Hemodynamic and Pressor Responses to Combination of Yoga and Blood Flow Restriction

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Running title: Yoga and BFR

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Abstract

Blood flow restriction (BFR) training has been incorporated into a more common activity of daily exercise (e.g., yoga) in recent years. A combination of yoga and BFR, each of which elicits marked pressor responses by augmenting vascular resistance and/or skeletal muscle chemoreflex, may further increase blood pressure and myocardial oxygen demand. **Purpose:** To determine the impact of a combination of yoga and BFR on hemodynamic responses. **Methods:** Twenty young healthy participants performed 20 yoga poses with and without BFR bands placed on both legs. **Results:** At baseline, there were no significant differences in any of the variables between the BFR and non-BFR conditions. Systolic and diastolic blood pressure and heart rate increased in response to the various yoga poses ($p<0.01$) but were not different between the BFR and non-BFR conditions. In general, hemodynamic responses were more pronounced during more difficult yoga. Rate-pressure products, an index of myocardial oxygen demand, increased significantly during yoga exercises with no significant differences between the two conditions. Rating of perceived exertion (RPE) was not different between the conditions. Blood lactate concentration was significantly greater after performing yoga with BFR bands ($p=0.007$). Cardio-ankle vascular index, an index of arterial stiffness, decreased similarly after yoga exercise in both conditions while flow-mediated dilation remained unchanged. **Conclusion:** The use of blood flow restriction bands in combination with yoga did not result in additive or synergistic hemodynamic and pressor responses.

Keywords: exaggerated blood pressure response, isometric exercise, ischemia, endothelial function

Introduction

Blood flow restriction training (BFR) is a cutting-edge training modality that works by placing blood flow restriction bands (or cuffs) on the proximal portion of the extremities (1). A pressurized air pump is then used to restrict venous outflow from the skeletal muscle while maintaining arterial inflow (2). Once blood flow of the skeletal muscle is sufficiently restricted, the combination of BFR and light exercise can produce exercise adaptations similar to high-intensity exercise training (3, 4). As such, this exercise modality has important implications for time sensitive physiological improvements in populations who often cannot exercise at high intensity (5). There has been a growing interest in BFR as an auxiliary or complementary exercise (6), and BFR has been incorporated into a variety of exercise situations including walking, swimming, and yoga (6, 7).

Blood flow restriction is known to elicit an exaggerated exercise-pressor response, increases in myocardial oxygen demand, and post-exercise reduction in endothelial function (2, 7). This exaggerated blood pressure response is attributed to the artificial elevation in vascular resistance as well as the accumulation of metabolic byproducts, which induce exercise pressor response via chemoreflex stimulation (2). As BFR has been increasingly incorporated into a more common exercise (e.g., yoga), it is important to evaluate the potential hemodynamic effects when BFR was added to different exercise modalities. In this context, the combination of BFR and yoga warrants a particular concern. Yoga is a modality of exercise characterized by systemic isometric muscle contractions that are accompanied by marked pressor responses (8) and known to produce greater elevations in mean arterial pressure than dynamic exercise (9).

Given that BFR and yoga independently elicit a marked exercise pressor response, we determined the impact of a combination of yoga and BFR on pressor and hemodynamic responses.

We hypothesized that the use of BFR during yoga will elicit marked elevations in blood pressure and myocardial oxygen demand as well as reductions in endothelial function.

Methods

Participants

A total of 20 young, apparently healthy adults between the ages of 18 and 35 participated in this study (Table 1). Exclusion criteria included 1) smoking within the past 6 months; 2) uncontrolled hypertension; 3) a history of heart disease, peripheral artery disease, kidney disease, or other known cardiovascular problems; 4) a history of diabetes, gout, or other metabolic disease; 5) obesity, defined as a body mass index (BMI) >30 kg/m^2; 6) major surgeries or changes in health within the last 6 months; 7) have been told by physicians to refrain from exercise; and 8) vulnerable populations (pregnant women, children, unable to consent, etc.). The Institutional Review Board reviewed and approved this study, and all participants provided written informed consent. The study was registered in the Clinicaltrials.gov (NCT03540147).

Protocols

Participants visited the laboratory on 2 separate occasions for 2 hours per visit. During the first visit, anthropometric measures of height, body weight, and body fatness were taken. Body fatness was estimated by using the 7-site skinfold technique with Lange skinfold calipers (Beta Technology, Santa Cruz, CA). Prior to all visits, participants fasted for a minimum of 4 hours, abstained from alcohol and caffeine for the previous 12 hours, and from strenuous physical activity for the previous 24 hours. After 20 minutes of supine rest, baseline measurements consisting of blood pressure, heart rate, blood lactate, endothelial function, and arterial stiffness were taken.

