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Acute Physiological and Perceptual Responses to Unilateral versus Bilateral Walking with Blood Flow Restriction

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Abstract

The use of blood flow restriction (BFR) has skyrocketed in popularity in the past few years as a therapeutic modality. Studies have shown that the application of BFR at 20-30% of maximal oxygen consumption (VO_{2max}) yields similar improvements in cardiovascular fitness, muscle mass, and strength when compared with traditional exercise at 60-90% of VO_{2max}. The substantially lower workload accompanying BFR allows for more tolerable workloads in special populations, such as those recovering from musculoskeletal injury. Because previous studies regarding BFR have mainly focused on bilateral BFR, it is unclear how unilateral BFR compares to bilateral BFR. Therefore, the purpose of this investigation was to examine the acute physiological and perceptual responses to BFR applied bilateral and unilateral during walking. Participants completed three randomized walking trials; control, bilateral BFR, and unilateral BFR. During each trial muscle excitation, tissue oxygenation, VO_2, heart rate, discomfort, and rating of perceived exertion were assessed.

Introduction

The American College of Sports Medicine (ACSM) recommends performing aerobic (endurance) exercise at an intensity between 60 to 90% of maximum heart rate in order to see significant improvements in cardiovascular fitness (1). Interestingly several recent studies have found positive improvements when utilizing a much lower intensity. These studies have used 20%-30% of maximal heart rate combined with a novel training technique called blood flow restriction (BFR) and have found significant improvements in cardiovascular fitness, as well as increases in muscle mass and strength despite the relatively low-intensity utilized (3, 6, 7, 9, 10, 13). This has led to BFR exercise garnering a great deal of attention as a safe and potentially effective alternative to high-intensity exercise (2, 4, 5, 12). Training with BFR involves decreasing blood flow, and therefore oxygen delivery, to a muscle by the application of a wrapping device, such as pressurized cuffs while performing various exercises (10, 12). While the exact mechanism(s) responsible for the observed adaptations after BFR training are unknown, several mechanisms have been proposed and include increased metabolic stress, reduced oxygen availability, and additional recruitment of high threshold motor units possibly due to the altered blood flow associated with BFR (8, 10, 11, 12).

Blood flow restriction is a training method in which external pressure is applied to a limb to partially restrict arterial inflow and fully restrict venous outflow in the distal muscle during exercise (12). Compression of the vasculature proximal to the affected muscles results in a hypoxic state due to reduced oxygen saturation and blood pooling in the surrounding capillaries (12). Previous studies conducted on BFR application during exercise have found that BFR should be applied in the range of 40-80% limb occlusion pressure (LOP) to provide a significant physiological stress while balancing participant discomfort (12).

The relatively low intensities that can be utilized with BFR have led to an interest in the use of BFR in individuals that cannot complete traditional high-intensity exercise. This can include individuals with several different musculoskeletal issues including those recovering from injuries and the elderly. Lower extremity musculoskeletal injuries most frequently occur to one leg (unilateral). Recovery from many of these injuries can result in muscle weakness in the injured limb, which can lead to a muscle imbalance between limbs. These imbalances can contribute to alterations in walking gait, which may make activities of daily living more difficult. The application of BFR to the injured limb (weaker limb) may help correct those potential muscle imbalances.

BFR application with aerobic exercise (e.g. walking, running, cycling) has been shown to elicit gains in aerobic capacity, skeletal muscle strength, and size, as well as improved functional abilities in daily living (10, 11, 12). These benefits make BFR a very effective exercise modality for the elderly population, for which most exercise and therapeutic programs focus on regaining, maintaining, and improving functional abilities for daily living. Although studies involving clinical populations are ongoing, previous studies have shown that the application of BFR does not exacerbate blood clotting factors and is safe to apply in numerous populations (2, 12).

However, current investigations that have examined walking with BFR have only examined the responses during bilateral (both legs) application of BFR. Therefore, it is unknown if the unilateral application of BFR during walking would result in similar physiological stress (e.g. heart rate) as the bilateral application of BFR. The acute physiological stress is important as the stress must be sufficient in order to cause chronic training adaptations, while remaining tolerable for participants. With the potential of BFR walking to be an effective alternative training modality, an understanding of both the physiological and perceptual responses is crucial.

