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The Effect of Muscle Blood Flow Restriction During Dynamic Exercise on Carotid Baroreflex Sensitivity

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Abstract

Background/Objectives: This study evaluated carotid baroreflex sensitivity (cBRS) during graded exercise tests to exhaustion in healthy individuals. It aimed to elucidate whether the augmented blood pressure response during heavy- and maximal-intensity dynamic exercise alters carotid baroreflex control of heart rate and contributes to exercise intolerance. **Methods**: Thirteen healthy males (age 33 ± 2 yrs, body mass 74.6 ± 2.4 kg, and $\dot{V}O_{2max}$ 54.12 ± 1.88 mL·kg^{-1}·min^{-1}) performed a 4 min constant-load cycling exercise at low—(30% PPO), moderate—(60% PPO), high—(80% PPO), and maximal—(100% PPO) intensity, in two experimental conditions: (a) with unrestricted muscle blood flow (no-BFR) and (b) with partial muscle blood flow restriction (BFR). **Results**: A significant decline in cBRS was observed during the graded maximal exercise test compared to baseline ($p < 0.001$), accompanied by an upward and rightward relocation of the linear relationship between systolic blood pressure (SBP) and heart rate (HR). However, the magnitude of cBRS reduction was attenuated towards maximum exercise. Application of BFR during exercise exaggerated the blood pressure rise ($p < 0.01$), the perceptual response ($p < 0.001$), the exercise-induced cBRS reduction ($p < 0.001$), and induced a further relocation of the SBP-HR relationship. Additionally, BFR limited the HR increase and resulted in reduced exercise performance compared to the no-BFR condition. **Conclusions**: These findings suggest that the pronounced increase in blood pressure during heavy- and maximal-intensity exercise may limit further increases in heart rate through arterial baroreflex activation. This may contribute to reduced exercise tolerance, as evidenced by the lower peak power output and attenuated maximal heart rate observed in muscle BFR condition.

Keywords: constant-load exercise test; baroreflex sensitivity; muscle blood flow restriction; exercise blood pressure; perceptual response; exercise tolerance; exercise haemodynamics

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1. Introduction

Arterial baroreflex is essential for the regulation of cardiovascular function through beat-to-beat modifications in heart rate, vasomotor tone, and blood pressure in response to acute hemodynamic disturbances [1,2]. Specifically, at rest, acute increments in blood pressure trigger compensatory adjustments in parasympathetic and sympathetic activity, resulting in heart rate reduction and, respectively, dilation of peripheral vascular beds to

normalize blood pressure [3]. During dynamic exercise, arterial baroreflex resets to higher pressures, facilitating the simultaneous increase in blood pressure and heart rate required for the perfusion of active skeletal muscles [4–7]. Moreover, the resetting of the operating point has been shown to be linearly related to exercise intensity [4,7–9].

Baroreflex sensitivity (BRS) reflects the efficacy of the arterial baroreflex control of heart rate and is defined as the variation in cardiac interval in response to a specific fluctuation in arterial blood pressure [10]. However, findings regarding BRS in response to dynamic exercise remain inconsistent. Indeed, studies that evaluated the full carotid baroreflex function curve have observed no significant changes in the sensitivity of the reflex. In contrast, recent studies that used linear dynamic analysis of heart rate and arterial blood pressure variability to evaluate carotid baroreflex sensitivity (cBRS) during dynamic exercise have reported that cBRS was reduced in direct relation to the exercise intensity [11–15]. These techniques determine the sensitivity around the operating point at which the baroreflex regulates heart rate. However, they do not measure maximal sensitivity, defined from the full stimulus-response curve of carotid baroreceptors [7]. Importantly, responses to maximal-intensity exercise have not been sufficiently described, as the majority of studies have primarily examined cBRS during mild to moderate exercise intensities (25–80% $\dot{V}O_{2max}$).

Furthermore, few studies have investigated the interaction between cBRS and blood pressure responses, as well as exercise tolerance, under conditions of restricted muscle blood flow. This condition, commonly known as blood flow restriction (BFR), involves the partial occlusion of arterial inflow and restriction of venous return, usually attained with the application of inflated pressure cuffs. This may simulate local ischemic stress and increase sympathetic activation, making BFR a useful experimental approach for investigating cardiovascular regulation during exercise. These mechanisms are clinically significant, as impaired baroreflex function has been associated with cardiovascular diseases, including hypertension, heart failure, and autonomic dysfunction, all of which appear to compromise exercise tolerance [10,16,17]. Thus, understanding how cBRS adapts during a period of high cardiovascular demand may provide important insights into the mechanisms underpinning exercise intolerance in both healthy and clinical populations.

A recent study conducted in our laboratory showed that BFR significantly impairs $\dot{V}O_{2max}$ and peak power output (PPO) by 17% and 28%, respectively. This impairment was accompanied by a 9% reduction in maximal heart rate, while mean arterial blood pressure was significantly higher at task failure in the BFR condition compared with the control condition [18]. Restricting blood flow to the working muscles during exercise has been reported to augment cardiovascular and pressor responses, potentially through greater activation of the exercise pressor reflex, although findings may vary according to exercise modality and BFR protocol [4,19–21]. As a result, the higher blood pressure during maximal exercise with BFR may limit further increases in heart rate by overriding the excitatory effect of the exercise pressor reflex. We hypothesized that the cessation of exercise coincides with a marked increase in baroreflex sensitivity (BRS), which may help to reduce or counteract the elevated blood pressure response observed during maximal exercise intensity [4,9,10].

Recent findings insinuate that changes in cBRS during physical activity may affect exercise performance, especially in conditions involving elevated blood pressure or restricted muscle perfusion [22,23]. However, the extent to which alterations in cBRS impair peak power output or maximal oxygen uptake ($\dot{V}O_{2max}$) remains unknown. Although cBRS and the effects of muscle blood flow restriction on exercise performance have been examined separately, their interaction under altered peripheral hemodynamics has not been fully elucidated. Specifically, it remains unclear whether BFR modifies the relationship

between cBRS and peak exercise performance and contributes to limitations in maximal heart rate, leading to reduced exercise tolerance. Therefore, the purpose of this study was to investigate changes in cBRS during graded dynamic exercise to exhaustion and to elucidate whether muscle blood flow restriction modifies the relationship between cBRS and exercise performance. In addition, we investigated whether the exaggerated blood pressure response during heavy- and maximal-intensity dynamic exercise modifies BRS and sets the limits for maximal heart rate, contributing to exercise intolerance. We hypothesized that (a) cBRS would progressively decrease with increasing exercise intensity, (b) the magnitude of cBRS reduction would be greater with muscle blood flow restriction, and (c) reduced cBRS would be associated with a lower maximal heart rate, impaired exercise tolerance, and elevated arterial pressure at exhaustion. This study addresses these hypotheses to improve understanding of baroreflex function during strenuous exercise and to highlight its potential role as a determinant of exercise capacity and a marker of cardiovascular risk in clinical settings.

2. Materials and Methods

2.1. Ethics Approval

All participants gave written informed consent after receiving a full explanation of the experimental procedures, possible risks, and adverse effects related to muscle BFR in accordance with the Declaration of Helsinki, as revised in 2013. The experimental protocol was approved by the Ethics Committee of the National and Kapodistrian University of Athens, School of Physical Education and Sports Science (18 May 2022, approval code 1384).

2.2. Participants

Thirteen healthy males volunteered to participate in this study, which is consistent with previous investigations employing similar experimental designs and physiological measurements, typically involving approximately 6–12 participants [24–26]. Their mean (±SEM) age was 33 ± 2 years, body mass was 74.59 ± 2.43 kg, stature height was 1.76 ± 0.01 m, body fat was 11.82 ± 1.28%, and $\dot{V}O_{2max}$ was 54.37 ± 1.88 mL·kg^{-1}·min^{-1}. All participants were recreational cyclists or triathletes with at least five years of specialized cycling training, were nonsmokers, and were free of any cardiovascular, respiratory, musculoskeletal, or neurological disorders. Inclusion criteria included a $\dot{V}O_{2max} \geq 50$ mL·kg^{-1}·min^{-1}. Participants reported to the laboratory having abstained from heavy meals and caffeine-containing beverages for at least 2 h, and from vigorous exercise for a minimum of 48 h before the first experimental session and between the first and second sessions. They were also instructed to maintain their usual diet and habitual physical activity throughout the study period.

2.3. Experimental Design

Experimental trials were conducted in two sessions. Two familiarization sessions were conducted during which pulmonary function was assessed, and an incremental exercise test to exhaustion was performed, both with and without muscle BFR to determine exercise workloads.

The experimental sessions included constant-workload cycling exercise lasting four minutes at 30%, 60%, 80%, and 100% PPO in a balanced ordering sequence with BFR and without muscle BFR (no-BFR). Participants rested for 10 min between the 30% and 60% PPO and 60% and 80% PPO exercise trials and 20 min between the 80% and 100% PPO exercise trials to re-establish baseline muscle oxygenation (Figure 1). The workload was determined based on the PPO attained in each experimental condition. The two conditions were conducted at the same time of day for each participant in a thermoneutral environ-

ment (temperature 21–22 °C and relative humidity 35–45%), separated by at least 48 h (4 ± 1 days).

