was no evidence for or against the null hypothesis for a sex effect (BF_{10} 0.334). This suggests that there is not enough information to state that the number of repetitions will differ between men and women.

Table 15. Discomfort ratings and number of repetitions for Experiment Six separated by condition and sex for the total sample. Discomfort ratings (mean $\pm$ SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean $\pm$ SD) performed during four sets of unilateral leg extensions is located at the bottom of this table, separated by condition and sex with the associated Bayes Factor for condition and sex effects. Values for average discomfort ratings and the number of repetitions is analyzed based on the total sample (i.e. those who had a measurable arterial occlusion pressure and those whose arterial occlusion pressure was estimated).

	Discomfort (0-100)	
	Men (n=42)	Women (n=53)
Wide cuff (5-cm 40% AOP)	75 (19)	73 (22)
Wide cuff (12-cm 40% AOP)	55 (21)	51 (21)
	Bayes Factor (BF_{10})	
Condition	$5.219 * 10^{22}$	
Sex	0.296	
Condition * Sex	0.353	
	Repetitions	
	Men (n=42)	Women (n=53)
Wide cuff (5-cm 40% AOP)	36 (9)	35 (8)
Wide cuff (12-cm 40% AOP)	57 (16)	53 (10)
	Bayes Factor (BF_{10})	
Condition	$5.528 * 10^{19}$	
Sex	0.334	
Condition * Sex	0.413	

Figure 20. Discomfort ratings for Experiment Six separated by condition and sex in the total sample. The discomfort ratings for the total sample separated by condition, with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. The average discomfort ratings were further broken down between men (black) and women (gray).

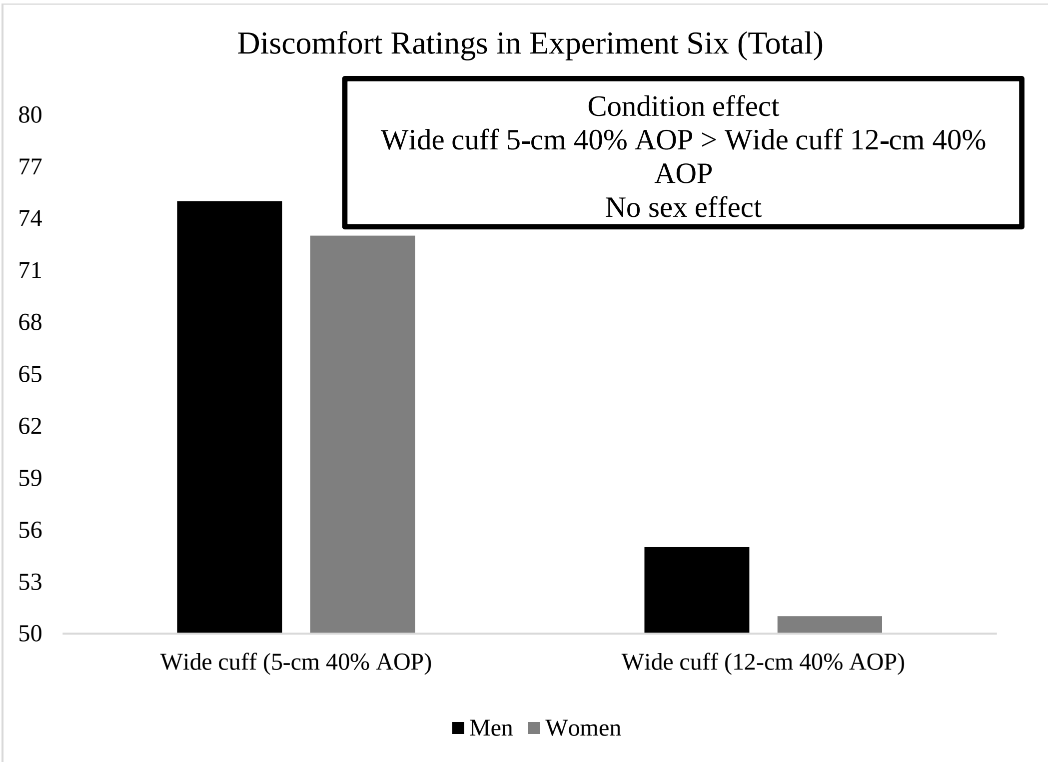
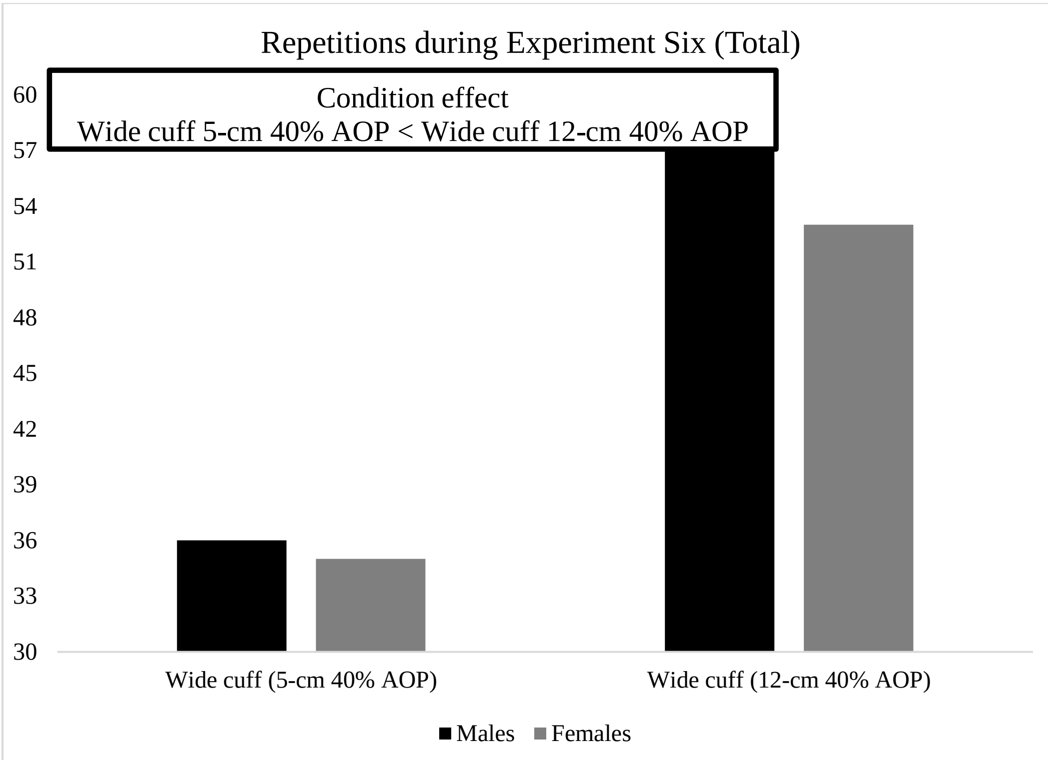


Figure 21. Number of repetitions completed during Experiment Six separated by condition and sex in the total sample. The average number of repetitions performed across four sets of unilateral leg extensions in all individuals, with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. The total number of repetitions is further broken down between males (black) and females (gray).