Methods

Experimental Design

Participants were asked to attend 4 laboratory sessions, during the same time of day for each session. Sessions were separated by a minimum of 48 hours. All exercise was performed on a motorized treadmill (GE Marquette T2100). During the first session, the study was explained to participants, and they signed an informed consent, as well as completed a previous medical history questionnaire to determine their ability to safely participate in the exercise. Age, gender, height, weight, resting blood pressure, mid-thigh circumference, and skinfolds at the vastus lateralis and lateral gastrocnemius were then recorded. Participants were then familiarized with the BFR cuffs and walked a short duration with the BFR cuffs inflated for familiarization.

Exercise Protocols

Each participant completed three constant exercise protocols (Control (CON), Bilateral BFR (B-BFR), and Unilateral (U-BFR) BFR) in a randomized order. Each constant exercise protocol followed the same pattern consisting of a 2-minute warm-up, followed by a 15-minute working interval, and finishing with a 3-minute cooldown. The total duration of each exercise protocol was 20 minutes including warm-up, exercise, and cool down (Figure 1).

The exercise protocols are as follows:

Control (CON)- Following a 2-minute warmup at 4.0 kilometers per hour (km/h), exercise was performed for 15 minutes at a walking speed of 4.9 km/h. A 3-minute cooldown was performed at 4.0 km/h.

Bilateral BFR (B-BFR)- Following a 2-minute warmup, exercise was performed for 15 minutes at a walking speed of 4.9 km/h. A 3-minute cooldown will be performed at 4.0 km/h. The BFR cuffs were placed on both legs (as described below) and were inflated to 70% of limb occlusion pressure (LOP) and remained inflated for the entire 15 minutes of the exercise period. BFR cuffs were deflated upon completion of the 15-minute exercise period.

Unilateral BFR (U-BFR)- Followed the same protocol as bilateral BFR protocol with the exception that only one leg had BFR applied to it. The BFR cuff was only applied to each participant's dominant leg and was inflated to 70% of LOP.

Following the completion of each exercise protocol, participants laid down in a supine position on the bed for 3 minutes, then the BFR cuff was inflated on their dominant leg to 110% LOP for 5 minutes to achieve a maximal oxygen desaturation of the local muscle tissues. This period was immediately followed by a 2-minute maximal re-saturation period after the pressure was released, allowing oxygen-rich blood to flow to the local tissues.

BFR Application

BFR involves decreasing the blood flow to a muscle by the application of a wrapping device, such as a pressurized cuff while performing various exercises. To determine the blood flow restriction pressure for each participant, participants stood on both legs on the treadmill and a cuff (Hokanson, SC12LD, Bellevue, WA, 12.0 cm width) was placed around the proximal portion of their thigh. The popliteal artery pulse was identified using Doppler auscultation (Figure 2). Then the thigh cuff was progressively inflated until the pulse was eliminated (i.e. no longer heard via the Doppler). The pressure associated with the cessation of the pulse was taken as the limb occlusion pressure (LOP). Prior to all exercise protocols, an occlusion cuff (Hokanson, SC12LD, Bellevue, WA, 12.0 cm width) was placed proximally on both legs and inflated to each participants' custom pressure (70% LOP).

Blood flow restriction (BFR) exercise techniques have been recently used considerably in the literature with minimal risk to the subject. Previous literature has indicated that subjects that partake in BFR exercise may experience minimal muscle soreness/discomfort (as seen with regular moderately-intense exercise), with no reported long-term adverse effects. In addition, previous investigations have examined the effect of BFR exercise on blood coagulation and nerve conduction and have not reported any negative effects.