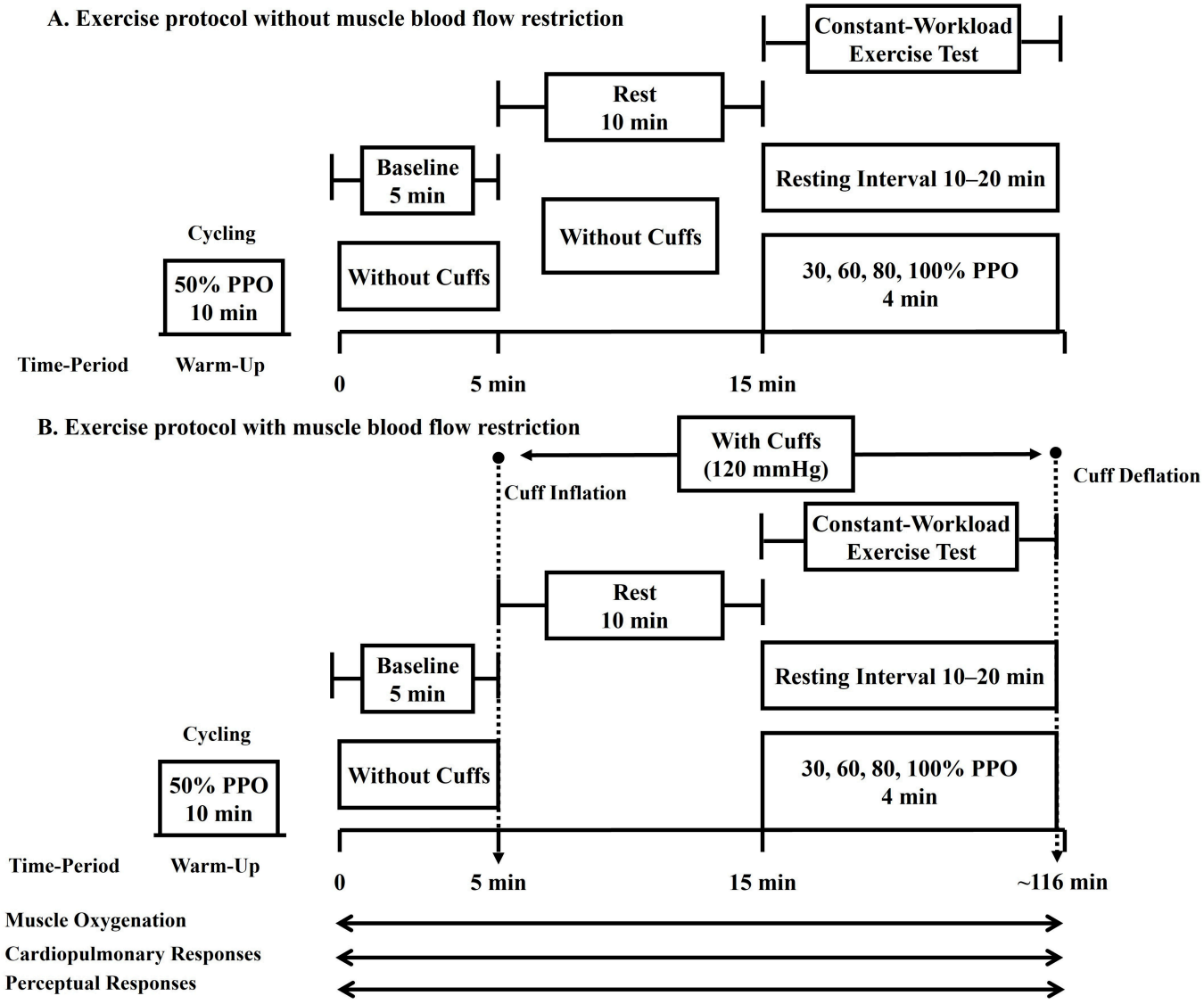

Figure 1. Overview of the main experimental protocol, which consisted of a 4 min constant-workload cycling exercise test at low—(30% PPO), moderate—(60% PPO), high—(80% PPO), and maximal—(100% PPO) intensity on two separate conditions: (**A**) without (no-BFR) and (**B**) with (BFR) muscle blood flow restriction. Thigh cuffs were inflated within 2–3 s immediately after baseline recordings, maintained throughout constant-workload cycling exercise with muscle blood flow restriction and deflated during the recovery period. Muscle oxygenation, cardiopulmonary, and perceptual responses were measured during the exercise protocol. PPO: peak power output, each time derived from the respective experimental condition (no-BFR and BFR) during the exhaustive incremental test.

2.4. Incremental Exercise Test to Exhaustion

Participants performed two incremental exercise tests to exhaustion on an electronically braked cycle ergometer (Lode RH, Groningen, The Netherlands) on two separate occasions (one with unrestricted muscle blood flow and one with muscle BFR) as previously described to determine $\dot{V}O_{2max}$ and the fractions of PPO for the constant-workload exercise trials. Briefly, following a 10 min rest (in the BFR condition, the participant rested for 10 min with BFR), the participant undertook an incremental exercise test with the initial workload set at 30 W and increased by 30 W every minute to volitional exhaustion. Verbal encouragement was provided during the final phases of each trial to optimize performance. For the

BFR condition, an inflatable thigh cuff (18 cm width) was applied around the most proximal portion of each femur, and inflated to 120 mmHg 10 min prior to initiating the incremental exercise test. The cuffs were connected to a calibrated analog sphygmomanometer (Mac-Check, Anats, model 501, Japan) to adjust and maintain the required levels of occlusion pressure on both thighs. The absolute occlusion pressure has been shown to restrict blood flow by approximately 55–65% at rest [27]. The cuffs were immediately deflated when the incremental exercise test was terminated.

Breath-by-breath pulmonary gas exchange and ventilatory variables were continuously recorded via open-circuit spirometry (Ultima CPX, MedGraphics, Saint Paul, MN, USA). Heart rate was continuously monitored using telemetry (Sport Tester^{TM} Polar, Kempele, Finland). $\dot{V}O_{2max}$ was defined as the maximal mean value recorded during the last 15 s of the test. Peak power output (PPO) was calculated as follows: PPO = PO_{final} + (t/60 × 30 Watts), where PO_{final} represents the last completed workload and t is the duration in seconds for which the final uncompleted workload was retained [28]. At exercise termination, participants provided a rating of perceived exhaustion.

2.5. Constant-Workload Exercise Trials

After obtaining anthropometric characteristics, the participant performed a standardized warm-up of 10 min of cycling at 50% PPO, followed by stretching and application of the instruments. For the BFR condition, the participant sat on a back-supported chair for a 5 min baseline period. Two thigh cuffs were then applied and inflated at 120 mmHg on each leg for 10 min. Thereafter, the participant performed the constant-workload exercise trials on an electronically braked cycle ergometer (Lode RH, Groningen, The Netherlands). Participants completed the same experiment without the application of thigh cuffs (Figure 1).

Muscle BFR during constant-workload exercise trials was induced as previously described during $\dot{V}O_{2max}$ evaluation. Specifically, thigh cuffs were inflated within 2–3 s immediately after baseline recordings and were maintained throughout the trials. The thigh cuffs were deflated during the interposed recovery periods (Figure 1).

2.6. Measurements

2.6.1. Cardiopulmonary Measurements

Systolic, diastolic blood pressure, and heart rate were continuously recorded on a beat-by-beat basis from the middle finger of the right hand using a photoplethysmometer (Finometer 2003, FMS, Arnhem, The Netherlands) as previously described [23,29]. During exercise, participants placed the dominant arm on an adjustable stand with the height set at heart level. The Finometer traces finger pulse waveforms to measure arterial pressure and reconstruct aortic flow. From this, stroke volume (SV) is estimated through the Modelflow method [30]. The validity and reliability of this method at rest and during cycling exercise in a wide range of intensities have been previously described [28,31]. Mean arterial pressure (MAP) and cardiac output ($\dot{Q}$) were calculated using BeatScope software (version 1. a, Finometer, Finapres Medical Systems, The Netherlands).

2.6.2. Carotid Baroreflex Sensitivity

The cross-correlation method (Beatscope 1a, Finometer, Finapres Medical Systems, The Netherlands) assessed carotid baroreflex sensitivity [32,33]. This method involves identifying systolic blood pressure (SBP) and pulse interval changes in the same direction, and their correlation with 0–5 s delays is calculated. This shift in time optimizes the cross-correlation. The 6th to the 9th min of steady-state data at rest and 4 min during exercise were used for spontaneous baroreflex analyses in each condition.