After baseline measurements, a randomized crossover study design was implemented, where participants acted as their own control and performed 21 yoga poses with blood flow restriction bands (BFR) and without (non-BFR) bands placed on the upper thighs (BStrong^{Tm}, Park City, Utah). The 21 yoga poses were; 1) Baseline, standing at anatomical neutral, 2) Warrior I, 3) Warrior II, 4) Reversed warrior, 5) Extended side angle, 6) Forward fold, 7) Halfway lift, 8) High plank, 9) Up dog, 10) Down dog, 11) Wide-legged forward fold, 12) Goddess, 13) Crescent lunge, 14) Half moon, 15) Chair pose, 16) Mountain pose, 17) Camel, 18) Easy pose, 19) Bridge pose, 20) Happy baby, and 21) Savasana. The order of these sessions, with and without bands, were randomized between the visits. Each testing session was separated by at least 2-3 days to control for potential fatigue or training effects. All yoga sessions were led by a certified yoga instructor. Blood pressure was measured continuously throughout the session using beat-by-beat, finger plethysmography (Portapress Finger Plethysmograph, Finapres Medical Systems BV, Amsterdam, Netherlands) as previously described (Miles et al. 2013). Participants were asked to keep the hand with the finger plethysmography at heart level during the entire exercise session. Double products or rate pressure products were calculated by systolic blood pressure and heart rate. Additionally, participants gave a rating of perceived exertion (RPE: the original Borg Scale) that corresponded to the perceived difficultly of the exercise task. Measurements were repeated immediately post yoga performance.

<u>Measurements</u>

Arterial stiffness was measured noninvasively using the cardio-ankle vascular index (CAVI) (Vasera, VS-1500AU, Fukuda Denshi Co., Ltd, Tokyo, Japan) as previously described (10). Blood pressure cuffs were placed on all 4 limbs for the measurements of blood pressure and arterial stiffness. CAVI score was calculated from the distance divided by transit time (the time delay between the two "foot" waveforms).

Endothelial function was measured via flow-mediated dilation (FMD) technique (11) by measuring the brachial artery's diameter increase following a brief period of occlusion using an automated diagnostic ultrasound system (UNEXEF-38G, UNEX Corp., Nagoya, Japan). After the acquisition of baseline diameter measurement of the brachial artery, the cuff was inflated to 50 mmHg above resting systolic blood pressure for 5 minutes to occlude blood flow. After 5 minutes of occlusion, the cuff was deflated, and ultrasound-derived measurements of the brachial artery diameters were recorded for 2 minutes. FMD was measured additionally at 1-hour post exercise to evaluate residual hemodynamic effects. FMD was calculated as a percent increase in brachial artery diameter at the post-blood flow occlusion compared with the pre-blood flow occlusion (11).

Blood samples were taken using standard aseptic techniques; sterilizing the finger with an alcohol swab, followed by pricking a finger with a lancet and taking a 0.3 µL sample volume of blood. The blood sample is collected onto a testing strip that is inserted into a blood lactate meter (Blood Lactate Pro, Arkray; Kyoto, Japan).

Statistical Analyses

Two-way ANOVA with repeated measures was used to identify significant differences in hemodynamic variables during the yoga exercise. Independent t-test was used to compare blood lactate concentrations between BFR and non-BFR groups. Significance was set at $p<0.05$, and the data were reported as mean±SD.

Results

Table 1 presents selected characteristics of the study participants. The participants were young, normotensive, and apparently healthy.

There were no significant differences in baseline measures between the BFR and non-BFR conditions. Compared with the baseline, systolic blood pressure was significantly elevated in all yoga poses ($p<0.01$) (Figure 1). Mean and diastolic blood pressure were also significantly elevated in most yoga poses. There were no significant differences in any of blood pressure between non-BFR and BFR conditions. As shown in Figure 2, heart rate and double product increased significantly during yoga practices but no differences were found between the two conditions ($p=0.542$). In general, most hemodynamic responses were more pronounced during more difficult yoga postures.

Rating of perceived exertion (RPE) was significantly greater throughout yoga practices than at baseline ($p< 0.01$). RPE was not significantly different between the non-BFR and BFR conditions ($p=0.404$) (Figure 3). Blood lactate concentration increased significantly for both conditions after exercise ($p<0.01$) (Figure 4). However, the increase in blood lactate concentration was significantly greater after performing yoga with BFR bands ($p=0.007$).