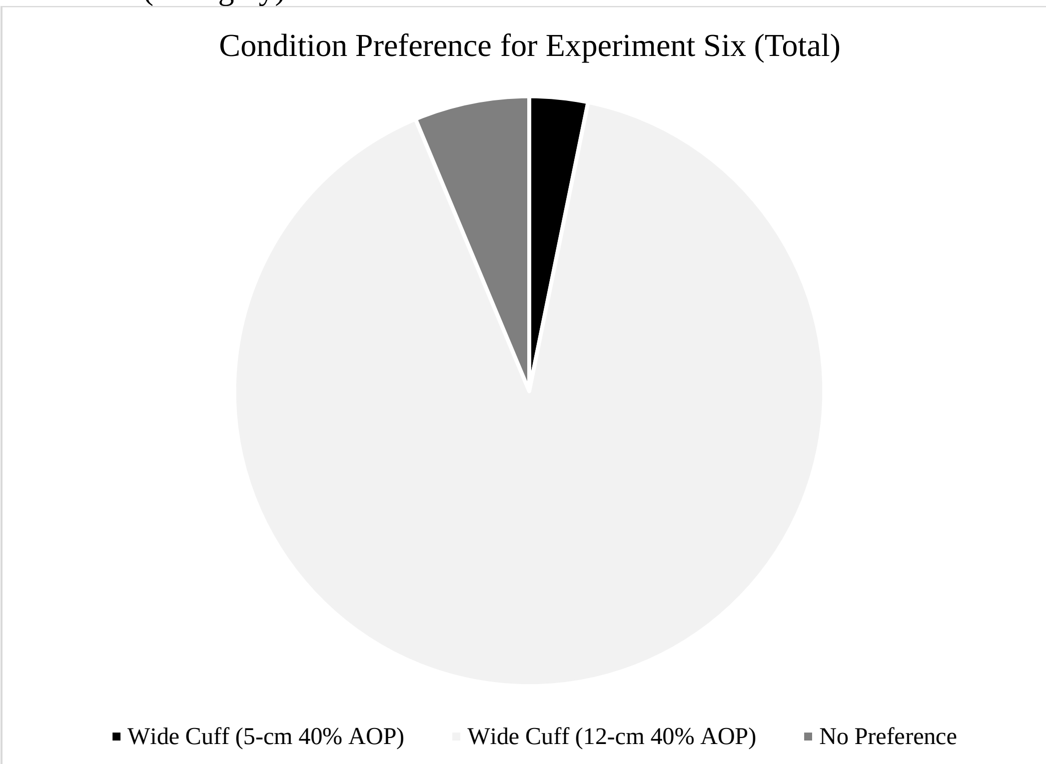
For condition preference and sex (Table 16 and Figure 22), there was no evidence for or against the null to determine if condition preference differed by sex (BF_{10} 0.375). This indicates that there is insufficient information to determine whether condition preference differed between sexes. Once all of differences in sex are collapsed together into each condition, there was strong evidence for the alternative hypothesis for all three options: the Wide cuff 5-cm 40% AOP condition (BF_{10} $2.100 * 10^{32}$), the Wide cuff 12-cm 40% AOP condition (BF_{10} $8.333 * 10^{28}$), and no preference between conditions (BF_{10} $2.798 * 10^{7}$). These values indicate that the proportion of individuals who chose each condition differed from the test value of 0.333. Out of the three conditions, the greatest proportion of individuals preferred to use the Wide cuff 12-cm 40% AOP condition (0.905).

Table 16. Condition preference for Experiment Six separated by sex in the total sample. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differs from the test value of 0.333.

	Men	Women	Total
Wide cuff (5-cm 40% AOP)	2	1	3
Wide cuff (12-cm 40% AOP)	35	51	86
No Preference	5	1	6
Total	42	53	95
Bayes Factor	0.375		

	Counts	Total	Proportion	Bayes Factor
Wide cuff (5-cm 40% AOP)	3	95	0.032	$2.100 * 10^{32}$
Wide cuff (12-cm 40% AOP)	86	95	0.905	$8.333 * 10^{28}$
No Preference	6	95	0.063	$2.798 * 10^{7}$

Figure 22. Condition preference for Experiment Six in the total sample. The proportion of individuals who selected the Wide cuff 5-cm 40% AOP condition (black), the Wide cuff 12-cm 50% AOP condition (light grey) and had no preference between the conditions (dark grey).



Measured Arterial Occlusion Pressure

Of the 95 participants included in Experiment Six, there were 20 participants [Males (n=8), Females (n=12)] whose arterial occlusion pressure was measurable with the cuff inflation system used. Although wide cuffs were used in both conditions, the average pressure for the Wide cuff 5-cm 40% AOP condition [Males: 101.5 mmHg (14); Females: 94.3 mmHg (14)] was higher than the average pressure for the Wide cuff 12-cm 40% AOP condition [Males: 54.8 mmHg (6); Females: 51.8 mmHg (7)].

For discomfort ratings in the sample of Experiment Six whose arterial occlusion pressure was measurable with the cuff inflation system (Table 17 and Figure 23), there was no evidence for or against the null with respect to a condition x sex interaction (BF_{10}

0.887). This indicated that there was insufficient evidence to conclude that discomfort changed differently across sexes. However, there was strong evidence for the alternative hypothesis for a condition effect (BF_{10} 35443.907). This suggested that there was a difference in discomfort between the two conditions, with the Wide cuff 5-cm 40% AOP condition producing greater discomfort when compared to the Wide cuff 12-cm 40% AOP condition. Finally, there was no evidence for or against the null with respect to a sex effect (BF_{10} 0.515). This suggests that there is not enough evidence to state whether discomfort is different between men and women.

For the number of repetitions in the sample of Experiment Six whose arterial occlusion pressure was measurable with the cuff inflation system (Table 17 and Figure 24), there was no evidence for or against the null with respect to the condition x sex interaction (BF_{10} 0.887). This indicated that there is insufficient evidence to determine whether there is any difference in the number of repetitions across level of sex. There was strong evidence for the alternative hypothesis for a main effect of condition (BF_{10} 287.874). This implies that condition impacts the number of repetitions performed, with the Wide cuff 5-cm 40% AOP condition resulting in fewer repetitions compared to the Wide cuff 12-cm 40% AOP condition. There was no evidence for or against the null with respect to a sex effect (BF_{10} 0.544). This suggests that there was not enough evidence to state whether there is any difference in the number of repetitions completed between sexes.

Table 17. Discomfort ratings and number of repetitions for Experiment Six separated by condition and sex in the individuals with a measurable arterial occlusion pressure. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean ± SD) performed during four sets of unilateral leg extensions is located at the bottom of this table, separated by condition and sex with the associated Bayes Factor for condition and sex effects. Values for average discomfort ratings and the average number of repetitions is analyzed based on the individuals whose arterial occlusion pressure was measurable with the cuff inflation system.

	Discomfort (0-100)	
	Men (n=8)	Women (n=12)
Wide cuff (5-cm 40% AOP)	71 (18)	67 (13)
Wide cuff (12-cm 40% AOP)	56 (23)	52 (15)
	Bayes Factor (BF_{10})	
Condition	35443.907	
Sex	0.515	
Condition * Sex	0.887	
	Repetitions	
	Men (n=8)	Women (n=12)
Wide cuff (5-cm 40% AOP)	40 (14)	39 (9)
Wide cuff (12-cm 40% AOP)	66 (27)	52 (10)
	Bayes Factor (BF_{10})	
Condition	287.874	
Sex	0.544	
Condition * Sex	0.887	

Figure 23. Discomfort ratings for Experiment Six separated by condition and sex in the individuals with a measurable arterial occlusion pressure. Discomfort ratings for the sample whose arterial occlusion pressure was measurable with the cuff inflation system separated by condition, with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. Discomfort ratings were further separated between males (black) and females (gray) within each condition.