2.6.3. Muscle Oxygenation

A near-infrared spectroscopy device (NIRS; Oxymon Mk III, Artinis Medical Systems, Elst, The Netherlands), operating at two continuous wavelengths (760 nm and 850 nm), was used to continuously assess muscle oxygenation throughout all experimental protocols. NIRS measures the relative micromolar concentration changes in oxy- ([O_2Hb]) and deoxy-hemoglobin ([HHb]), providing an assessment of the equilibrium between O_2 delivery and O_2 utilization within the monitored tissue [34]. Variation in total hemoglobin (Δ[THb]) was interpreted as changes in regional microvascular blood volume [35], while changes in hemoglobin difference (Δ[HbDiff]) were used as an indicator of tissue oxygenation status [36].

The emitter-detector optode pair was positioned over the mid-portion of the left vastus lateralis muscle at mid-thigh level, aligned with the longitudinal axis of the muscle (~15 cm above the proximal edge of the patella, and ~5 cm lateral to the thigh's midline). To enable subsequent attachments, the NIRS probe's site was marked with permanent ink. NIRS signals were sampled at a frequency of 10 Hz. Prior to recording baseline values, all signals were zero-adjusted (bias) to allow expression of exercise-induced changes in muscle deoxygenation relative to resting values under both no-BFR and BFR conditions.

2.6.4. Perceptual Responses

Rate of perceived exertion related to dyspnea ($RPE_{dyspnea}$) and leg fatigue (RPE_{leg}) was assessed on a minute-by-minute basis throughout the experimental protocols using Borg's 6–20 rating scale [37]. In addition, discomfort associated with thigh cuff inflation was evaluated with Borg's Category-Ratio (CR-10) pain scale [38].

2.7. Data Analysis and Statistics

Normality of the data was confirmed by the Shapiro–Wilk test. Physiological variables were continuously monitored from baseline until completion of each exercise bout. Resting values for all measurements were calculated as the mean of the 6th to 9th minute of the 10 min resting period, performed either under unrestricted blood flow or during muscle BFR. During constant-workload trials, mean values of the last minute of the exercise were calculated for all physiological responses except for cBRS analysis, which was used for the entire duration of the exercise. A two-way ANOVA with repeated measures on both factors [2 conditions (no-BFR and BFR) × 4 workloads (30, 60, 80, and 100% PPO)] was used to evaluate the effects of muscle BFR and exercise intensity. Significant main effects and interactions were analyzed by using Tukey's post hoc test. Student's paired *t*-test was employed to evaluate possible differences in physiological responses during exercise at the same absolute workload (~200 W corresponding to 60% and 80% in BFR and no-BFR conditions, respectively) between no-BFR and BFR conditions. Person's correlation coefficients determined the relationship between cBRS and exercise capacity ($\dot{V}O_{2max}$, PPO, and maximal heart rate) and among other physiological variables as well (blood pressure response, heart rate, and exercise capacity). Linear regression analysis was performed for each condition to investigate the predicted value of the independent variables (heart rate, cBRS, and SBP) on exercise capacity and/or cardiovascular response. The derived regression models were applied across conditions to estimate predicted values, and prediction accuracy was evaluated using mean absolute error (MAE), root mean square error (RMSE), and Pearson's correlation coefficients. Finally, general linear models (GLM) were employed to compare the slopes of the linear relationships between conditions. Each model included the independent variables, the condition (with/without muscle BFR), and their interaction, along with a random intercept for each participant to account for repeated measurements within individuals. Data are presented as mean ± standard error of measurements (SEM),

and statistical significance was accepted at two-tailed p-values of <0.05. Where appropriate, effect sizes (r^2, β coefficients) and model accuracy indices (MAE, RMSE) were reported to support interpretation.

3. Results

3.1. Exercise Tolerance and Exercise Intensity of Constant-Workload Trial

Exercise tolerance significantly deteriorated with muscle BFR (Table 1) as indicated by PPO and $\dot{V}O_{2max}$ reduction of 27 ± 2% and 17 ± 2%, respectively ($p < 0.001$). The intensity of the constant-workload exercises corresponding to 30%, 60%, 80%, and 100% PPO was 100 ± 4 W, 200 ± 7 W, 267 ± 10 W, and 334 ± 12 W in the no-BFR conditions, and 75 ± 3 W, 150 ± 6 W, 200 ± 8 W, and 250 ± 10 W in the BFR condition, respectively. All participants completed each constant-workload trial. The work rate at 60% PPO in the no-BFR was similar to the work rate at 80% PPO in the BFR condition (no-BFR: 200 ± 7 W and BFR: 200 ± 8 W, $p = 0.957$).

Table 1. Mean values ± SEM ($n = 13$) of physiological responses during incremental exercise to exhaustion without (no-BFR) and with muscle blood flow restriction (BFR) in 13 participants.

	No-BFR Condition	BFR Condition	*p*-Values
PPO (Watt)	334 ± 12	250 ± 10 †	0.000
$\dot{V}O_{2max}$ (ml·kg·$^{-1}$ min^{-1})	54.37 ± 1.88	44.99 ± 1.56 †	0.000
HR_{max} (beats·min^{-1})	178 ± 3	161 ± 4 †	0.000
HR_{max} (%pred)	94 ± 1	86 ± 2 †	0.000
RER_{max}	1.22 ± 0.03	1.17 ± 0.03	0.066

PPO: peak power output, $\dot{V}O_{2max}$: maximal oxygen consumption, HR_{max}: maximal heart rate, RER_{max}: respiratory gas exchange ratio. † Significant differences between conditions, without and with muscle blood flow restriction ($p < 0.01$).

3.2. Cardiovascular Responses During Constant-Workload Trials

Baseline cardiovascular parameters were similar between conditions. During constant-workload exercise, heart rate increased progressively across trials with increasing exercise intensity (30, 60, 80, and 100% PPO) in both conditions and was significantly higher in the no-BFR condition compared to the BFR condition ($p < 0.001$) (Figure 2a). Furthermore, SV increased progressively across trials in both conditions and tended to be higher ($p = 0.08$) in all intensities in the no-BFR condition compared to the BFR condition (Figure 2b). Thus, $\dot{Q}$ also progressively increased across trials with increasing exercise intensity in both conditions and was significantly higher ($p = 0.037$) in the no-BFR compared to the BFR condition due to the higher heart rate (Figure 2c). When compared at the same absolute work rate (~200 W), heart rate was significantly higher ($p < 0.001$), and SV was lower ($p = 0.03$) in the BFR than the no-BFR condition, whereas $\dot{Q}$ was similar ($p = 0.194$) between conditions.

Blood pressure (SBP, DBP, and MAP) increased from baseline in all constant-workload exercise trials in both conditions (Figure 3). However, the magnitude of the blood pressure rise was significantly greater in the BFR condition compared to the no-BFR condition ($p < 0.001$) (Figure 3). In the no-BFR condition, the mean increase in SBP, DBP, and MAP was 45.92 ± 2.85 mmHg, 24.49 ± 2.11 mmHg, and 35.09 ± 2.41 mmHg, respectively, whereas in the BFR condition, the increase was 62.84 ± 3.50 mmHg, 35.45 ± 3.00 mmHg, and 49.29 ± 3.20 mmHg, respectively. When compared at the same absolute work rate (~200 W), blood pressure was significantly higher in the BFR condition than in the no-BFR condition ($p \leq 0.01$).