Tissue Oxygenation

Local tissue oxygenation was recorded throughout for all conditions using Near-Infrared Spectroscopy (NIRS) sensors placed at the vastus lateralis and the lateral gastrocnemius (Figure 3). A continuous-wave, wireless NIRS (Moxy Muscle Oxygen Monitor, Fortiori Design, LLC, Hutchinson, Minnesota, USA) was used to monitor tissue oxygen saturation (measured in arbitrary units, AU) responses at wavelengths of 680, 720, 760, and 800 nanometers. Before placement of the NIRS sensor, the skin was shaved and cleansed with an alcohol pad. The NIRS sensor was positioned midway between the anterior superior iliac spine and the superior border of the patella over the muscle belly of the vastus lateralis. The NIRS sensor was covered with a shield, to prevent stray visible light sources from affecting the data collection.

Perceptual Responses

A rating of perceived exertion scale (RPE) was used to assess perceived exertion. This was done using a Borg scale (6-20 scale), for which participants were instructed to rate the intensity of their effort and coached to integrate sensation of pain and effort into a single overall rating based on the perception of the tolerability of the exercise. In addition, participants were asked to rate their discomfort during each exercise protocol using the Borg discomfort scale (CR-10+).

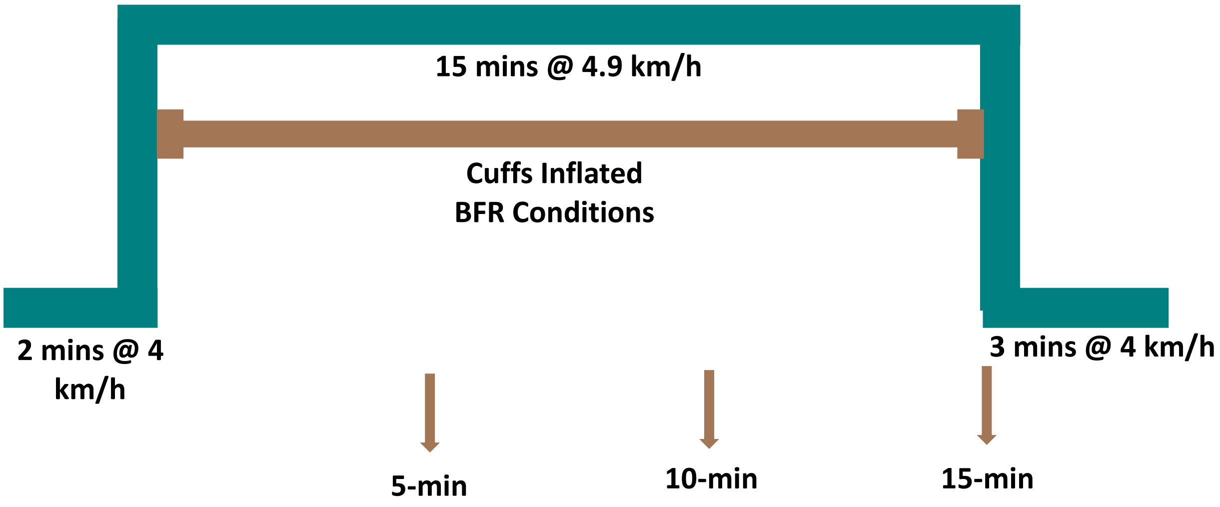

Figure 1. Exercise Protocols- Control (CON), Bilateral BFR (B-BFR), Unilateral BFR (U-BFR). Data were analyzed at minutes 5, 10, and 15 of exercise for each condition.

Figure 2. BFR cuffs (Occlusion Cuffs©) and Doppler (MD6)

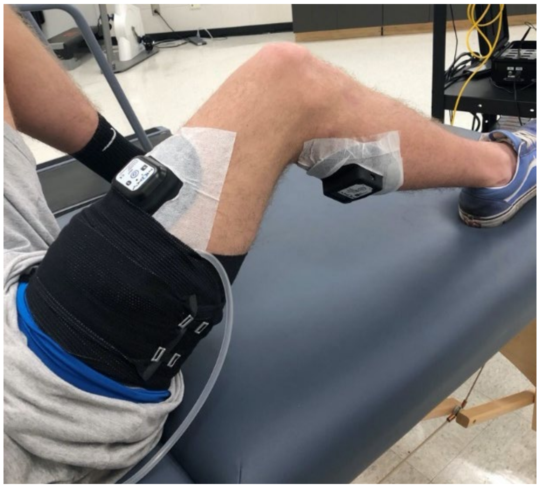

Figure 3. Cuff and NIRS placements

Statistical Analysis

A two-way (trial [B-BFR, U-BFR, CON] by time [5-min, 10-min, 15-min]) repeated measures ANOVA was used to compare StO2, VO2, HR, RPE, and discomfort between trials. Subsequent Bonferroni pairwise post-hoc comparisons were made when necessary. Statistical significance was established if $p \leq 0.05$.