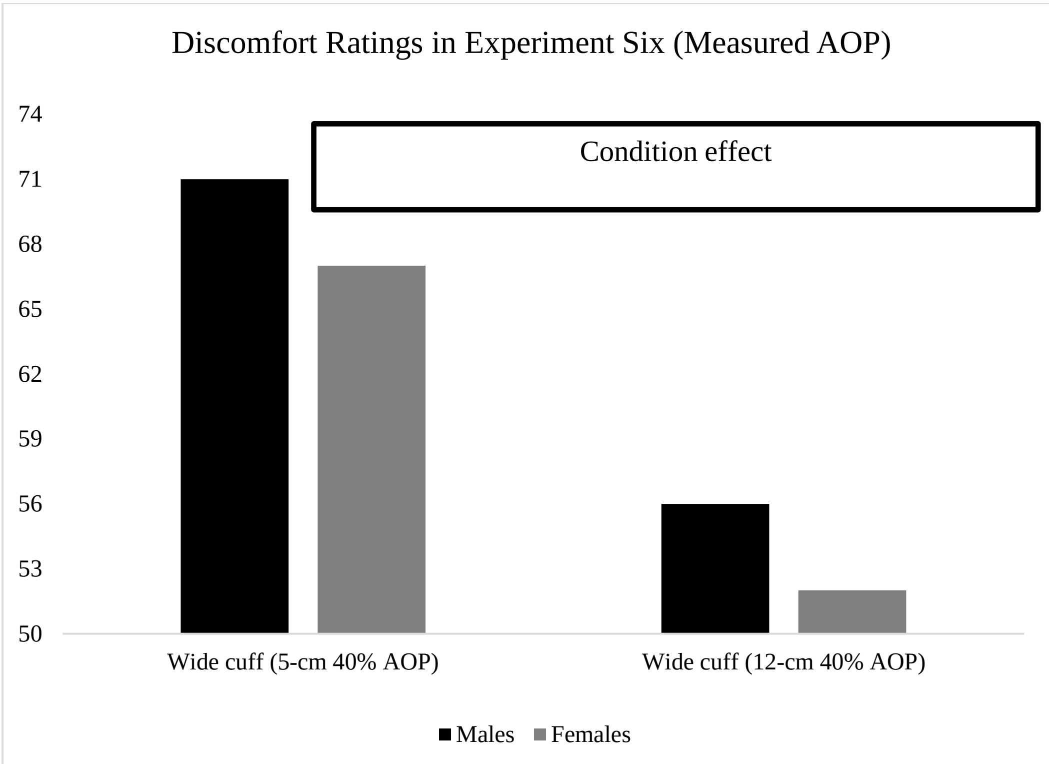
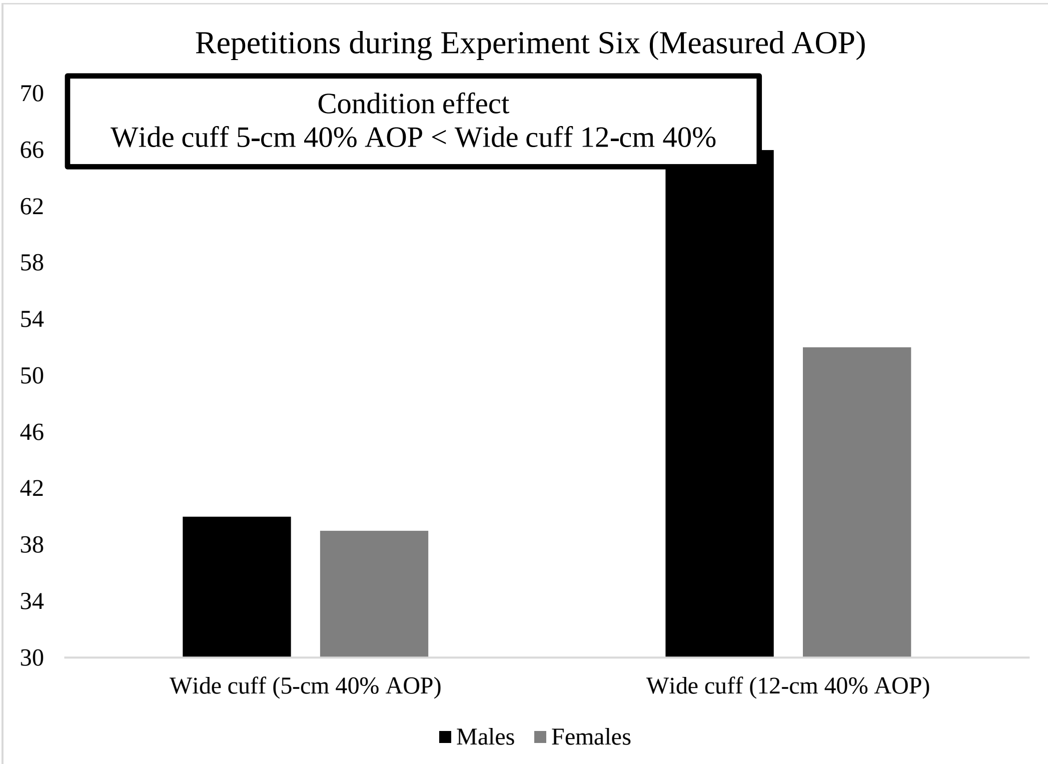


Figure 24. Number of repetitions completed during Experiment Six separated by condition and sex in the sample with a measurable arterial occlusion pressure. The number of repetitions performed across four sets of unilateral leg extensions in the individuals whose arterial occlusion pressure was measurable with the cuff inflation system, with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. The total number of repetitions is further broken down between males (black) and females (gray)



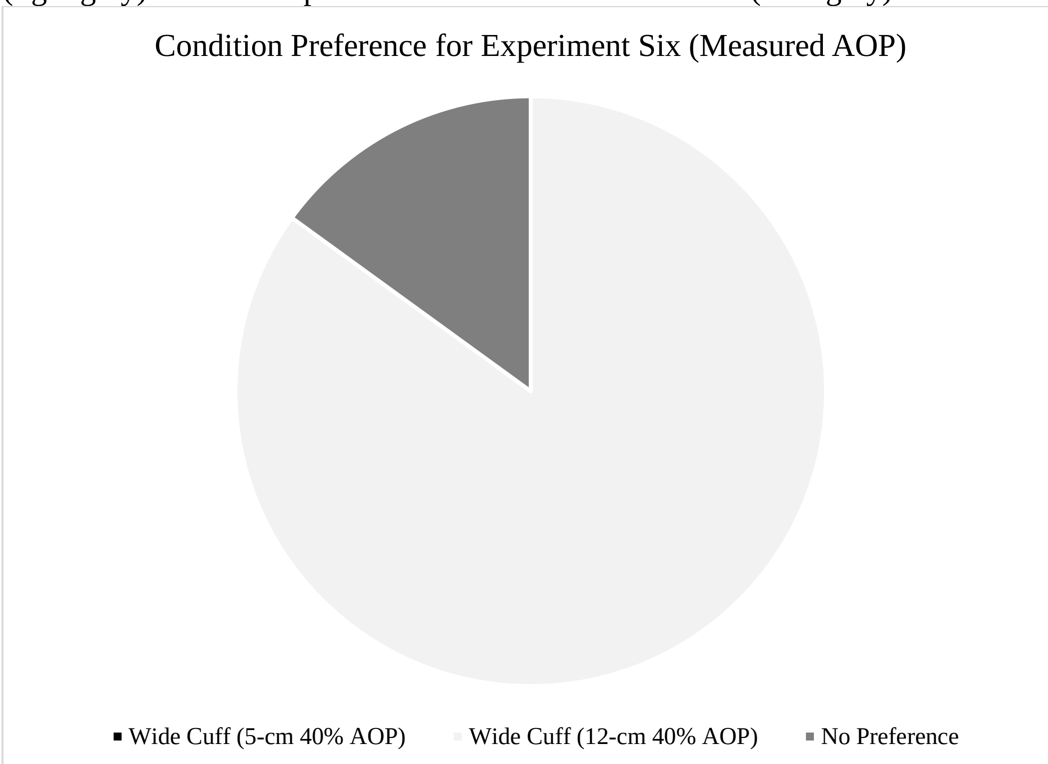
For condition preference and sex (Table 18 and Figure 25) there was no evidence for or against the null to determine if condition preference differed by sex (BF_{10} 0.845). This indicated that there was not enough information to determine whether condition preference differed between sexes. Once all of the values were collapsed together into the three conditions, there was no evidence for or against the alternative hypothesis for those individuals who had no preference for either condition (BF_{10} 1.052). This implied that there was not enough information to state whether the proportion of individuals who had no preference differed from the test value. On the other hand, there was strong evidence for the alternative for the Wide cuff 12-cm 40% AOP condition (BF_{10} 21277.200). This indicated that there was a difference in the proportion of individuals who preferred to use that condition from the test value. Furthermore, the greatest proportion of individuals preferred to use the Wide cuff 12-cm 40% AOP condition (0.850).