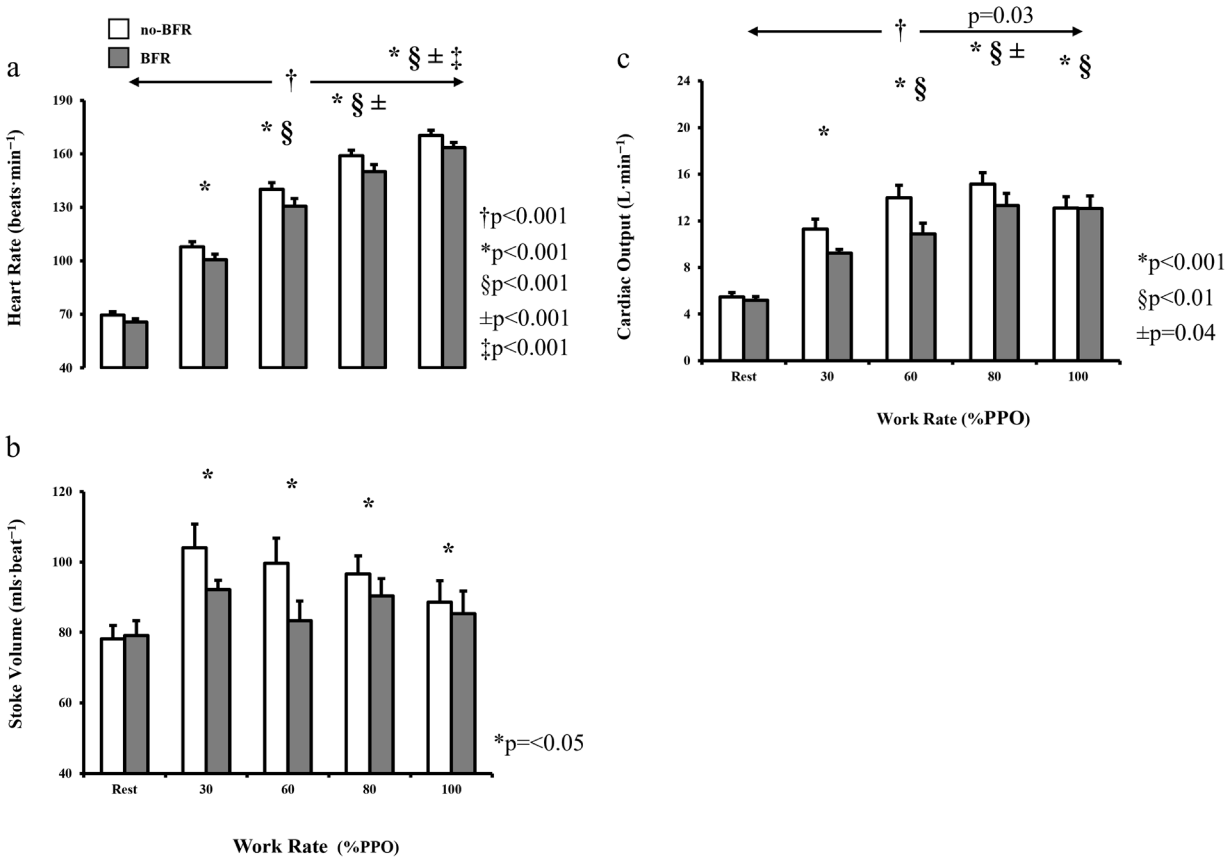

Figure 2. Heart rate (**a**), stroke volume (**b**), and cardiac output (**c**) during constant-workload exercise of different intensity (30, 60, 80, and 100% of specific per experimental condition peak power output, PPO) without (no-BFR) and with muscle blood flow restriction (BFR; 120 mmHg). Bars and error bars represent mean values ± SEM of 13 participants, respectively. * Significant differences vs. rest, § Significant differences vs. 30% PPO, ± Significant differences vs. 60% PPO, ‡ Significant differences vs. 80% PPO, † Significant differences between conditions without and with muscle blood flow restriction.

A significant positive correlation between SBP and PPO (r = 0.326, p = 0.018) was observed in the no-BFR condition (Figure 3d), although the correlation coefficient was relatively weak, explaining 10.7% of the PPO variance (PPO = −25.894 + 1.473 × SBP). However, the SBP-PPO correlation was more pronounced in the BFR condition (r = 0.506, p = 0.000), accounting for 25.6% of the PPO variance (PPO = −117.177 + 1.512 × SBP). Furthermore, a general linear model revealed a significant main effect of SBP (p = 0.001) and SBP X Condition interaction (p = 0.05), whereas the main effect of the condition did not reach statistical significance (Figure 3d). These findings suggest that SBP is positively associated with PPO, but the relationship between SBP and PPO was significantly different between conditions (p = 0.05), suggesting that for a given peak power output, muscle BFR enhances the systolic blood pressure response (Figure 3d). In addition, a significant positive correlation between SBP and heart rate was observed in both conditions (no-BFR: r = 0.428, p = 0.002 and BFR: r = 0.534, p = 0.000) during constant-workload exercise, whereas the slope of the SBP-HR relationship was similar (p = 0.737) between the no-BFR and BFR conditions (Figure 4b). Collectively, these findings indicate that, although SBP increases with heart rate during exercise, the muscle BFR does not significantly modify this relationship. That is, SBP increases in response to heart rate similarly in both conditions, and the muscle BFR does not significantly alter the strength of the SBP-HR relationship.

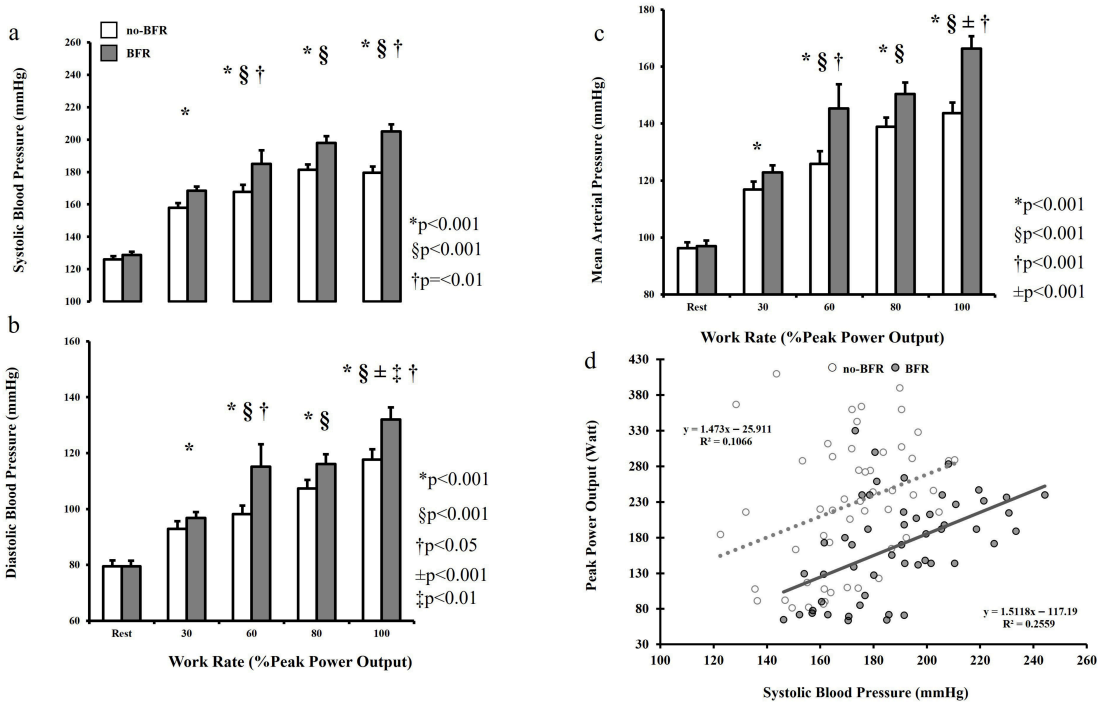

Figure 3. Systolic (**a**), diastolic (**b**), and mean arterial pressure (**c**), and linear relationship (**d**) between systolic blood pressure and peak power output during constant-workload exercise at different intensity (30, 60, 80, and 100% of specific per experimental condition peak power output, PPO) without (no-BFR) and with muscle blood flow restriction (BFR; 120 mmHg). Bars and error bars represent mean values ± SEM of 13 participants, respectively. Gray and white circles (**d**) represent individual data for the BFR and the no-BFR conditions, respectively. * Significant differences vs. rest, § Significant differences vs. 30% PPO, ± Significant differences vs. 60% PPO, ‡ Significant differences vs. 80% PPO, † Significant differences between conditions without and with muscle blood flow restriction.

3.3. Baroreflex Sensitivity

Baseline carotid baroreflex sensitivity was significantly lower with muscle BFR compared to the no-BFR condition (p = 0.026). Mean cBRS was 11.66 ± 0.74 ms·mmHg^{-1} in the no-BFR and 9.74 ± 0.40 ms·mmHg^{-1} in the BFR condition, respectively. In all constant-workload exercise trials, cBRS was significantly reduced ($p < 0.001$) compared to baseline values (Figure 4a). The magnitude of cBRS reduction was significantly greater in the BFR (−8.01 ± 0.80 ms·mmHg^{-1}) compared to the no-BFR (−6.53 ± 0.64 ms·mmHg^{-1}) condition (p = 0.01). Furthermore, the magnitude of cBRS reduction was less pronounced during the exercise trial at 100% PPO compared to the exercise trial at 30% (p = 0.046) and 60% (p = 0.015) PPO (Figure 4a). The mean decrease in BRS was −8.44 ± 0.83 ms·mmHg^{-1}, −9.35 ± 1.24 ms·mmHg^{-1}, −5.92 ± 1.03 ms·mmHg^{-1}, and −5.38 ± 0.60 ms·mmHg^{-1} during the exercise trials at 30%, 60%, 80% and 100% PPO, respectively. When compared at the same absolute work rate (~200 W), cBRS was similar between conditions (no-BFR: 2.68 ± 0.70 ms·mmHg^{-1} and BFR: 3.98 ± 0.44 ms·mmHg^{-1}, p = 0.087).

A significant positive correlation between SBP and heart rate was observed in both conditions (no-BFR: r = 0.428, p = 0.002 and BFR: r = 0.534, $p < 0.001$) during constant-workload exercise, indicating a linear increase in SBP with heart rate across trials with increasing exercise intensity (Figure 4b). In addition, the linear relationship between SBP and heart rate was relocated upward and rightward during exercise compared to baseline in both experimental protocols (Figure 4b). Muscle BFR during exercise induced a further upward and rightward shift in this relationship compared to the no-BFR condition. Specifically, a significant main effect of condition ($p < 0.001$) and workload ($p < 0.001$) was found on both

the slope (Figure 5a) and intercept (Figure 5b) of the SBP-HR relationship. Furthermore, there was a significant condition x workload interaction ($p < 0.01$), indicating that both slopes (Figure 5a) and intercepts (Figure 5b) increased significantly during exercise from baseline, and the magnitude of this increase was more pronounced in the BFR condition compared to the no-BFR condition.