A measure of arterial stiffness, CAVI, decreased significantly and similarly after yoga practices in both conditions ($p<0.01$) (Figure 5). However, there were no differences in CAVI values between the BFR and non-BFR conditions. Flow-mediated dilation remained unchanged throughout the experimental protocol for both groups ($p=0.877$) (Figure 6). There were no significant differences between sexes for any of the hemodynamic variables of interest; systolic blood pressure ($p=0.568$), diastolic blood pressure ($p=0.757$), heart rate ($p=0.58$), or mean arterial pressure ($p=0.710$).

Discussion

The present study investigated the hemodynamic responses induced by combining BFR and yoga exercise. We found that there were no further elevations in arterial blood pressure and myocardial oxygen demand when BFR was added to yoga practices. These results suggest that

BFR can be added to yoga without inducing exaggerated pressor and myocardial responses in young healthy adults.

Yoga postures consist of systemic isometric contractions that are known to elicit marked increases in mean blood pressure that are not observed during dynamic exercise (8). Hemodynamic responses were more pronounced during more difficult yoga postures (e.g., Crescent lunge, Half moon, Chair pose, and Downward facing dog). Furthermore, myocardial oxygen demand as assessed by double product, also known as rate pressure product, were not elevated further with the application of BFR and were found to be intermediate during exercise. These results are consistent with the notion that BFR can be safely combined with yoga in healthy populations.

The application of BFR on limbs could impair endothelial function presumably via ischemia-reperfusion injury upon cuff release. Indeed this has been reported in acute BFR exercise studies using adapted blood pressure cuffs, which are rigid and may elicit different effects on the vaculature (7), although this is not a consistent finding (12). In the present study using yoga, we found that endothelial function as assessed by FMD did not change throughout the experimental periods and was not different between the conditions. Similarly, a measure of arterial stiffness, CAVI, was not different between the conditions although CAVI decreased for both BFR and non-BFR conditions after an acute bout of yoga. In addition to whole-body isometric contractions, yoga consists of a unique combination of stretching exercises and relaxation techniques. Stretching exercise intervention has been associated with arterial destiffening (13), and flexibility is associated with arterial stiffness (14). Additionally, relaxation could lead to reductions in arterial stiffness and improvements in endothelium-dependent vasodilation via decreased sympathetic vasoconstrictor tones.

One of the proposed mechanisms of BFR for augmenting muscle hypertrophy is the greater production of ~~lactic acid~~lactate and other metabolites that stimulate the release of growth hormone,~~e and~~ insulin-like growth factors, and protein synthesis (15). Blood lactate concentration was significantly greater after yoga with BFR. Greater concentrations of blood lactate have been observed in a number of previous BFR exercise studies (4, 16-18). Our findings indicate that BFR can be applied to yoga while avoiding unfavorable hemodynamic responses and preserving the intended effects on muscle hypertrophy.

An application of BFR during walking exercises has been associated with greater RPE (2, 7, 19). In the present study using yoga, there was no significant difference between the conditions in reported RPE throughout the exercise duration. One potential explanation is the use of different kinds of BFR cuffs. A number of BFR cuffs made up of various materials and widths have been used in the literature such as elastic knee wraps (20), elastic belts with a pneumatic bag inside (21), nylon pneumatic cuffs (22), or a traditional nylon blood pressure cuff (23). The type of blood flow restriction cuff has the potential to impact the degree of exaggerated blood pressure response. In previous studies using walking exercises (2, 7, 19), non-elastic wide rigid BFR cuffs (e.g., Hokanson) were used. However, pneumatically-controlled, narrow elastic BFR bands (e.g., original Kaatsu, B-strong) were used in the present study. Narrow elastic bands~~-~~ allow for muscle expansion during contraction which enables blood to flow past the site of venous occlusion~~ block~~ whereas non-elastic wide rigid cuffs ~~constantly~~ compress the working muscle resulting in partial ~~which facilitates~~ arterial occlusion and ~~can cause~~ a variable rise in blood pressure responses (2, 24).

This study contained a number of limitations. Hemodynamic responses to exercise may vary between demographics and clinical diseases such as older hypertensive adults. The lack of significant difference between BFR and non-BFR conditions may be due to the young and healthy nature of the participants used in the present study. Stroke volume, cardiac output, and total peripheral resistance were not obtained in this study. However, total peripheral resistance may not have been significantly different between the two conditions which may explain the lack of significant difference in hemodynamic responses.