Table 18. Condition preference for Experiment Six separated by sex in the individuals with a measurable arterial occlusion pressure. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differs from the test value of 0.333.

	Men	Women	Total
Wide cuff (5-cm 40% AOP)	0	0	0
Wide cuff (12-cm 40% AOP)	6	11	17
No Preference	2	1	3
Total	8	12	20
Bayes Factor	0.845		

	Counts	Total	Proportion	Bayes Factor
Wide cuff (5-cm 40% AOP)	0	20	0.000	--
Wide cuff (12-cm 40% AOP)	17	20	0.850	21277.200
No Preference	3	20	0.150	1.052

Figure 25. Condition preference for Experiment Six in the sample with a measurable arterial occlusion pressure. The proportion of individuals who selected the Wide cuff 5-cm 40% AOP condition (black), the Wide cuff 12-cm 50% AOP condition (light grey) and had no preference between the conditions (dark grey).



Estimated Arterial Occlusion Pressure

Of the 95 participants who completed Experiment Six, there were 75 participants [Males (n=34), Females (n=41)] whose arterial occlusion pressure surpassed the maximum pressure of the cuff inflation system. The average pressure inflated into the Wide cuff 5-cm 40% AOP condition [Males: 155.3 mmHg (10); Females: 155.1 mmHg (10)] was higher than the average pressure inflated into the Wide cuff 12-cm 40% AOP condition [Males: 64.4 mmHg (8); Females: 62 mmHg (10)].

For discomfort in the individuals with an estimated arterial occlusion pressure (Table 19 and Figure 26), there was no evidence for or against the null with respect to a condition x sex interaction (BF_{10} 0.318). This suggests that there is insufficient evidence to state whether discomfort changed differently across sexes. There was strong evidence for the alternative hypothesis for a condition effect (BF_{10} 1.144 * 10^{18}). This signifies that discomfort did differ between the conditions, with the Wide cuff 5-cm 40% AOP resulting in greater discomfort compared to the Wide cuff 12-cm 40% AOP condition. There was evidence for the null for a sex effect (BF_{10} 0.286). This indicates that there is no difference in the way men and women perceived discomfort.

For the number of repetitions in the individuals with an estimated arterial occlusion pressure (Table 19 and Figure 27), there was evidence for the null hypothesis for a condition x sex interaction (BF_{10} 0.318). This implied that there was no difference in discomfort across sexes. There was strong evidence for the alternative hypothesis for a main effect of condition (BF_{10} 3.340 * 10^{32}). This signifies that condition impacted the number of repetitions completed, with the Wide cuff 5-cm 40% AOP resulting in fewer repetitions compared to the Wide cuff 12-cm 40% AOP condition. There was evidence for the null hypothesis for a sex effect (BF_{10} 0.257). This suggests that there was no difference in the number of repetitions completed between men and women.

Table 19. Discomfort ratings and number of repetitions for Experiment Six separated by condition and sex in the individuals with an estimated arterial occlusion pressure. Discomfort ratings (mean ± SD) separated by condition and sex with the associated Bayes Factor for condition and sex effects. Additionally, the number of repetitions (mean ± SD) performed during four sets of unilateral leg extensions is located at the bottom of this table, separated by condition and sex with the associated Bayes Factor for condition and sex effects. Values for average discomfort ratings and the number of repetitions is analyzed based on the individuals whose arterial occlusion pressure was not measurable with the cuff inflation system.

	Discomfort (0-100)	
	Men (n=34)	Women (n=41)
Wide cuff (5-cm 40% AOP)	76 (19)	74 (24)
Wide cuff (12-cm 40% AOP)	54 (21)	50 (23)
	Bayes Factor	
Condition	$1.144 * 10^{18}$	
Sex	0.286	
Condition * Sex	0.318	
	Repetitions	
	Men (n=34)	Women (n=41)
Wide cuff (5-cm 40% AOP)	35 (7)	34 (7)
Wide cuff (12-cm 40% AOP)	55 (11)	53 (10)
	Bayes Factor	
Condition	$3.340 * 10^{32}$	
Sex	0.257	
Condition * Sex	0.318	

Figure 26. Discomfort ratings for Experiment Six separated by condition and sex in the individuals with an estimated arterial occlusion pressure. Discomfort ratings for the sample whose arterial occlusion pressure was not measurable with the cuff inflation system separated by condition, with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. Discomfort ratings were further separated between males (black) and females (gray) within each condition.