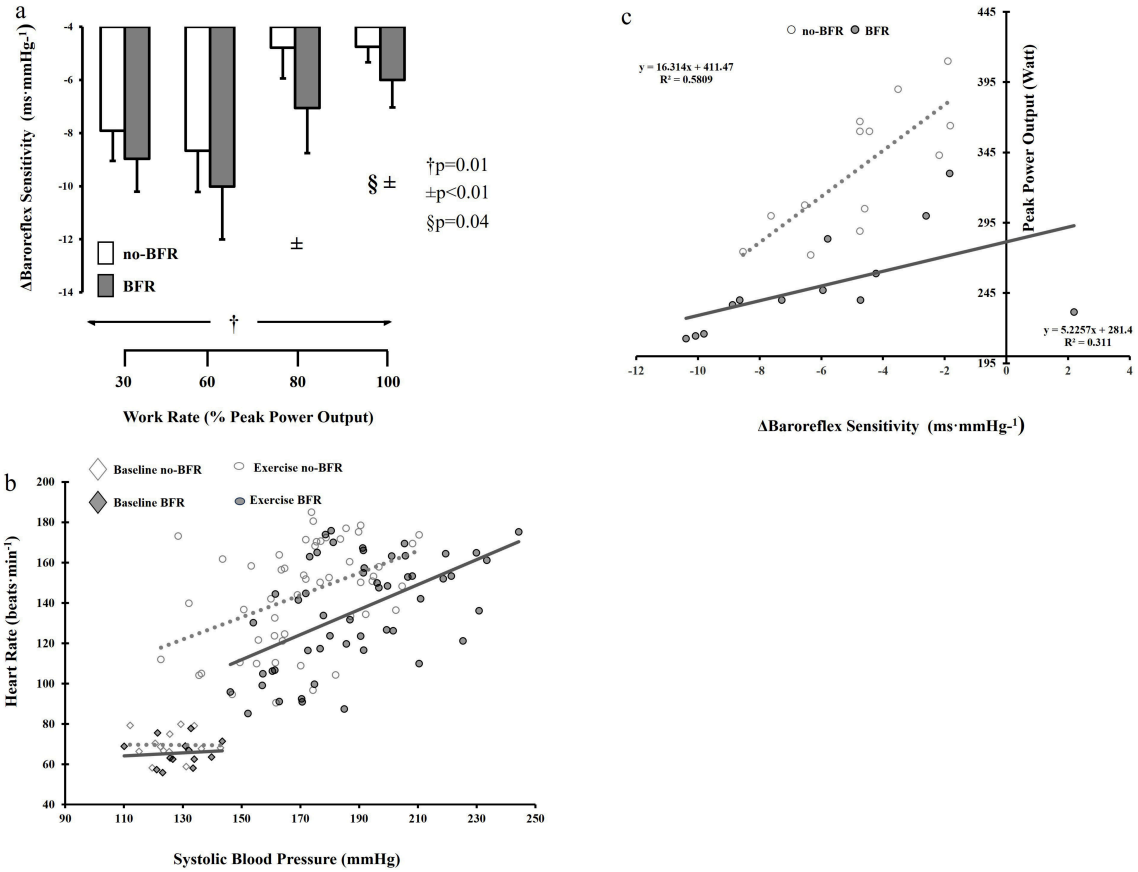

Figure 4. Baroreflex sensitivity reduction (**a**) during constant-workload exercise at different intensity (30, 60, 80, and 100% of specific per experimental condition peak power output, PPO), linear relationship (**b**) between systolic blood pressure and heart rate at rest and during exercise without (no-BFR) and with muscle blood flow restriction (BFR; 120 mmHg), and linear relationship (**c**) between baroreflex sensitivity reduction and peak power output during exercise without (dot line) and with (solid line) muscle blood flow restriction. Bars and error bars represent mean values ± SEM of 13 participants, respectively. Gray and white circles (**b**,**c**) represent individual data for the BFR and the no-BFR conditions, respectively. § Significant differences vs. 30% PPO, ± Significant differences vs. 60% PPO, † Significant differences between conditions without and with muscle blood flow restriction.

Baroreflex Sensitivity and Exercise Performance

A significant positive correlation between the magnitude of cBRS reduction, which means increased sensitivity, since exercise sensitivity values are expressed relative to the idle condition, and PPO (r = 0.762, $p = 0.002$) was observed in the no-BFR condition (Figure 4c), explaining 58.1% of the PPO variance (PPO = 411.47 + 16.31 × cBRS). This indicates that a smaller reduction in cBRS (i.e., less negative ΔcBRS values, namely higher baroreflex sensitivity) was associated with a higher PPO. In contrast, under muscle BFR, this relationship was attenuated (r = 0.558, $p = 0.048$), accounting for 31.1% of the PPO variance (PPO = 281.40 + 5.23 × cBRS). Furthermore, a general linear model revealed a significant main effect of cBRS ($p = 0.004$) and condition ($p < 0.001$), as well as a significant cBRS × Condition interaction ($p = 0.010$). These findings indicate that the relationship

between cBRS and PPO differs between conditions. Furthermore, a significant positive correlation between the magnitude of cBRS reduction and $\dot{V}O_{2max}$ was found in the no-BFR condition (r = 0.697, p = 0.008), whereas there was no correlation in the BFR condition (r = 0.393, p = 0.184). The magnitude of cBRS reduction was not correlated to maximal heart rate in both conditions (no-BFR: r = −0.045, p = 0.883 and BFR: r = 0.121, p = 0.694).

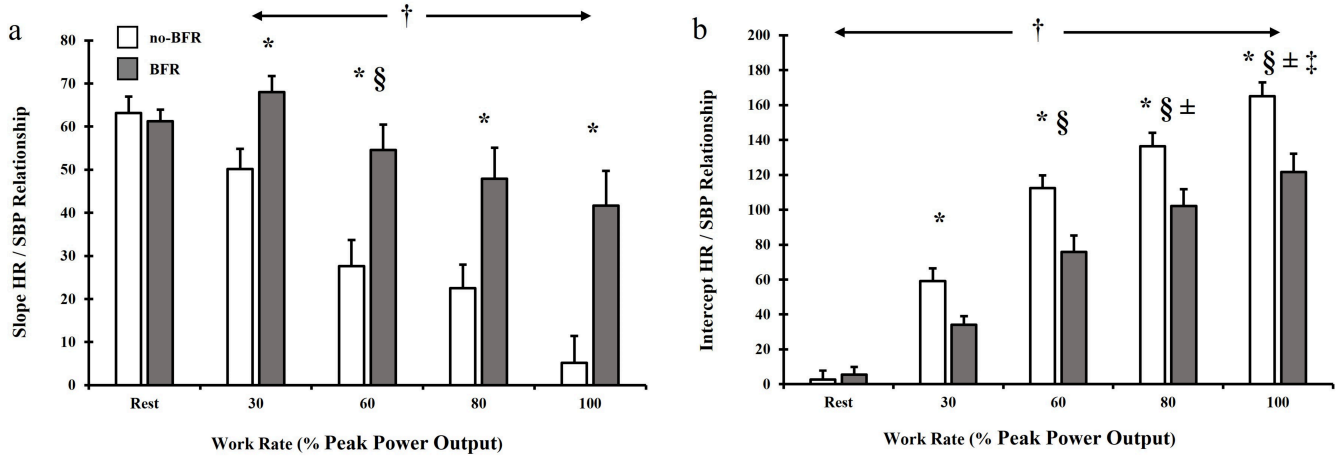

Figure 5. Slope (**a**) and intercept (**b**) of the heart rate and SBP relationship during constant-workload exercise at different intensities (30, 60, 80, and 100% of specific per experimental condition peak power output, PPO) without (no-BFR) and with muscle blood flow restriction (120 mmHg). Bars and error bars represent mean values ± SEM of 13 participants, respectively. * Significant differences vs. rest, § Significant differences vs. 30% PPO, ± Significant differences vs. 60% PPO, ‡ Significant differences vs. 80% PPO, † significant differences between conditions without and with muscle blood flow restriction. Both slope and intercept increased from baseline during exercise, with a greater increase observed in the BFR condition, consistent with the significant condition × workload interaction (p < 0.01).

3.4. Muscle Oxygenation

Baseline, muscle-Δ[O_2Hb] tended to be higher (p = 0.09) during the BFR condition (1.49 ± 0.63 μM) than in the no-BFR condition (0.01 ± 0.48 μM). Muscle-Δ[HHb] (no-BFR: −0.02 ± 0.43 μM vs. BFR: 9.83 ± 1.82 μM, p < 0.001) and Δ[THb] (no-BFR: −0.01 ± 0.24 μM vs. BFR: 11.32 ± 2.21 μM, p < 0.001) were significantly higher in BFR than in no-BFR, whereas muscle Δ[HbDiff] was lower (p < 0.001) in BFR (−8.35 ± 1.59 μM) than in the no-BFR condition (0.03 ± 0.87 μM).