Conclusion

The use of blood flow restriction bands in combination with systemic isometric exercise like yoga did not result in marked hemodynamic and pressor responses in young healthy normotensive adults.

Acknowledgements

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Conflict of Interest

A conflict of interest was declared by Sten Stray-Gundersen, who is presently employed by BStrong[Tm], Park City, Utah. For the remaining authors, none were declared. The results of the present study do not constitute endorsement by ACSM. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

Commented [s1]: I am technically not employed, but am related to the owner of the company. I am not sure how we should re-word this section.

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Figure Legends

Figure 1. Changes in arterial blood pressure during yoga poses with blood flow restriction (BFR) or without (non-BFR). Yoga poses were 1) Baseline, standing at anatomical neutral, 2) Warrior I, 3) Warrior II, 4) Reversed warrior, 5) Extended side angle, 6) Forward fold, 7) Halfway lift, 8) High plank, 9) Up dog, 10) Down dog, 11) Wide-legged forward fold, 12) Goddess, 13) Crescent lunge, 14) Half moon, 15) Chair pose, 16) Mountain pose, 17) Camel, 18) Easy pose, 19) Bridge pose, 20) Happy baby, and 21) Savasana. Systolic blood pressure was elevated above baseline in all yoga poses ($p<0.01$). Mean and diastolic blood pressure were elevated in all yoga poses except for poses 2 and 16 for mean blood pressure and poses 2, 16, 18, 20 and 21 for diastolic blood pressure ($p<0.01$). Data are means±SD.

Figure 2. Changes in heart rate and double products during yoga poses with blood flow restriction (BFR) or without (non-BFR). Yoga Poses were 1) Baseline, standing at anatomical neutral, 2) Warrior I, 3) Warrior II, 4) Reversed warrior, 5) Extended side angle, 6) Forward fold, 7) Halfway lift, 8) High plank, 9) Up dog, 10) Down dog, 11) Wide-legged forward fold, 12) Goddess, 13) Crescent lunge, 14) Half moon, 15) Chair pose, 16) Mountain pose, 17) Camel, 18) Easy pose, 19) Bridge pose, 20) Happy baby, and 21) Savasana. All values were significantly elevated ($p<0.05$) from baseline except for poses 6, 7, 19, 20, and 21. Data are means±SD.

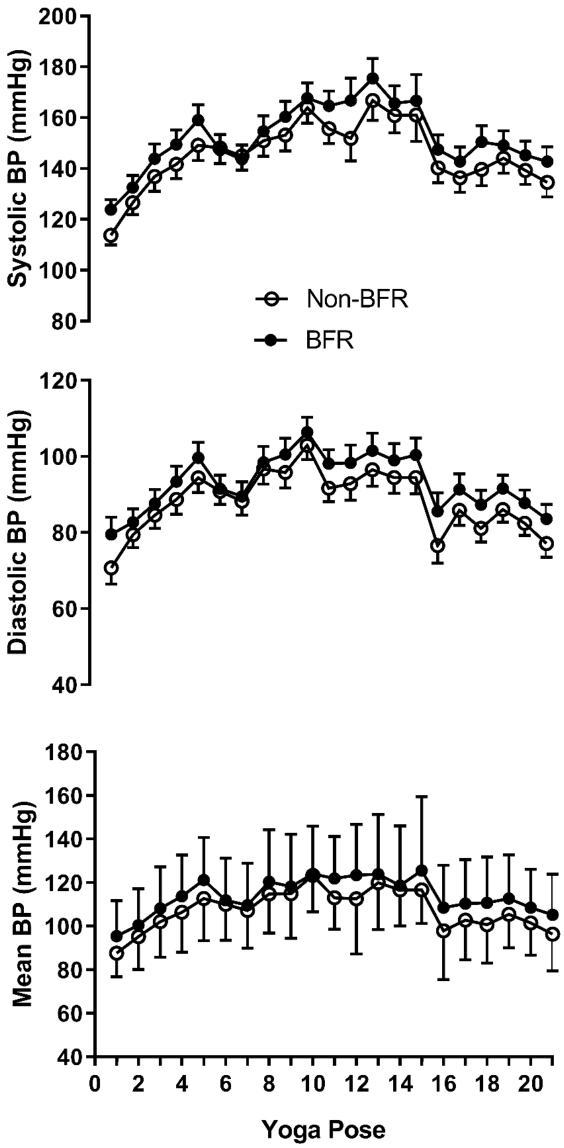
Figure 3. Rating of perceived exertion (RPE) during yoga exercise with blood flow restriction (BFR) or without (non-BFR). Data are means±SD. * $p<0.01$ vs. Baseline.