Results

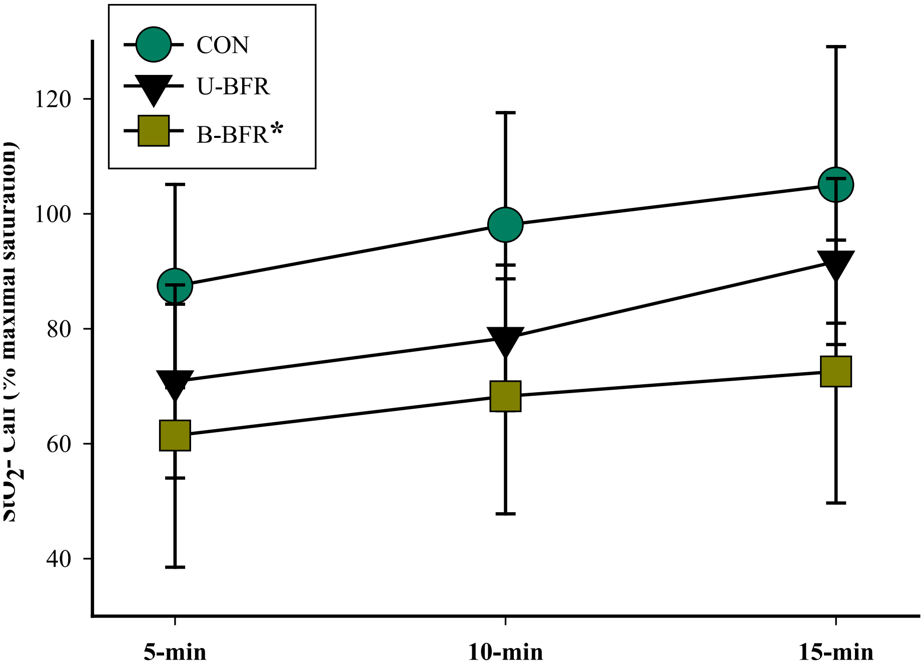

Figure 4. Tissue oxygenation in the dominant calf. Bilateral BFR was found to result in significantly lower levels of tissue oxygenation in the dominant leg's calf muscle when compared to the control protocol. (* - significantly different from CON)