During constant-workload exercise, muscle-Δ[O_2Hb] and Δ[HbDiff] were progressively reduced (p < 0.001) compared to baseline in both conditions (Figure 6a,d). The magnitude of muscle-Δ[O_2Hb] decrease was significantly higher (p = 0.033) in the no-BFR condition, whereas significant differences between conditions were observed for muscle-Δ[HbDiff] during exercise at 80% PPO (p = 0.017). In contrast, muscle-Δ[HHb] progressively increased during exercise in both conditions and was significantly higher in the BFR condition compared to the no-BFR condition (p = 0.04) (Figure 6b). Furthermore, muscle-Δ[THb] response during constant-workload exercise was significantly different between exercise protocols (p = 0.015). Specifically, muscle-Δ[THb] was significantly decreased during exercise without muscle BFR at intensities from 80% PPO and above, whereas it increased during exercise with muscle BFR compared to baseline values over the entire range of exercise intensities, and consequently, it was significantly higher in the BFR condition compared to the no-BFR condition (Figure 6c). When compared at absolute work rate (~200 W), muscle oxygenation response (Δ[O_2Hb], Δ[THb], and Δ[HbDiff]) was similar (p = 0.176–0.712) between exercise protocols, whereas muscle-Δ[HHb] was significantly higher (p = 0.019) in BFR (10.58 ± 1.46 μM) compared to no-BFR (7.94 ± 1.20 Mm) condition.

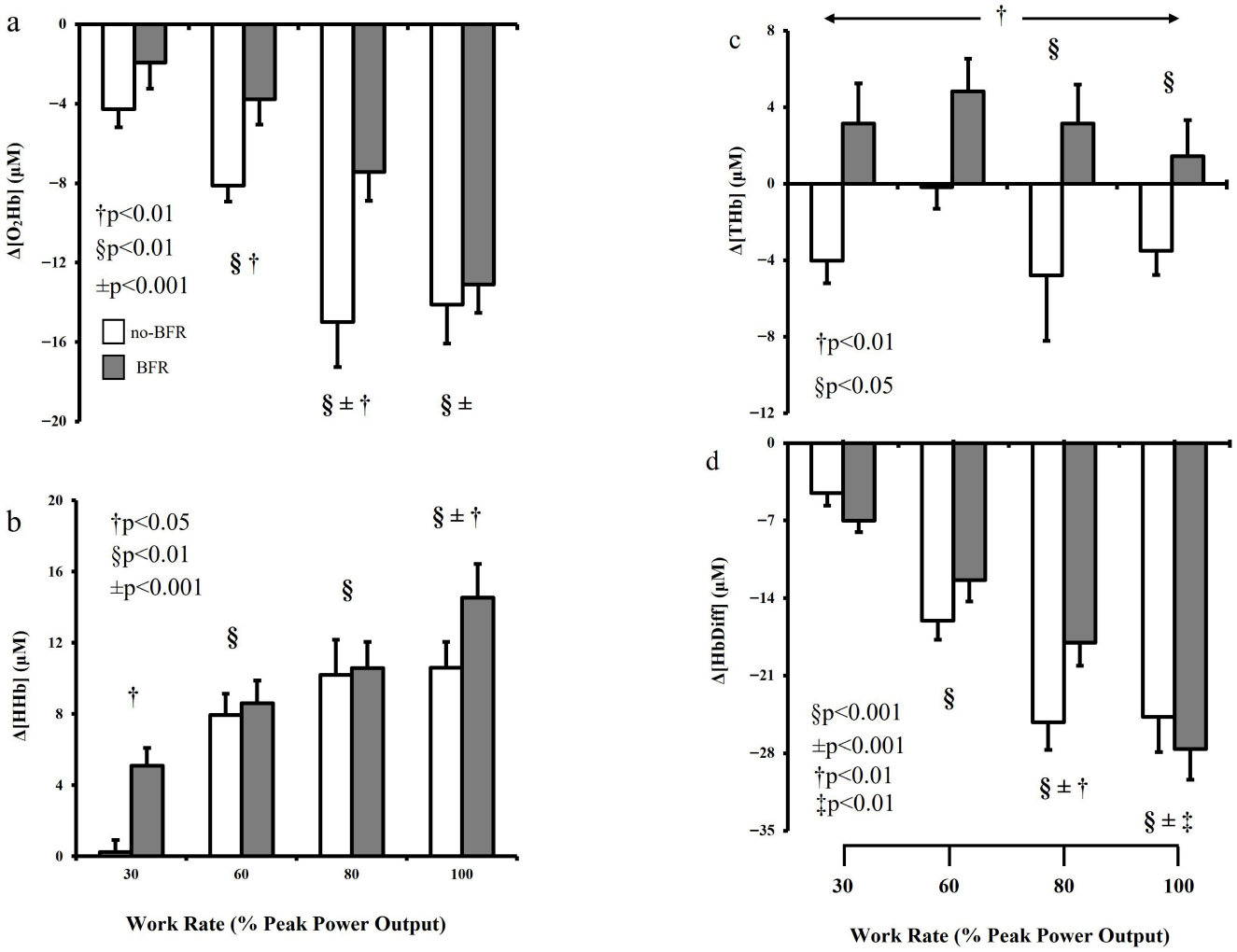

Figure 6. Muscle concentration changes from baseline in (**a**) oxyhemoglobin, (**b**) deoxyhemoglobin, (**c**) total hemoglobin, and (**d**) difference in hemoglobin during constant-workload exercise at different intensities (30, 60, 80, and 100% of specific per experimental condition peak power output, PPO) without (no-BFR) and with muscle blood flow restriction (BFR; 120 mmHg). Mean values ± SEM and individual points of 13 participants are presented. § significant differences vs. 30% PPO, ± Significant differences vs. 60% PPO, ‡ significant differences vs. 80% PPO, † significant differences between conditions without and with muscle blood flow restriction.

3.5. Perceived Exertion

Baseline rate of perceived dyspnea ($RPE_{dyspnea}$) was similar (p = 0.110) between conditions, whereas the rate of perceived leg discomfort (RPE_{leg}) was significantly higher ($p < 0.001$) with muscle BFR compared to the no-BFR condition (Figure 7a). During constant-workload exercise, the $RPE_{dyspnea}$ and RPE_{leg} were progressively increased ($p < 0.001$) compared to baseline in both conditions, and significant differences were observed between exercise conditions and intensities. Specifically, $RPE_{dyspnea}$ was significantly higher ($p < 0.001$) during exercise at 80% and 100% PPO in BFR compared to the no-BFR condition (Figure 7a), whereas RPE_{leg} was significantly higher ($p < 0.001$) during exercise at 30%, 60%, and 80% PPO with muscle BFR. No significant differences (p = 0.333) were observed at 100% PPO between exercise protocols (Figure 7b). At absolute work rate (~200 W), the $RPE_{dyspnea}$ and RPE_{leg} were significantly higher with muscle BFR compared to the no-BFR condition ($RPE_{dyspnea}$ no-BFR: 10.54 ± 0.62 vs. BFR: 12.38 ± 0.60, $p < 0.01$ and RPE_{leg} no-BFR: 11.70 ± 0.38 vs. BFR: 16.08 ± 0.45, $p < 0.001$).

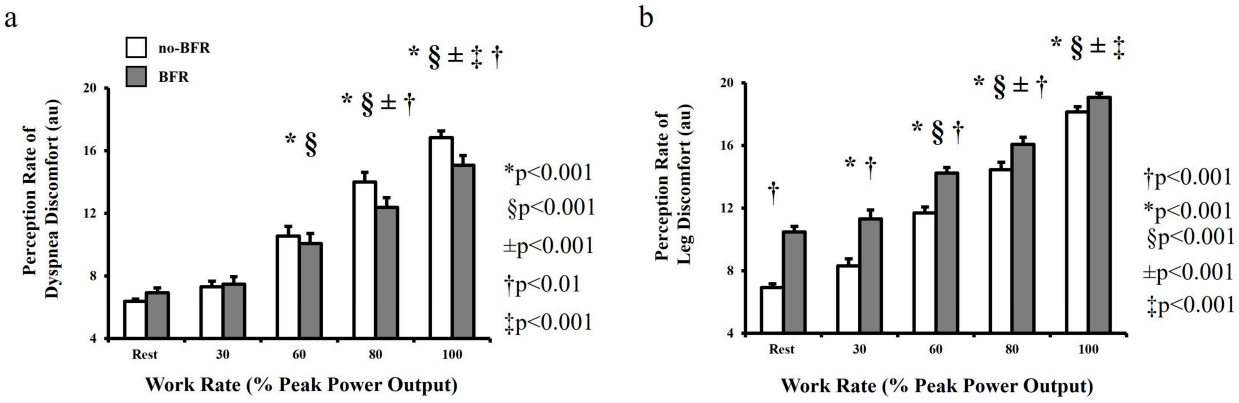

Figure 7. Perception rate of dyspnea (**a**) and leg discomfort (**b**) during incremental constant-workload exercise of different intensity (30, 60, 80, and 100% of specific per experimental condition peak power output, PPO) without (no-BFR) and with muscle blood flow restriction (BFR; 120 mmHg). Bars and error bars represent mean values ± SEM of 13 participants, respectively. * significant differences vs. rest, § significant differences vs. 30% PPO, ± significant differences vs. 60% PPO, ‡ significant differences vs. 80% PPO, † significant differences between conditions without and with muscle blood flow restriction.