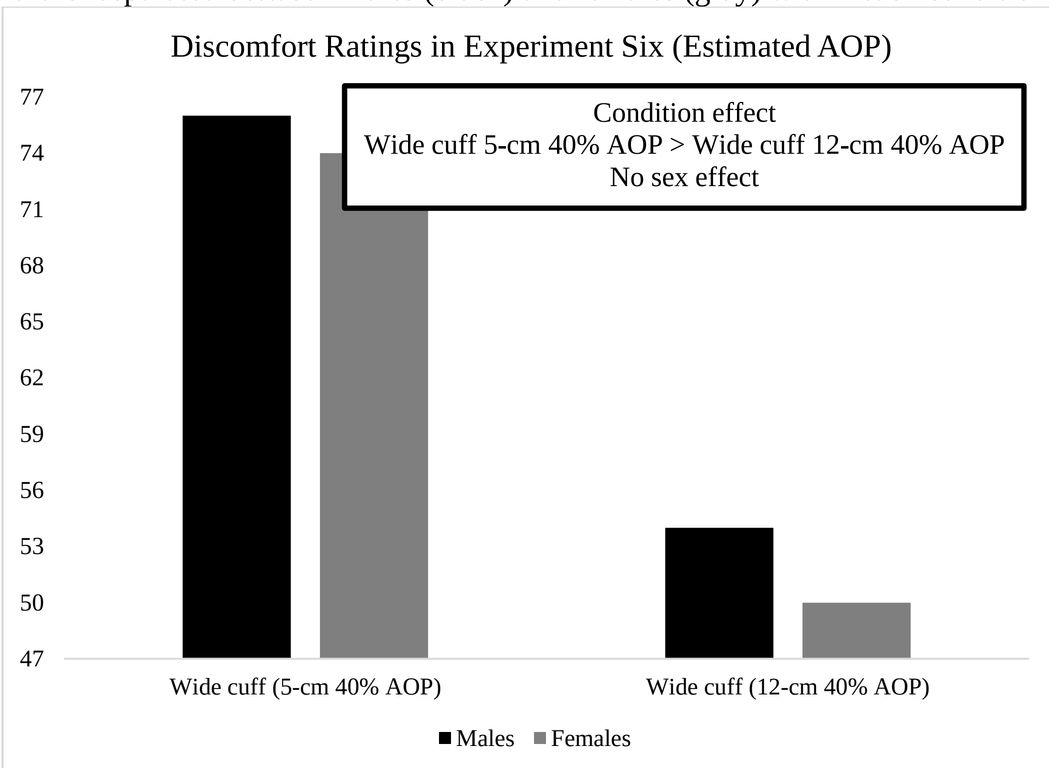
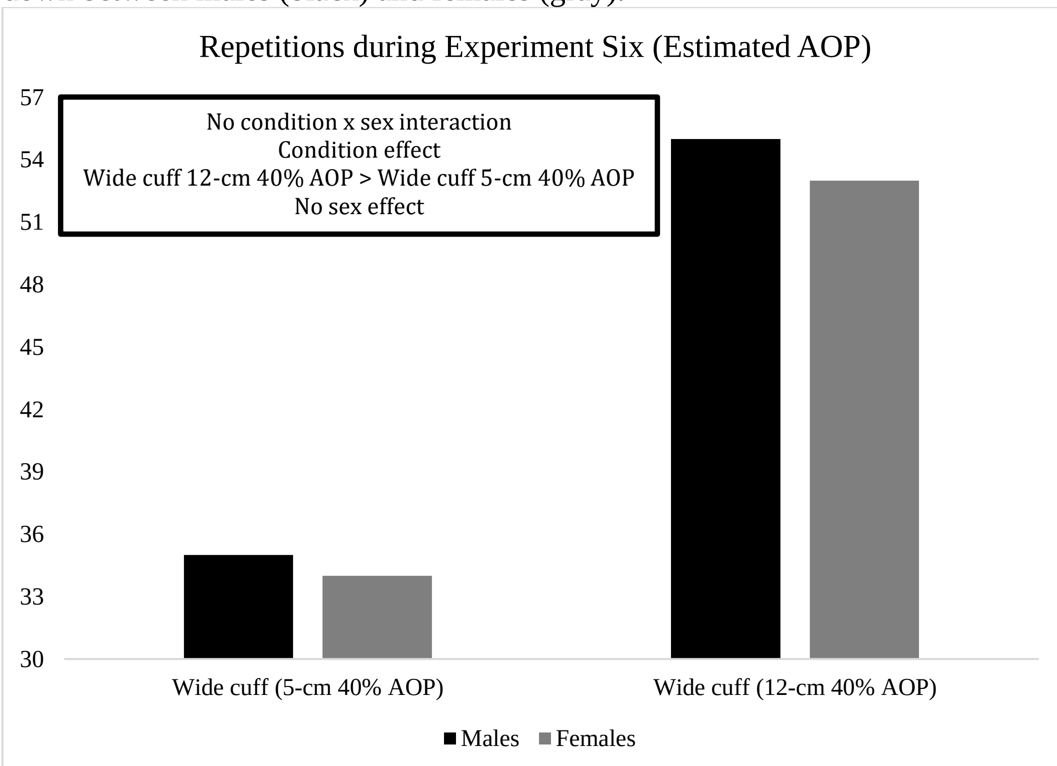


Figure 27. Number of repetitions completed during Experiment Six separated by cuff size and sex in the sample with an estimated arterial occlusion pressure. The average number of repetitions performed across four sets of unilateral leg extensions in the individuals whose arterial occlusion pressure was not measurable with the cuff inflation system, with the Wide cuff 5-cm 40% AOP condition on the left and the Wide cuff 12-cm 40% AOP condition on the right. The number of repetitions is further broken down between males (black) and females (gray).



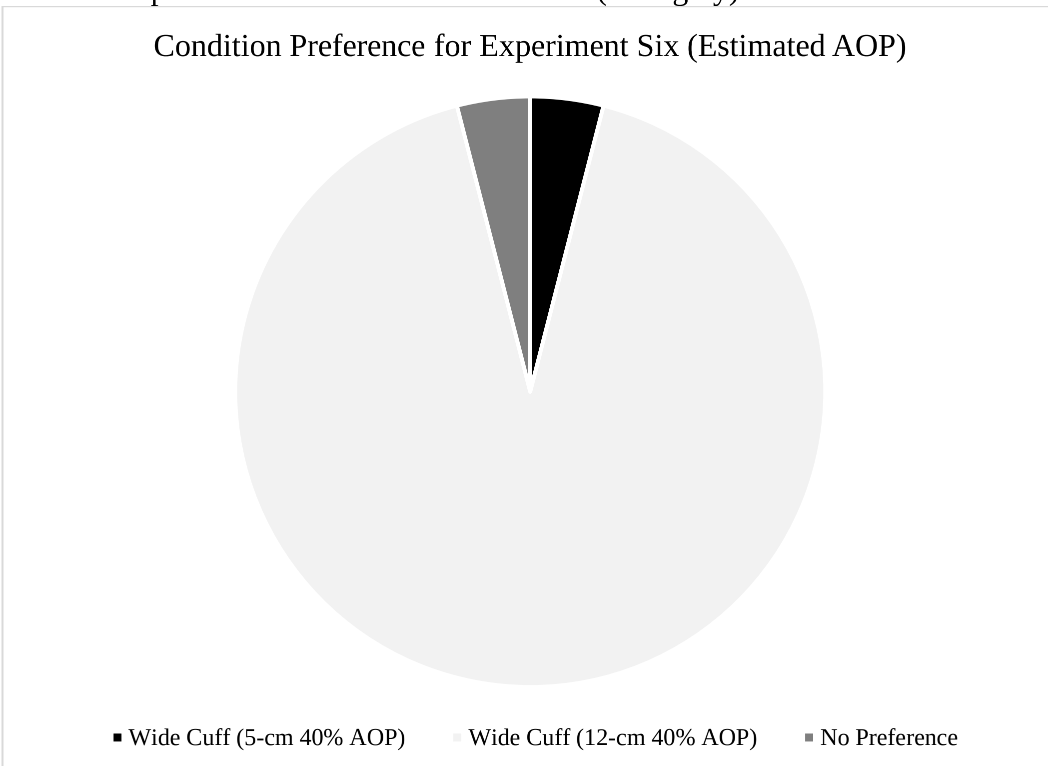
For condition preference and sex (Table 20 and Figure 28) there was evidence for the null to determine if condition preference differed by sex (BF_{10} 0.327). This indicated that there was no difference in condition preference between sexes. Once preferences were collapsed together for each individual condition, there was strong evidence for the alternative hypothesis for all three choices: Wide cuff 5-cm 40% AOP condition (BF_{10} $1.806 * 10^7$), Wide cuff 12-cm 40% AOP condition (BF_{10} $1.206 * 10^{24}$), and no preference (BF_{10} $1.806 * 10^7$). This implied that there was a difference in the proportion of individuals who preferred each condition than what was predicted by the test value. Of the three choices, the greatest proportion of individuals preferred to use the Wide cuff 12-cm 40% AOP condition (0.920).