Figure 4. Blood lactate concentrations before and after yoga exercises with blood flow restriction (BFR) and without (non-BFR). * $p<0.01$ vs. Pre, † $p<0.01$ vs. non-BFR. Data are means±SD.

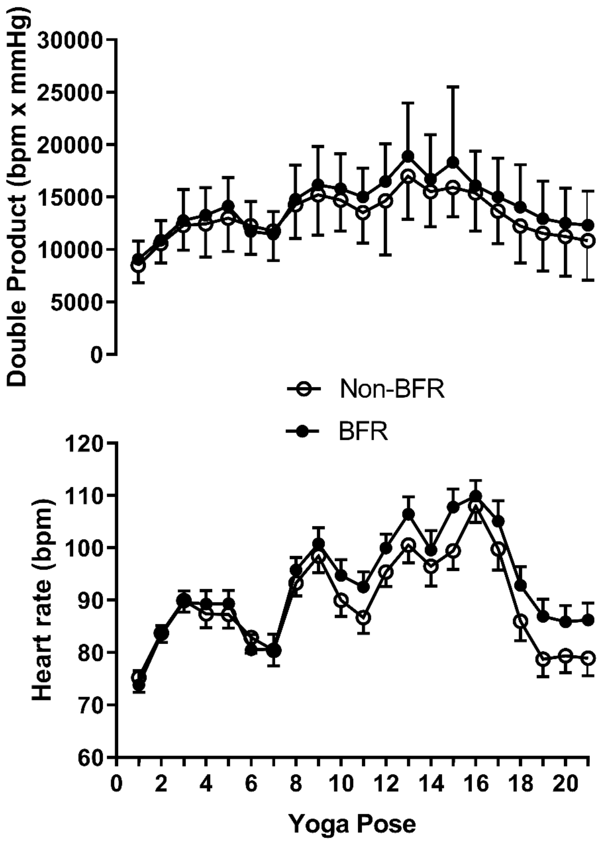
Figure 5. Cardio-ankle vascular index (CAVI), an index of arterial stiffness, and flow-mediated dilation (FMD), an index of endothelium-mediated vasodilation, before and after yoga exercises with blood flow restriction (BFR) and without (non-BFR). * $p<0.05$ vs Pre. Data are means±SD.

Table 1. Selected Participant Characteristics

Variable	**Mean ± SD**
Men/Women (n)	10/10
Age (years)	23 ± 4
Height (cm)	173 ± 10
Body Weight (kg)	71 ± 10
BMI (kg/m^2)	23.7 ± 4.2
Systolic Blood Pressure (mmHg)	117 ± 7
Diastolic Blood Pressure (mmHg)	68 ± 7
Heart Rate (bpm)	60 ± 9
CAVI (AU)	5.4 ±0.1
FMD (%)	7.17 ± 2.64


Systolic BP (mmHg)
200
180
160
140
120
100
80
Non-BFR
BFR
Diastolic BP (mmHg)
120
100
80
60
40
Mean BP (mmHg)
180
160
140
120
100
80
60
40
0 2 4 6 8 10 12 14 16 18 20
Yoga Pose

311 Figure 1



Double Product (bpm x mmHg)
30000
25000
20000
15000
10000
5000
0
Non-BFR
BFR
Heart rate (bpm)
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20
Yoga Pose