4. Discussion

The purpose of this study was to elucidate whether the augmented blood pressure response during maximal-intensity dynamic exercise would contribute to exercise intolerance in healthy individuals. We investigated changes in carotid baroreflex sensitivity during a series of constant-workload exercise trials at increasing intensities (30%, 60%, 80%, and 100% PPO) with and without muscle BFR. The main findings of this study include: (a) cBRS decreased during exercise compared to baseline; the magnitude of cBRS reduction was progressively attenuated as the exercise intensity reached the maximum level (100% PPO), (b) muscle BFR during exercise, compared to the no-BFR condition, further attenuated the exercise-induced reduction in cBRS and induced an additional adjustment of the HR–SBP relationship, while limiting the rise in heart rate and exercise performance. The observed resetting pattern, together with the findings that both SBP and cBRS were significantly correlated with exercise performance (e.g., peak power output and heart rate), supports the hypothesis that augmented exercise pressor responses may constrain exercise tolerance under conditions of restricted muscle perfusion. Importantly, this mechanism limiting maximal heart rate during BFR exercise may reflect the same physiological constraints underlying the reduced maximal heart rate observed in aging and in populations with chronic disease, including heart failure, obstructive pulmonary disease and autonomic dysfunction, thereby underscoring the broader relevance of the present findings.

4.1. Baroreflex Sensitivity During Constant-Workload Exercise Trials Without BFR

The arterial baroreflex is essential for the regulation of cardiovascular responses during exercise [6]. It is well established that arterial baroreflex resetting occurs at the onset of dynamic exercise to higher operating pressures, facilitating the simultaneous increase in blood pressure and heart rate necessary for the perfusion of active skeletal muscles. Moreover, the arterial baroreflex is relocated to a more effective position for responding to systemic blood pressure fluctuations during exercise, thereby counteracting the hypertensive stimulus [4,8,12,13].

In the current study, we investigated whether carotid baroreflex sensitivity is modulated during a series of constant-workload exercise trials at increasing intensities (30%, 60%, 80%, and 100% PPO), aiming to characterize the progressive cardiovascular adjustments in

healthy individuals. The findings indicate a significant reduction in cBRS during exercise compared with baseline, with the magnitude of this reduction progressively attenuated as exercise intensity increased. Additionally, the linear relationship between heart rate and SBP fluctuations was shifted upward and rightward at higher blood pressure levels compared to baseline, consistent with previous findings [11,39–41]. Collectively, these findings indicate that central command and muscle afferent feedback progressively override the baroreflex control of heart rate during exercise [42,43]. This attenuated arterial baroreflex responsiveness appears to be a physiological adaptation that supports the cardiovascular demands of exercise by facilitating blood pressure elevations in the context of marked vagal withdrawal.

Findings on arterial baroreflex responsiveness during dynamic exercise are inconsistent in the literature. The sensitivity of the arterial baroreflex has been reported to either increase [19,44], remain unaffected [4,8,12,13,20,45] or decrease [9,11,13–15] during dynamic exercise. This discrepancy may be attributed to the different methodological techniques employed in assessing arterial baroreflex sensitivity. Human studies indicate that the arterial baroreflex sensitivity remains unchanged when estimated from the full baroreflex stimulus-response curve [4,8,12,13] with a few exceptions [19,44]. In contrast, cBRS seems to be attenuated during dynamic exercise when assessed with the dynamic spontaneous analysis technique [11–15]. Confirming previous findings, in this study, during the no-BFR condition, the cBRS operating point was significantly lower across the series of constant-workload exercise trials compared to baseline. This reduction is thought to reflect both a centrally and a peripherally mediated adjustment that facilitates the maintenance of elevated arterial blood pressure and cardiac output during physical exertion.

However, to our knowledge, only a few studies have investigated whether the spontaneous baroreflex sensitivity is modified during incremental dynamic exercise [12–15] with inconsistent findings. In human studies, cBRS during incremental exercise has been reported to decrease either in direct relation to the intensity of dynamic exercise, with the lowest values observed at the highest intensity [13,15,46] or up to submaximal intensity without additional modification with further workload increase [12] or remained unaffected [14,47]. It is worth mentioning that, in the previously mentioned studies, the exercise intensity ranged mainly from mild to moderate (26–140 W), with heart rates between 90 and 150 beats·min^{-1}. Consequently, the response of cBRS at elevated intensities remains inadequately comprehended.

In this study, cBRS was attenuated during exercise at 30% and 60% PPO compared to baseline, and the magnitude of cBRS reduction was significantly reduced at higher intensities (80% and 100% PPO). Furthermore, the magnitude of the cBRS response was similar between experimental conditions. These findings confirm the established decrease in cBRS during exercise and further show that this reduction becomes progressively greater as workload increases. The observed gradual reduction in cBRS might represent an adaptive mechanism facilitating the cardiovascular system to tolerate and maintain elevated blood pressure levels. Nevertheless, the markedly reduced cBRS observed at maximal exercise may indicate impaired blood pressure regulation, a condition that could lead to hemodynamic instability or reduced exercise tolerance in specific physiological or clinical settings [5,47–49]. Changes in cBRS in response to exercise throughout the entire intensity spectrum are inadequately investigated in the current literature, highlighting the need for further studies.

4.2. Muscle Blood Flow Restriction and Baroreflex Sensitivity

It is well established that activation of group III (mechanoreceptors) and IV (metaboreceptors) muscle afferents during exercise evokes the exercise pressor reflex, characterized

by sympathetically mediated increases in heart rate, blood pressure, and peripheral vasoconstriction [4,19,20]. In the current study, blood flow to the active muscles was partially restricted to augment stimulation of these afferents. In accordance with previous findings, BFR during dynamic exercise elicited greater increases in blood pressure and heart rate at the same absolute workload compared to the no-BFR condition [21,50]. However, not all studies have reported exaggerated pressor responses during muscle BFR exercise, as reduced exercise blood pressure without changes in metaboreflex activity has also been described, likely due to differences in exercise modality, cuff pressure, and participant characteristics [51].

Furthermore, we observed that muscle BFR during exercise, compared with the no-BFR condition, further attenuated the exercise-induced cBRS reduction and induced an additional upward and rightward resetting of the HR–SBP relationship in accordance with previous findings [15,39–41]. These findings add complexity to our understanding of the cardiovascular regulation during physical exercise. Specifically, cBRS remained consistently lower with muscle BFR across all exercise intensities, suggesting an additive or enhancing effect of muscle BFR on the exercise-induced attenuation of arterial baroreflex function.

The augmented impairment of baroreflex control of heart rate and blood pressure with muscle blood flow restriction may be attributed to several interacting mechanisms. Initially, muscle ischemia due to BFR activates groups III and IV muscle afferents, which may inhibit cardiac vagal activity while enhancing sympathetic drive [52,53]. This increased sympathetic activation may contribute to the observed attenuation of cBRS by restricting the baroreflex-mediated vagal responses to blood pressure fluctuations.

Importantly, activation of the muscle metaboreflex, triggered by blood flow restriction and subsequent metabolite accumulation, significantly influences the interplay among reflex systems. Specifically, metaboreflex activation enhances sympathetic outflow, leading to a rightward shift in the baroreflex function curve towards elevated arterial pressure values, consistent with baroreflex resetting during exercise. Whether this response is accompanied by a true shift in the full baroreflex curve remains uncertain and cannot be addressed by the current methodology using cBRS. Therefore, the observed reduction in cBRS under peripheral blood flow restriction in the present study primarily reflects a shift in the baroreflex operating point, although a contribution of altered reflex gain (sensitivity) cannot be excluded.

Secondly, the augmented blood pressure response and the additional upward and rightward resetting of the HR–SBP relationship observed during exercise with muscle BFR may indicate a relocation of the baroreflex operating point toward elevated pressure levels. Arterial baroreflex resetting is well documented at the onset of dynamic exercise [4,7–9,54]; however, the magnitude of this resetting during exercise with muscle BFR was more pronounced due to the exaggerated pressure response associated with restriction of muscle perfusion.

Thirdly, muscle BFR during dynamic cycling may reduce the mechanical efficiency of the active skeletal muscle, resulting in a modified motor-unit-profile recruitment and enhanced central command. In the current study, oxygen consumption was markedly elevated during exercise at the same absolute workload with muscle BFR, indicating an inefficient mode of exercise. Furthermore, mechanical efficiency calculated using the cycling economy index, defined as the average workload divided by the average oxygen consumption, was significantly higher ($p < 0.001$) in the no-BFR (72.33 ± 2.00 $W \cdot L^{-1} \cdot min^{-1}$) than in the BFR ($63.29 \pm 1.87$ $W \cdot L^{-1} \cdot min^{-1}$) condition. Therefore, it appears that the enhanced central command due to muscle BFR during exercise may have facilitated the recruitment of additional motor units to maintain the exercise intensity, contributing to the observed reduction in mechanical efficiency.