Table 20. Condition preference for Experiment Six separated by sex in the sample with an estimated arterial occlusion pressure. The top of the table lists the number of males and females, as well as the total number of individuals, who preferred each condition; with the associated Bayes factor for a sex effect in preference. The bottom of the table provides the proportion of the sample that chose each option, with the associated Bayes factor of how each proportion differs from the test value of 0.333.

	Men	Women	Total
Wide cuff (5-cm 40% AOP)	2	1	3
Wide cuff (12-cm 40% AOP)	29	40	69
No Preference	3	0	3
Total	34	41	75
Bayes Factor	0.327		

	Counts	Total	Proportion	Bayes Factor
Wide cuff (5-cm 40% AOP)	3	75	0.040	$1.806 * 10^{7}$
Wide cuff (12-cm 40% AOP)	69	75	0.920	$1.206 * 10^{24}$
No Preference	3	75	0.040	$1.806 * 10^{7}$

Figure 28. Condition preference for Experiment Six in sample with an estimated arterial occlusion pressure. The proportion of individuals who selected the Wide cuff 5-cm 40% AOP condition (black), the Wide cuff 12-cm 50% AOP condition (light grey) and had no preference between the conditions (dark grey).



CHAPTER V: DISCUSSION

There were four primary purposes in this series of studies: (1) to examine the impact of cuff width on discomfort at rest and determine if there is a difference between sexes; (2) to examine the impact of cuff width on discomfort following exercise and determine if there is a difference between sexes; (3) to examine the impact that a pressure intended for a narrow cuff had when inflated to a wide cuff on discomfort following exercise and determine if there is a difference between sexes; and (4) to examine whether there is a preference between two different cuff conditions following exercise and determine if there is a difference between sexes. Each of these were addressed in the upper and lower body. The major findings of all six experiments include:

- There were no differences in perceived discomfort between cuff widths in the absence of exercise in the upper body. This was also not affected by sex.
- Discomfort was greatest during exercise with a wide cuff in the upper body.
- There were no sex differences in discomfort following exercise in the upper body.
- There was some evidence to indicate that the narrow cuff condition resulted in a greater perceived discomfort compared to the wide cuff condition in the lower body during rest. However, this only occurred in the individuals with an estimated arterial occlusion pressure.
- There was some evidence to suggest that women experienced lower feelings of discomfort following exercise in the lower body. However, this only occurred in women with an estimated arterial occlusion pressure.

- A wide cuff inflated to a pressure intended for a narrow cuff resulted in a greater feeling of discomfort and fewer repetitions completed in the upper body and the lower body.
- Individuals preferred to use the cuff condition inflated to the pressure that was intended for that cuff, in both the upper and lower body.

Cuff Width and Discomfort

A variety of cuff widths, from 3-cm to 18-cm pneumatic cuffs, have been used in previous blood flow restriction literature.[9,10,48] We utilized a 5-cm, narrow cuff and a 12-cm, wide cuff to determine if there was a difference in perceive d discomfort between different cuff widths during exercise and in the absence of exercise. In a study using a similar protocol to ours, Rossow et al. found that a 5-cm, narrow cuff resulted in less discomfort when compared to a 13.5-cm, wide cuff following four sets of knee extension exercise using 20% of 1-RM.[10] Nonetheless, this may not be a fair comparison in terms of discomfort because both cuffs were inflated to the same absolute pressure. Previous work has shown that arterial occlusion pressure is highly dependent on the width of the cuff, with a narrow (i.e. 5-cm) cuff requiring a greater pressure to reach full occlusion compared to a wide (i.e. 12-cm) cuff.[20] However, these differences in arterial occlusion pressure amongst different cuff widths may be mitigated if the pressure inflated into the cuff accounts for the cuff width used.[12] Work by Mouser et al. revealed a pressure set relative to a certain cuff width will elicit a similar blood flow restriction stimulus amongst multiple cuff widths at rest.[12] Therefore, we chose to inflate 5-cm and 12-cm cuffs to the same relative arterial occlusion pressure; which hypothetically would deliver a similar stimulus, to determine if there were any differences in perceived discomfort.

Our results indicate that there was a difference in discomfort in the upper body following exercise that was not observed when the cuff was inflated in the absence of muscle contraction. The ratings of perceived discomfort were greatest following the use of the wide cuff condition in the upper body, despite both cuffs being inflated to the same relative arterial occlusion pressure. In contrast to our findings, Laurentino et al. found no difference in ratings of perceived pain following exercise in the upper body when a 10-cm wide cuff and a 5-cm narrow cuff were inflated to the same relative arterial occlusion pressure. However, there is a gap in the methods regarding the collection of data for ratings of perceived pain. Perceived pain was measured using the Borg-CR 10 scale, but it is unknown whether the ratings were taken before or after cuff deflation. It was also not specified whether the ratings were taken following each condition as it was completed or following the completion of both conditions, which could present an order bias. Furthermore, it seemed that the ratings of perceived pain were averaged over a period of time rather than after each exercise bout.[76] All of these factors are potential confounders that could have influenced the ratings of perceived pain in the upper body.

The investigation of discomfort following blood flow restriction in the lower body differed slightly from that observed in the upper body. Our results suggest that discomfort differed between cuff widths when applied in the absence of exercise. Specifically, the feelings of discomfort were greatest for the narrow cuffs, but only in the individuals whose arterial occlusion pressure exceeded 300 mmHg (i.e. the maximum pressure of the cuff inflation system) and had to have their pressure estimated based on the noise emitted from the Doppler probe. A study by Rossow et al. revealed that there was no difference in ratings of perceived pain during a seated rest period between a 13.5-cm pneumatic cuff and a 5-cm elastic cuff.[10] However, the ratings of perceived pain in the absence of exercise were taken prior to cuff inflation, whereas the cuffs had been inflated for four minutes prior to discomfort ratings in our protocol. Additionally, the results of Rossow's study indicated that the wide cuff condition resulted in a higher rating of perceived pain both during and immediately following the exercise bout. This is likely due to both cuffs being inflated to the same absolute pressure rather than being made relative to the cuff width. Since cuff width has a strong influence on cuff pressure[12] and the cuffs in our protocol were inflated to the same relative pressure, it is possible that this is the reason we did not observe any difference in discomfort between the 12-cm and 5-cm cuff conditions in the lower body following exercise.

We thought it necessary to test this in both the upper and lower body due to the potential impact that differences in muscle architecture between sites may have on discomfort.[9] More specifically, the biceps brachii is a fusiform muscle while the rectus femoris of the quadriceps is a bipennate muscle. The contraction of a fusiform muscle results in a "balling up" effect since the parallel muscle fibers converge together at the tendon. When applying the cuff during blood flow restricted exercise, the pressure inflated into the cuff can add a compressive force onto the muscle that is covered by the cuff. This may result in intensified discomfort seen in the upper body, since the fusiform muscle is "balling up" against the pressure inflated into the cuff. This added pressure on a "balled up" muscle may be further exaggerated depending on the width of the cuff that is applied. For example, a 12-cm cuff would cover much more of the muscle belly compared to a 5-cm cuff. Even if the cuffs are inflated to the same relative pressure, the amount of musculature that is under pressure by the cuff will result in a greater feeling of discomfort. However, the arrangement of muscle fibers in pennate muscles does not result in the "balling up" effect as it does in fusiform muscles. The lower body may not experience the same level of discomfort in the upper body due to the lack of added compressive force on the muscle belly of the quadriceps. This difference in muscle fiber arrangement could potentially provide a reason why differences were observed between cuff widths in the upper body but not the lower body.