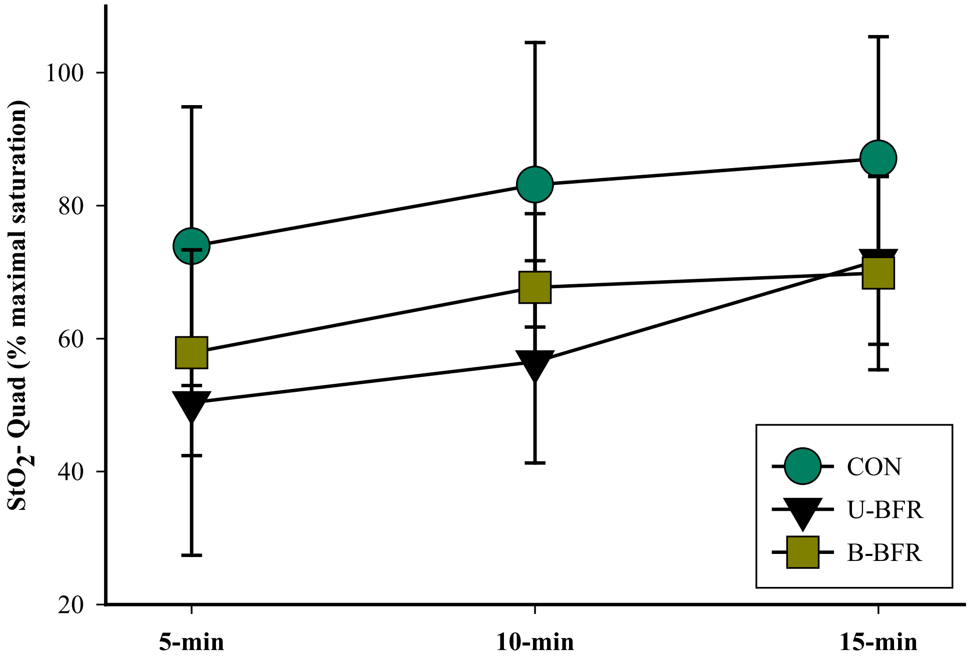

Figure 5. Tissue oxygenation (StO$_2$) in the dominant leg's quad. There were no statistically significant tissue oxygenation differences found when comparing conditions at the dominant leg's quad.

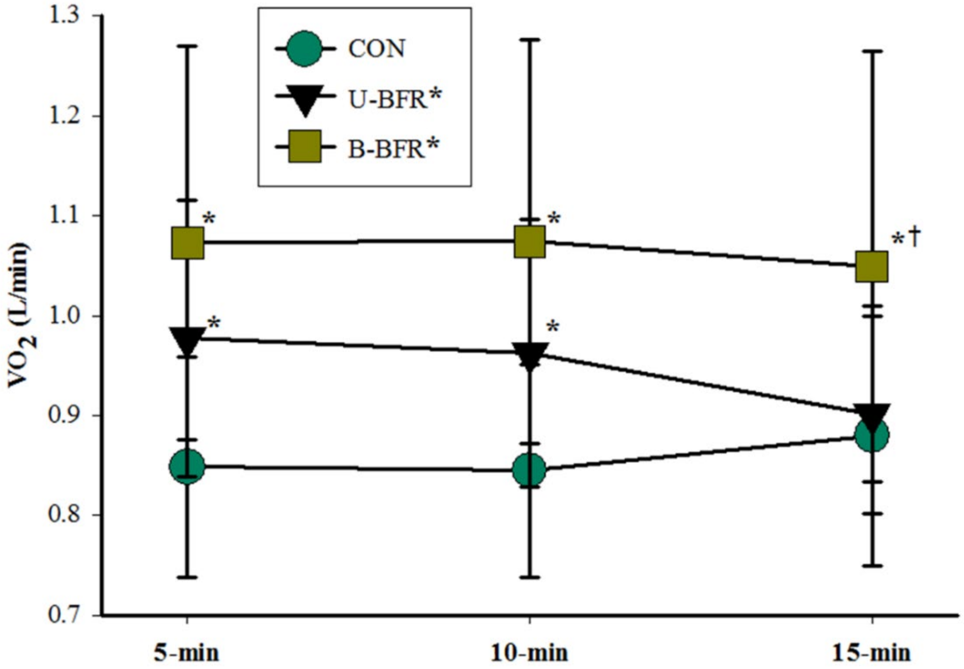

Figure 6. The volume of oxygen consumed (VO_2). Both unilateral and bilateral BFR were found to have statistically significant effects on VO_2 when compared with the control condition. (* - significantly different from CON, †- significantly different from U-BFR)