Central command has been demonstrated to primarily increase heart rate through parasympathetic withdrawal [55] and to reset the operating point of the full stimulus-response curve of carotid arterial baroreceptors toward the threshold point, i.e., to a region of lower sensitivity [12,13,45]. Therefore, the greater central command during exercise with muscle BFR may also have contributed to the additional exercise-induced reduction in cBRS observed in the current study.

Somatosensory feedback from exercising muscle has been shown to inhibit spinal and supraspinal areas of the central nervous system that regulate central motor drive, thus facilitating central fatigue during whole-body dynamic exercise [56,57]. Activation of the muscle metaboreflex during exercise inhibits the α-motoneurons innervating active skeletal muscles, reducing their excitability [56,57]. Consequently, an augmentation of central motor drive is essential to maintain the required exercise intensity [56,57]. Indeed, in the current study, exaggerated muscle metaboreflex activation was observed during dynamic exercise at the same absolute and relative intensities with muscle BFR compared to the no-BFR condition. The augmented blood pressure response to exercise consistently indicates an elevation in central motor drive [58,59]. Moreover, the rating of perceived leg discomfort, an index associated with both central command and muscle afferent feedback [60,61], was significantly greater with muscle BFR compared to the no-BFR condition.

Interestingly, the depression of cBRS during exercise with muscle BFR might compromise the short-term buffering capacity of arterial blood pressure fluctuations, particularly at high exercise intensities, potentially increasing cardiovascular strain. Although the reductions in cBRS observed in the present study were acute and reversible, they may provide a physiological model that partially resembles conditions characterized by chronically impaired baroreflex function, such as reduced carotid sinus integrity following neck irradiation or other vascular pathology [62]. Arterial baroreceptors located within the carotid sinus and aortic arch normally regulate short-term blood pressure through stretch-mediated afferent signaling to central autonomic centers. In chronic pathological conditions, structural alterations of the carotid artery (e.g., fibrosis, endothelial dysfunction, or accelerated atherosclerosis) may impair carotid sinus mechanosensitivity, resulting in persistent baroreflex dysfunction, reduced baroreceptor sensitivity, and sustained autonomic imbalance, often with sympathetic predominance [63]. In contrast, BFR induces transient hemodynamic perturbations without structural vascular injury, leading to short-lived autonomic adjustments. In such clinical settings, chronic baroreflex dysfunction has been associated with impaired blood pressure buffering and increased cardiovascular risk. This is especially relevant in individuals with preexisting cardiovascular constraints or in exercise contexts where blood flow restriction is used as a training method. Functionally, the augmented cBRS reduction may contribute to an earlier onset of exhaustion, reduced exercise performance, and/or increased cardiovascular stress during maximal exercise. The aforementioned concept is supported by the findings of lower maximal heart rate concomitant with reduced power output, and increased blood pressure observed at exhaustion with muscle BFR in the current study. Collectively, these findings indicate that muscle BFR not only imposes local metabolic and mechanical stress but also modifies central cardiovascular regulatory mechanisms. Comprehending the interplay between peripheral afferent feedback and central baroreflex regulation is crucial for interpreting cardiovascular responses under blood flow restriction conditions and for enhancing training protocols that incorporate BFR.

4.3. Baroreflex Sensitivity and Exercise Performance

In the current study, exercise tolerance was significantly deteriorated, and maximal heart rate was significantly reduced during exercise with muscle blood flow restriction.

The observed reduction appears to be strongly associated with baroreflex sensitivity modification. Indeed, cBRS was significantly attenuated at exhaustion compared to baseline, and the magnitude of this reduction was significantly correlated with maximal heart rate and peak power output. Thus, we suggest a mechanistic association between impaired baroreflex function and the observed limitations in cardiovascular performance.

It is worth mentioning that participants who exhibited the greatest reduction in cBRS during dynamic exercise also demonstrated the lowest maximal heart rate and peak power output, indicating the potential predictive value of baroreflex function for exercise tolerance. These findings are consistent with previous studies indicating that the impairment of arterial baroreflex function could constrain chronotropic responsiveness and impair cardiovascular response during intense exercise [64–66].

Physiologically, during high-intensity dynamic exercise, a functioning baroreflex facilitates optimal heart rate and blood pressure modulation in response to increased metabolic demands. When baroreflex buffering is compromised, as shown in our study, an inadequate balance between sympathetic activation and vagal withdrawal might result in reduced heart rate acceleration and exaggerated pressor responses [48,67]. This autonomic imbalance can result in premature cessation of exercise due to insufficient cardiac output or increased cardiovascular strain.

Interestingly, the strong associations observed between baroreflex sensitivity and both exercise tolerance and maximal heart rate indicate that cBRS may not only reflect autonomic status but may also play an important role in determining the upper limits of exercise tolerance. To our knowledge, no studies have evaluated the possible effects of arterial baroreflex sensitivity on exercise performance in healthy individuals. However, data in clinical populations provide some evidence for a possible association between the baroreflex function attenuation and exercise performance. Specifically, patients with cardiovascular disease, including heart failure, autonomic dysfunction, and aging, exhibit depressed cBRS, which correlates with decreased exercise tolerance [5,68–70]. This suggests that blunted cBRS is a reliable predictor of exercise intolerance. These findings indicate that a decrease in baroreflex sensitivity, especially during mechanical or circulatory stress conditions, may markedly contribute to the observed reduction in exercise tolerance attributed to limitations in heart rate reserve and enhanced cardiovascular strain.

4.4. Study Limitation

Certain limitations should be acknowledged in this study. First, the sample consisted of young, healthy individuals, which limits the generalizability to clinical populations. Secondly, while the muscle blood flow restriction model effectively imposed circulatory and metabolic stress, it fails to fully replicate pathophysiological conditions, including chronic ischemia or autonomic neuropathy. Third, the evaluation of carotid baroreflex sensitivity was performed using a dynamic measurement technique, which is based on the linear dynamic analysis of heart rate and blood pressure fluctuations during graded maximal exercise trials. This technique determines only the sensitivity at the operating point of the carotid arterial baroreflex, which differs from the maximal sensitivity obtained from the full stimulus-response curve. Thus, the sensitivity only around the operating point of the HR-BP relationship decreases during exercise. Furthermore, muscle BFR significantly increased diastolic blood pressure during exercise compared to the no-BFR condition. Therefore, the possible effect of cardiopulmonary receptors as an additional neural stimulus on arterial baroreflex function should not be completely ignored. Finally, our study showed significant associations between cBRS and cardiovascular performance; however, causality remains unconfirmed. Further interventional studies, such as those involving baroreflex stimulation

or blockade, are necessary to investigate whether the enhancement of baroreflex function can directly improve exercise tolerance or cardiovascular performance.

5. Conclusions

In conclusion, this study provides novel insight into the alterations of cBRS during a series of constant-workload exercise trials at increasing intensities with and without muscle BFR. Importantly, the significant associations between cBRS, maximal heart rate, and exercise performance suggest that impaired baroreflex function may contribute to cardiovascular limitations in healthy individuals. These findings have significant implications for enhancing training and performance in athletes, as well as for applications in clinical settings. Specifically, the assessment of changes in cBRS may be an important method for identifying individuals with impaired autonomic regulation, including those with hypertension, heart failure, or metabolic syndrome, who may face increased risk during physical exertion or demonstrate reduced responsiveness to exercise interventions. Future studies should investigate the determinants of baroreflex impairment and assess whether interventions intended to preserve or enhance baroreflex function, such as aerobic training, pharmacological modulation, or neuromodulation, can improve exercise tolerance and cardiovascular resilience in both healthy individuals and clinical populations.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BFR	Blood flow restriction
BRS	Baroreflex sensitivity
cBRS	Carotid baroreflex sensitivity
Δ[O_2Hb]	Changes in oxyhemoglobin concentration
Δ[HbDiff]	Changes in hemoglobin difference concentration
Δ[HHb]	Changes in deoxyhemoglobin concentration
Δ[THb]	Changes in total hemoglobin
DBP	Diastolic blood pressure
GLM	General linear models
HR-BP	Heart rate-blood pressure
MAE	Mean absolute error
MAP	Mean arterial pressure
no-BFR	No blood flow restriction
RMSE	Root mean square error
SBP	Systolic blood pressure

SV	Stroke volume
PPO	Peak power output
$\dot{Q}$	Cardiac output
RER_{max}	Respiratory gas exchange ratio
$RPE_{dyspnea}$	Perception rate of dyspnea
RPE_{leg}	Perception rate of leg discomfort
SEM	Standard error of measurements
$\dot{V}O_{2max}$	Maximal oxygen consumption

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