Furthermore, this is the first study that has considered the variable of cuff preference. Our results indicate that individuals prefer to exercise with the narrow cuff condition, in both the upper and lower body. Additionally, individuals prefer to use the cuff condition that utilizes the correct pressure rather than a pressure intended for a different sized cuff.

Though the differences in discomfort were not similar between the upper and lower body; the average number of repetitions completed during the exercise bouts was greatest when using the narrow cuff condition in both the upper and lower body. The amount of repetitions could be related to the ischemic conditions that results from the buildup in metabolites following blood flow restricted exercise.[39] There seems to be a difference in blood flow during exercise between cuff widths, with a potentially greater reduction in blood flow when using the wide cuff. This may provide some indication of blood flow during the exercise bout, since limited blood flow appears to cause difficulty completing repetitions.[10] Importantly, this difference was observed between cuffs even when each one was inflated to the same relative pressure.

Cuff Pressure and Discomfort

Early studies in blood flow restriction literature utilized different sized cuffs that were inflated to the same absolute pressure for all participants.[13,16] However, further research revealed that wide cuffs require a much lower pressure to reach full occlusion compared to narrow cuffs.[22,77] Although this was first confirmed using tourniquets in surgical literature,[78] Loenneke et al. designed another protocol to determine the average pressure to fully occlude the artery in a narrow cuff and a wide cuff, both of which were commonly used in blood flow restriction literature.[11] This was the first study using blood flow restriction cuffs to provide adequate evidence that arterial occlusion pressure should be based on the width of the cuff and thigh circumference, or in other words, should be a pressure that is made relative to the participant themselves. A relative arterial occlusion pressure can account for individual differences, such as the participant's blood pressure and limb circumference, as well as the pressure differences that arise from different cuff widths.[21,48] To illustrate, one particular study had an unusually high number of participants choose to withdraw from a blood flow restriction training protocol due to the discomfort associated with the exercise.[79] The participants performed three sets of isometric handgrip exercise with a 16-cm cuff inflated to 150 mmHg for the younger participants and 160 mmHg for the older participants. However, the results from Loenneke's study[11] reveal that on average the arterial occlusion pressure is 235 mmHg for a 5-cm pneumatic cuff and 144 mmHg for a 13.5-cm pneumatic cuff. Therefore, it is very likely that the participants in Kim's study were exercising with a cuff pressure that far exceeded arterial occlusion pressure, which resulted in exercise-induced discomfort with blood flow restriction. In order to further investigate the discomfort that may be associated with incorrect pressures, we compared the perceptual response of a 12-cm cuff that was inflated to a pressure measured in that cuff to a 12-cm cuff that was inflated to a pressure intended for a 5-cm cuff.

Overall, in both the upper and lower body, our results indicate that discomfort was heightened in the 12-cm cuff that was inflated to a pressure measured and intended for a 5-cm cuff. However, the difference in perceptual responses are more pronounced in the lower body when compared to the upper body. The results corroborate the findings of multiple studies that assert a higher pressure will increase cardiovascular and perceptual responses.[10,40,68] Rossow's study indicated that the wide cuff, which was inflated to the same absolute pressure as a narrow cuff, resulted in greater feelings of discomfort. This is also the case in Estebe's study[80] where a 14-cm and 7-cm cuff are inflated to two different pressures, systolic pressure + 100 mmHg and loss of arterial pulse + 10 mmHg. The results indicate that ratings of pain increased in the condition with the much greater pressure (i.e. systolic pressure + 100 mmHg). The higher pressure in both studies is analogous to our Wide cuff 5-cm 40% AOP condition, where we were able to demonstrate that discomfort will be intensified if a pressure intended for a narrow cuff is inflated into a wide cuff. Furthermore, Kim's study[79] did not directly measure discomfort, but it is important to consider the reason why close to a quarter of the participants discontinued the study due to exercise-induced discomfort. The arbitrary pressure chosen by Kim et al. came from the protocol of a previous study that applied blood flow restriction using a 6-cm cuff.[81] Given that narrow cuffs occlude an artery at a much higher pressure that wide cuffs[11] and the results of the current study, it is likely that inflating the cuff to a pressure measured in a 6-cm cuff into a 16-cm cuff resulted in a blood flow restriction stimulus that was more discomforting than intended.

Our findings also revealed that the difference in repetitions between the Wide cuff 5-cm 40% AOP condition and Wide cuff 12-cm 40% AOP condition was only found in the lower body. There was not enough evidence to make an assertion that there was a difference in repetitions between these two conditions when completed in the upper body; but nonetheless, the difference is numerically greater in the lower body compared to the upper body. In the study by Dankel et al.[68], the participants performed sets of knee extension exercise with different relative arterial occlusion pressures inflated into a 10-cm cuff (40% AOP or 80% AOP). The results indicated that exercise volume decreased most notably in the condition where participants were exercising at 80% of arterial occlusion pressure. Additionally, this condition is also where the greatest feelings of discomfort were experienced following bouts of exercise to failure. Similar to our results, Dankel's work provided evidence that exercising with a higher pressure in a wide cuff will result in fewer repetitions, specifically in the lower body.

Sex Differences

Throughout blood flow restriction literature, the number of females who are included in acute and chronic research protocols is far less compared to the number of males.[7] The majority of blood flow restriction research does not state a reason for excluding females in data collection, but many studies attribute the exclusion of females to interference from the menstrual cycle.[6,59]

Instead, we took the approach of recruiting roughly an equal number of males and females to participate in the protocol to observe any sex differences.

Although our results indicate that men experienced greater discomfort when exercising with different cuff widths in the lower body, this is only true of individuals with an estimated arterial occlusion pressure. To date, an isotonic knee-extension protocol by Labarbera et al. is the only other study that has compared perceptual differences between sexes following a blood flow restriction stimulus.[70] Although males and females expressed similar amounts of quadriceps muscle pain, the results of this study reported that females experienced greater cuff pain compared to males by the end of the exercise protocol. There are a few distinctions in our protocol and the protocol of Labarbera et al. that could explain the differences in results. First, we asked our participants to rate their discomfort just prior to cuff deflation whereas the participants in Labarbera's study provided a cuff pain rating during the last moments of the exercise bout. The other major difference in the protocol is the type of cuff inflation device used. The participants in Labarbera's protocol exercised with a 5-cm KAATSU cuff placed at the most proximal portion of the lower limb, but everyone's cuff was inflated to the same absolute pressure of 180 mmHg. Prior research has shown that the width of the cuff[12] and limb circumference[18,48] are two important considerations to make when inflating a cuff to a specified pressure. Inflating a narrow cuff to the same absolute pressure, rather than a pressure made relative to the size of the cuff, could influence the cuff pain ratings. In fact, Labarbera et al. proposes the idea that a greater time spent under the blood flow restriction stimulus or the females' overall smaller thigh circumference may be plausible reasons for the differences in cuff pain ratings. Since the cuffs in our protocol were inflated to pressures made relative to the size of the cuff and the limb circumference of the participant, we can eliminate the possibility of an incorrect pressure influencing the differences in discomfort between sexes.

Despite there being no differences in discomfort between sexes in the upper body, females did complete more repetitions when exercising with the narrow and wide cuff conditions. In Labarbera's sex comparison, females completed 50% more repetitions compared to males, with and without blood flow restriction.[70] One proposed mechanism of the increased endurance in females could be attributed to differences in fatiguability between males and females.[69] Muscle fatigue, which is the steady decline in muscle power so that a contraction can no longer be sustained at a desired force output, seems to have different characteristics in males and females. In other words, it appears that women are able to withstand a longer duration of a contraction compared to men.[82,83] We can make the assertion that females were able to complete a greater number of repetitions; since muscle fatigue seems to be task-specific and both our protocol and Labarbera's protocol utilized low-load isotonic contractions.