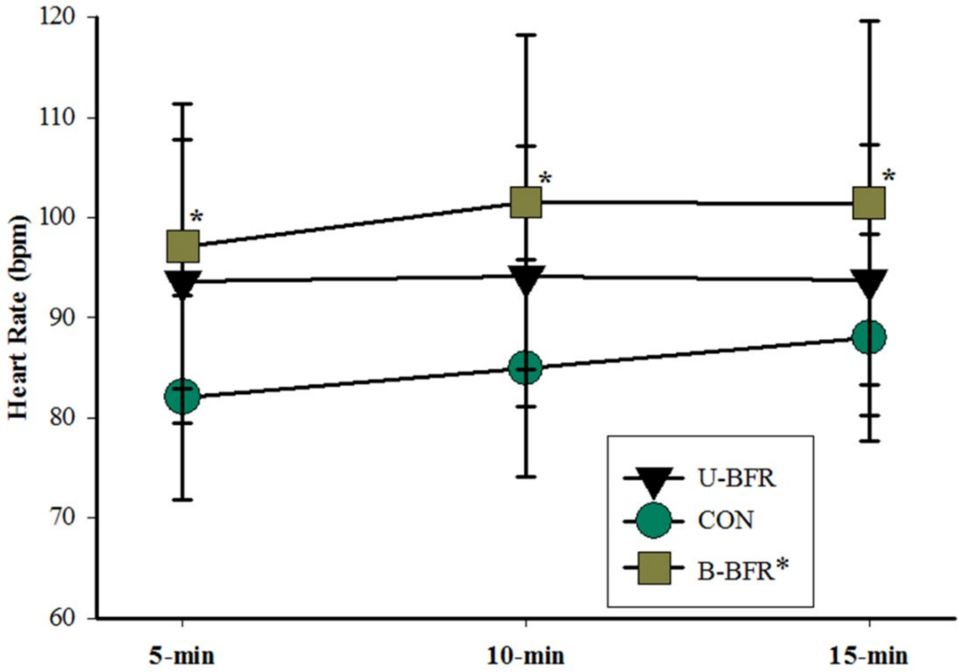

Figure 6. Heart rate. Bilateral BFR was found to have a statistically significant effect on heart rate when compared with the control condition. (* - significantly different from CON)

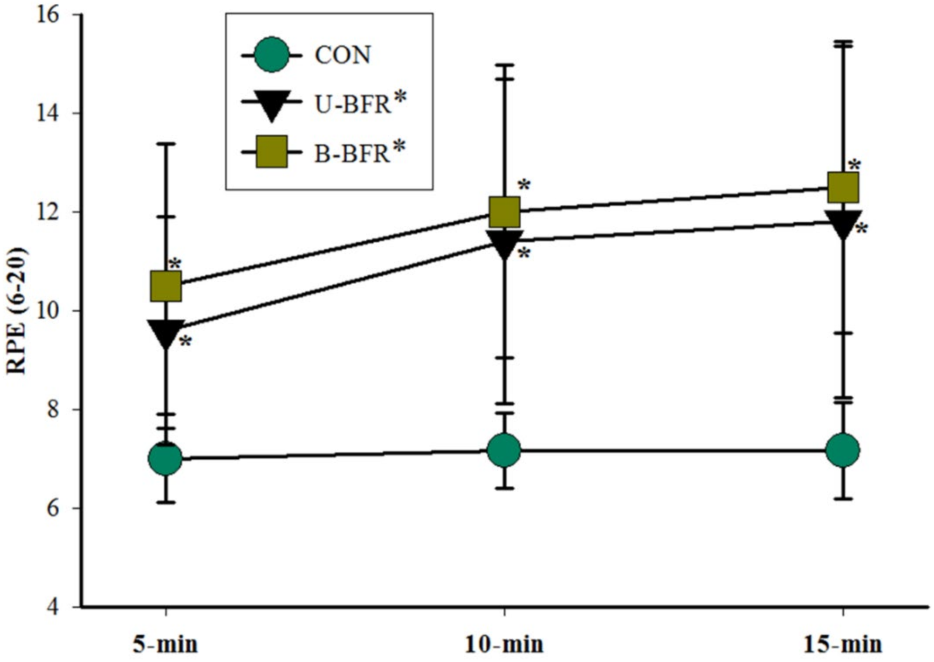

Figure 8. Rating of Perceived Exertion (RPE). Both unilateral and bilateral BFR were found to yield significant differences in the measure of RPE when compared with the control condition. (* - significantly different from CON)