312 Figure 2

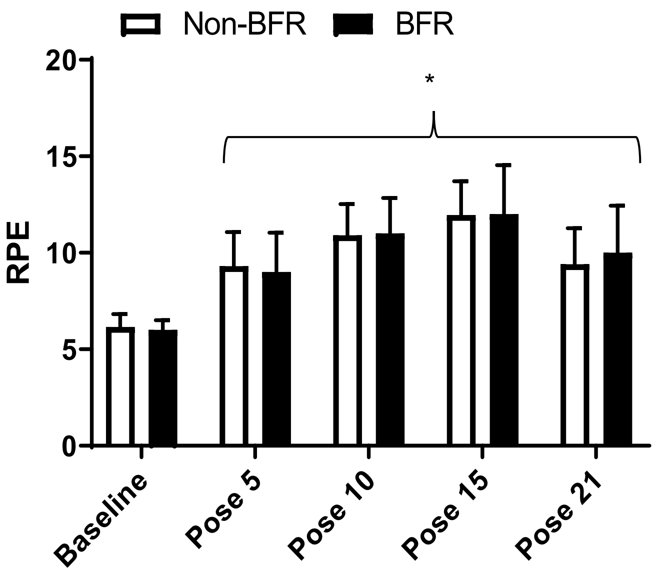
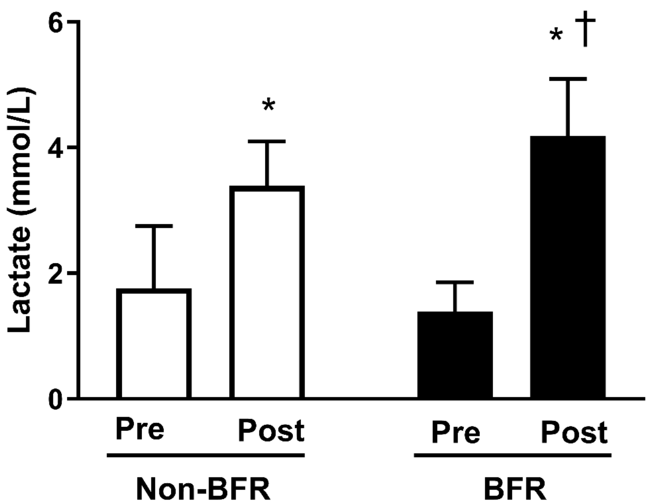
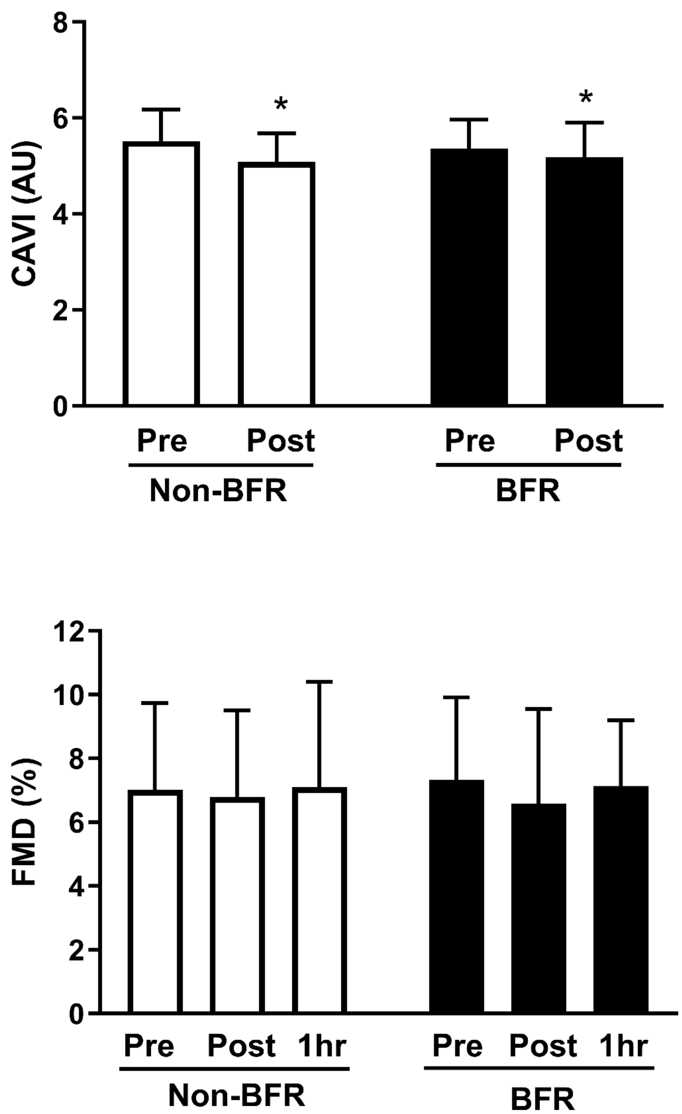

Non-BFR
BFR
RPE
20
15
10
5
0
*
Baseline
Pose 5
Pose 10
Pose 15
Pose 21

Figure 3



315 Figure 4



CAVI (AU)
8
6
4
2
0
*
*
Pre
Post
Non-BFR
Pre
Post
BFR
FMD (%)
12
10
8
6
4
2
0
Pre
Post
1hr
Non-BFR
Pre
Post
1hr
BFR

316 Figure 5