Limitations

This series of studies is not without limitations. First, the cuff inflation system that was used to inflate the cuffs to arterial occlusion pressure could only inflate to a maximum pressure of 300 mmHg. Although this did not present itself as an issue for any of the participants in the upper body; a majority (78 out of 99) of the participants' arterial occlusion pressure with the narrow cuff was not detectable by the cuff inflation system in the lower body and had to be estimated through another method. After separating the results between individuals with a measured arterial occlusion pressure and those with an estimated arterial occlusion pressure, there was evidence to believe that the estimation method could have contributed to some of the outcomes rather than the conditioning protocol itself.

Another limitation of our study included some aspects of the discomfort rating process. The time point at which discomfort was assessed may be viewed as a limitation, since all of the participants provided a discomfort rating for both conditions immediately following the exercise bout (or the four-minute inflation period during rest), rather than *during* the exercise bout. This decision in our protocol also resulted in discomfort ratings for all of the exercise visits to be assessed at different time points. The exercise bouts on each leg were separated by a ten-minute period of rest. While this may be viewed as a limitation, the researchers reminded each of the participants of their discomfort rating from the previous exercise bout to serve as an anchor.

Additionally, the 0-100 discomfort scale, which was both visually displayed and verbally explained, was the only scale used to assess discomfort. Other studies have used multiple pain pressure thresholds in order to gauge discomfort.

CHAPTER VI: CONCLUSION

Main Findings

In conclusion, our results in the upper body indicated that there were higher ratings of discomfort following the four sets of low-load elbow flexion exercise when using the wide cuff. However, this distinction in discomfort between cuff widths did not appear in the absence of exercise. There was also a greater rating of discomfort when a 12-cm cuff was inflated to 40% of arterial occlusion pressure that was measured in a 5-cm cuff (i.e. 5-cm 40% AOP condition).

This implies that it is necessary for cuff size to be taken into account, by making the pressure relative to the cuff width, to ensure that the application of a blood flow restriction stimulus is as intended. Furthermore, the highest average number of repetitions was completed when exercising with the narrow cuff. Following the completion of Experiment Two and Experiment Three, it seemed that individuals preferred to use the condition that resulted in the least discomfort. Although there were no sex differences in discomfort following exercise in the upper body, females completed more repetitions than males when both sexes were exercising with different cuff widths. Yet, there was insufficient evidence to indicate that differences in discomfort or repetitions changed differently between sexes.

Additionally, we observed some similarities and differences in perceptual discomfort in the lower body compared to that of the upper body. There was evidence to indicate that discomfort was greatest in the narrow cuff condition compared to the wide cuff condition, but only following the four-minute rest period. It is important to interpret this finding with caution since the difference in discomfort was reported in just the individuals with an estimated arterial occlusion pressure. There were no differences in discomfort between cuff widths following exercise, but the narrow cuff condition resulted in the highest number of repetitions. Men, however, seemed to experience a greater feeling of discomfort when exercising with different cuff widths; but this finding was only evident when arterial occlusion pressure was not detectable with the cuff inflation system. Nonetheless, a large proportion of individuals claimed they would prefer to use the narrow cuff over the wide cuff despite there not being any differences in discomfort. Lastly, discomfort ratings were considerably higher when a pressure inflated into the cuff was not set relative to cuff width. The overall sample felt that a pressure intended for a narrow cuff inflated into a wide cuff was not only more discomforting, but also more difficult to complete repetitions. The greatest proportion of individuals felt that it was more preferable to exercise with the condition inflated to the correctly applied pressure.

Hypotheses

1. We hypothesized that discomfort would not differ in the absence of exercise between cuff widths in both the upper and lower body, if both cuffs were inflated to the same relative arterial occlusion pressure. Although this was supported in the upper body, there was evidence to suggest that this may not be the case in the lower body. However, this was only true of those with an estimated arterial occlusion pressure and not those whose arterial occlusion pressure was detectable by the cuff inflation system.
2. We hypothesized that discomfort would not differ following exercise between different cuff widths in both the upper and lower body, if both cuffs were inflated to the same relative arterial occlusion pressure. This was not supported in the upper

body because the 12-cm cuff appeared to elicit a greater feeling of discomfort following exercise.

3. We hypothesized that a pressure intended for a narrow cuff that was inflated into a wide cuff would elicit greater discomfort following exercise compared to a wide cuff inflated to the appropriate pressure. Our results supported this hypothesis in the upper and lower body.
4. We hypothesized that the condition that resulted in the least discomfort following exercise would be the most preferable condition. This was supported when comparing cuff widths in the upper body, but there was only minimal evidence to support that this was true in the lower body. However, this was very evident when the misapplied pressure conditions were perceived as more discomforting and less preferable in both the upper and lower body.
5. We hypothesized that there would be no differences in the way males and females perceived discomfort following use of blood flow restriction. This was supported in all interventions, except the sex comparison between cuff widths in the lower body. It appeared that males perceived greater feelings of discomfort compared to females, but only in those individuals with an estimated arterial occlusion pressure.

Significance of findings

The American College of Sports Medicine recommends completing resistance exercise two to three times per week for a number of health benefits, such as protective benefits from sarcopenia and osteoporosis. Unfortunately, many individuals do not adhere to these guidelines to receive the health benefits that can be provided from regular resistance exercise. An effort has been made to devise alternatives, such as blood flow restriction, for traditional high-load resistance exercise. Through this series of studies, we aimed to discover more about the perceptual response to blood flow restriction exercise when using different cuff widths. Our results revealed that there could possibly be differences in discomfort between the upper and lower body. This may be something for clinicians to consider when prescribing blood flow restricted exercise. A specific cuff width in the upper body may provide a certain stimulus in the upper body but may not be experienced the same way in the lower body. Despite differences in discomfort, it does seem that narrow cuffs are more preferable to use in both the upper and lower body. Moreover, we were able to provide substantial evidence that the pressure inflated into a cuff should be made relative to the cuff width itself. As our results indicate, using a certain percentage of arterial occlusion pressure is not enough to ensure a comparable blood flow restriction stimulus is being applied if the pressure is not specific to the cuff width. From a clinical perspective, this is important to consider because pressures that are utilized for narrow cuffs could elicit high feelings of discomfort if arbitrarily applied to a wide cuff.

Future Research

Using the results from this series of studies, there are a number of factors that can be considered for future protocols. First, we proposed a possible reason for the variance in perceptual discomfort following exercise in the upper and lower body to differences in muscle architecture. By performing the same protocol in muscles that differ in architecture, one could further investigate if the distinctions in discomfort can be attributed to those differences in architecture or some other factor. Secondly, the majority of protocols evaluating perceptual discomfort with blood flow restriction utilized single-joint exercises, such as elbow flexions or knee extensions. Future research could incorporate blood flow restriction in multi-joint exercises, such as squatting or bench pressing. Although it would require recruiting a sample that is skilled in performing the exercise to ensure proper form, multi-joint exercises would be representative of what much of the population incorporates in a typical workout. Finally, our results showed that there was either no evidence or insufficient evidence to indicate a difference in perceptual discomfort between sexes. Future studies should aim to not only include both males and females in sample sizes, but also analyze results separately to determine if there is any difference in discomfort between sexes.

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