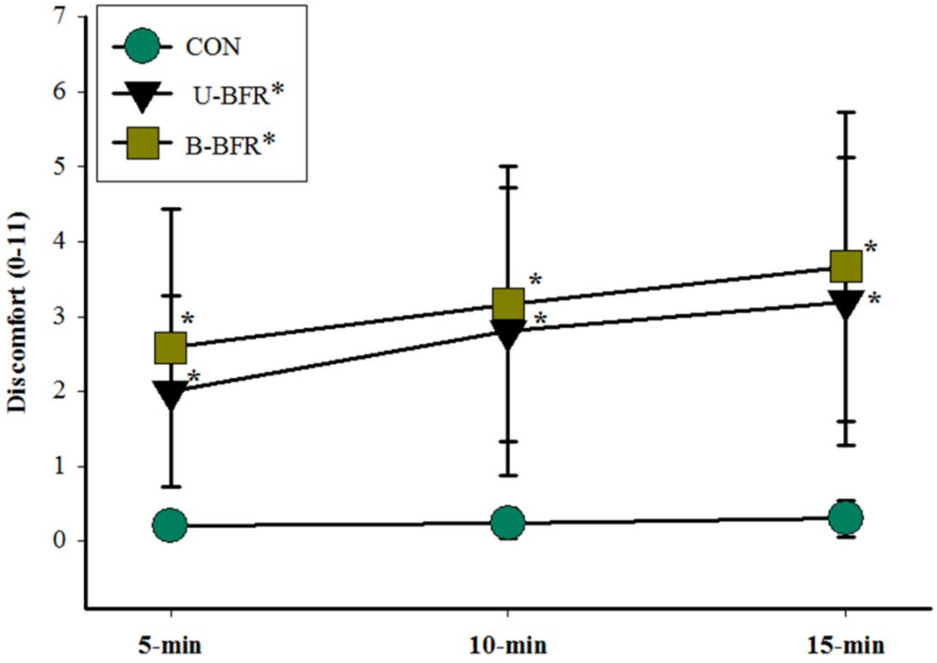

Figure 9. Discomfort. Both unilateral and bilateral BFR were found to yield significant differences in the measure of discomfort when compared with the control condition. (* - significantly different from CON)

Discussion

Our results demonstrate that either unilateral or bilateral BFR may be utilized during walking to provide an increased physiological stress (StO_2, VO_2, HR) with similar effects on discomfort and rating of perceived exertion.

The greater volume of oxygen consumed (VO_2) during the bilateral BFR protocol compared to the control protocol may have been due to decreased economy of movement and an increase in muscle fiber recruitment. The economy of effort may have decreased with the application of bilateral BFR when compared with the control protocol as gait patterns may be altered leading to increases in energy demand during walking, and therefore a higher VO_2. These altered gait patterns may have included increased hip abduction/adduction or increased arm swing during walking. However, these potential biomechanical changes were not assessed in the current investigation and warrant further consideration. The application of BFR resulted in a greater hypoxic environment at the muscle, as evident from the StO_2 changes observed in the current investigation. This increased hypoxic environment may have increased the local metabolic stress and resulted in increased neuromuscular fatigue. This increased fatigue may have resulted in an increase in motor unit recruitment in order to maintain the necessary force. This additional motor unit recruitment would result in the additional activation of muscle fibers which would result in an increased VO_2, as the VO_2 is a measure of whole-body oxygen consumption.

Heart rate was significantly higher during the bilateral BFR protocol than the control protocol due to the restricted venous return associated with blood flow restriction training. Venous return is the amount of blood returning to the heart. A decrease in venous return can result in a lower stroke volume, which is the amount of blood ejected from the heart with each heartbeat. As stroke volume decreases, the heart rate must increase to maintain cardiac output, which is the amount of blood pumped per minute. Cardiac output has to be maintained in order to meet the demand of the exercise, therefore, as venous return falls, heart rate rises inversely. Heart rate was not significantly higher during unilateral BFR than the control protocol because although venous return may have been reduced by applying BFR to one leg, it may not have been reduced to the same degree as in the B-BFR condition. Therefore, a smaller change in stroke volume may have occurred, and heart rate did not need to increase to the same degree in order to maintain cardiac output.

The local tissue oxygen saturation at the calf was significantly lower for the bilateral BFR condition in comparison to the control condition. This could have resulted from the reduction in arterial inflow caused by the application of the BFR cuffs. This would prevent the oxygen-bound hemoglobin from entering the capillaries that supply oxygen to the muscle. During continuous steady-state exercise (exercise intensity stays the same) the demand for oxygen at the muscle stays the same. However, if exercise intensity increases the oxygen demand increases, which during normal conditions (control in this study) results in increased blood flow to provide more oxygen to meet the new demand. The application of BFR however prevents the normal supply of blood that would meet the oxygen demand at the muscle. Therefore, in the current investigation as the oxygen demand was not met by the oxygen supply during the BFR conditions the muscle oxygen saturation decreased during exercise.

In conclusion, the current results of this investigation suggest that either unilateral or bilateral BFR can be utilized during walking to provide an increased physiological stress with similar effects on discomfort and rating of perceived exertion. Future investigations should examine the long-term training adaptations that may occur from either unilateral or bilateral walking with BFR.

References

1. Thompson WR, Gordon NF, Pescatello LS (2010) ACSM's guidelines for exercise testing and prescription. 8th edn. Lippincott Williams & Wilkins, Philadelphia
2. Clark BC, Manini TM, Hoffman RL, Williams PS, Guiler MK, Knutson MJ, McGlynn ML, and Kushnick MR. Relative safety of 4 weeks of blood flow-restricted resistance exercise in young, healthy adults. *Scandinavian journal of medicine & science in sports* 21: 653-662, 2011.
3. Corvino RB, Rossiter HB, Loch T, Martins JC, and Caputo F. Physiological responses to interval endurance exercise at different levels of blood flow restriction. *Eur J Appl Physiol* 117: 39-52, 2017.
4. Loenneke JP, Wilson JM, Wilson GJ, Pujol TJ, and Bemben MG. Potential safety issues with blood flow restriction training. *Scandinavian journal of medicine & science in sports* 21: 510-518, 2011.
5. Nakajima T, Iida H, Kurano M, Takano H, Morita T, Meguro K, Sato Y, Yamazaki Y, Kawashima S, Ohshima H, Tachibana S, Ishii N, and Abe T. Hemodynamic responses to simulated weightlessness of 24-h head-down bed rest and KAATSU blood flow restriction. *Eur J Appl Physiol* 104: 727-737, 2008.
6. Abe, T., et al., Effects of Low-Intensity Cycle Training with Restricted Leg Blood Flow on Thigh Muscle Volume and VO2MAX in Young Men. J Sports Sci Med, 2010. 9(3): p. 452-8.
7. Park, S., et al., Increase in maximal oxygen uptake following 2-week walk training with blood flow occlusion in athletes. Eur J Appl Physiol, 2010. 109(4): p. 591-600.

8. Lauver, J.D., et al., The effect of eccentric exercise with blood flow restriction on neuromuscular activation, microvascular oxygenation, and the repeated bout effect. Eur J Appl Physiol, 2017. 117(5): p. 1005-1015.
9. Abe, T., et al., Effects of low-intensity walk training with restricted leg blood flow on muscle strength and aerobic capacity in older adults. J Geriatr Phys Ther, 2010. 33(1): p. 34-40.
10. Scott, B.R., et al., Exercise with blood flow restriction: an updated evidence-based approach for enhanced muscular development. Sports Med, 2015. 45(3): p. 313-25.
11. Pearson SJ and Hussain SR. A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. Sports medicine 45: 187-200, 2015.
12. Patterson SD, Hughes L, Warmington S, Burr J, Scott BR, Owens J, Abe T, Nielsen JL, Libardi CA, Laurentino G, Neto GR, Brandner C, Martin-Hernandez J and Loenneke J (2019) Blood Flow Restriction Exercise: Considerations of Methodology, Application, and Safety. Front. Physiol. 10:533. doi: 10.3389/fphys.2019.00533
13. Ozaki, H., Sakamaki, M., Yasuda, T., Fujita, S., Ogasawara, R., Sugaya, M., . . . Abe, T. (2010). Increases in thigh muscle volume and strength by walk training with leg blood flow reduction in older participants. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 66A*(3), 257-263. doi:10.1093/gerona/glq182