

Acute physiological and perceptual responses to moderate intensity cycling with different levels of blood flow restriction

AUTHORS: Jia Wei¹, George P. Nassis^{1,2}, Zhengqiu Gu¹, Yongdi Zou¹, Xiaolu Wang¹, Yongming Li^{1,3}

¹ School of Physical Education and Sport Training, Shanghai University of Sport, Shanghai, China

² Department of Sports Science and Clinical Biomechanics, Faculty of Health Sciences, SDU Sport and Health Sciences Cluster, University of Southern Denmark, Odense, Denmark

³ China Institute of Sport Science, Beijing, China

ABSTRACT: The aim of this study was to compare: i) the physiological and perceptual responses of low-load exercise [(moderate intensity exercise (MI)) with different levels of blood flow restriction (BFR), and ii) MI with BFR on the bike with high intensity (HI) exercise without BFR. The protocol involved large muscle mass exercise at different levels of BFR, and this differentiates our study from others. Twenty-one moderately trained males (age: 24.6 ± 2.4 years; VO_{2peak} : 47.2 ± 7.0 ml·kg⁻¹·min⁻¹, mean \pm sd) performed one maximal graded exercise test and seven 5-min constant-load cycling bouts. Six bouts were at MI [40% peak power (P_{peak}), 60% VO_{2peak}], one without BFR and five with different levels of BFR (40%, 50%, 60%, 70%, 80% of estimated arterial occlusion pressure). The HI bout (70% P_{peak} , 90% VO_{2peak}) was without BFR. Oxygen uptake (VO_2), heart rate (HR), blood lactate (BLa), rate of perceived exertion (RPE), and tissue oxygen saturation (TSI) were recorded. Regardless of pressure, HR, BLa and RPE during MI-BFR were higher compared to MI ($p < 0.05$, ES: moderate to very large), and TSI reduction was greater in MI-BFR than MI ($p < 0.05$, ES: moderate to large). The responses of VO_2 , HR, BLa, RPE and TSI induced by the different levels of BFR in MI-BFR were similar. Regardless of pressure, the responses of VO_2 , HR, BLa and RPE induced by MI-BFR were lower than HI ($p < 0.05$), except for TSI. TSI change was similar between MI-BFR and HI. It appears that BFR equal to 40% of arterial occlusion pressure is sufficient to reduce TSI when exercising with a large muscle mass.

CITATION: Wei J, Nassis GP, Gu Z et al. Acute physiological and perceptual responses to moderate intensity cycling with different levels of blood flow restriction. *Biol Sport*. 2021;38(3):437–443.

Received: 2020-08-06; Reviewed: 2020-09-04; Re-submitted: 2020-09-20; Accepted: 2020-10-05; Published: 2020-10-28.

Corresponding author:

Yongming Li

School of Physical Education and Sport Training
Shanghai University of Sport
Shanghai, China

Key words:

Blood flow restriction
Aerobic exercise
Oxygen uptake
Near-infrared spectrum

INTRODUCTION

Lack of exercise for a long time may accelerate muscle atrophy, induce skeletal muscle metabolism changes, interfere with the ability of skeletal muscles to adapt to stimulation, and increase the risk of chronic diseases [1, 2]. Proper aerobic exercise (AE) is beneficial for cardiovascular, neurocognitive and physical function [3], and is also helpful for performance enhancement [4] and recovery from exercise [5]. Although high intensity exercise is beneficial to health [6], it may not be feasible for people who are unable to tolerate higher exercise intensity, such as the obese, those under rehabilitation and the elderly [7].

Recently, blood flow restriction (BFR) combined with AE has received wide attention because it requires lower exercise intensity and less training time [8]. Long-term studies have reported that low intensity (30–40% VO_{2max}) aerobic exercise with blood flow restriction (LI-BFR AE) could improve aerobic (e.g. VO_{2max}) [9, 10] and anaerobic capacity [10] as well as endurance performance [11]. In addition, LI-BFR AE can induce significant muscle hypertrophy and result in muscle strength gains [12]. The uniqueness of BFR is that the venous blood flow is pooled by applying external positive pressure

and the inflow of the artery is partially reduced, thereby achieving a state of ischemic hypoxia [13, 14]. This state is considered to lead to higher hemodynamic and metabolic stress compared to exercise sessions of similar exercise intensity without BFR which results in positive acute and chronic adaptations [15].

There are some studies which compare the acute effects of low intensity AE with or without BFR and HI AE on variables which are important to training adaptations [15–19]. It is reported that BFR AE significantly increased the exercise-induced elevation in heart rate (HR) [15–19] and blood lactate concentration (BLa) [15–18] compared to AE at the same relative intensity without BFR. However, different studies showed inconsistent results with regards to VO_2 and rate of perceived exertion (RPE) responses. Some studies report that BFR AE induced a significant increase in VO_2 compared to AE with the same intensity without BFR [15, 18, 19], while others reported similar VO_2 responses between the two [17, 20, 21]. Additionally, some studies found that RPE induced by traditional HI-AE was significantly greater than during LI-BFR AE [16–18], whereas others showed no difference between the groups [15]. Although there are

some differences in the exercise protocols of these studies, one factor to explain the discrepancies between studies is the different levels of BFR used.

External pressure is a key factor in BFR training, which could affect training adaptations. According to the “hormesis effect”, substances that have harmful biological effects at moderate to high doses may have beneficial effects at low doses [22]. If the “hormesis effect” holds in BFR training an optimal external pressure could produce the maximal training effect [23]. An important methodological problem in BFR training is that the fixed absolute pressure may not restrict participants’ blood flow to an equal degree in all individuals [24]. Recently, a better method was suggested, which is to estimate the arterial occlusion pressure (AOP) based on the thigh circumference of the individual [24, 25]. Research suggests that muscular blood flow is relatively constant in the range of 40% to 90% of arterial occlusion pressure [26]. However, acute studies are either at rest [25, 27] or during exercise with small muscle groups [28]. Among the studies involving exercise at submaximal intensities with large muscle mass such as running [15] and cycling [16–18] only one has employed different levels of occlusion pressure, which are 40% and 60% AOP [16]. Their results showed no difference between the two BFR groups in terms of blood lactate, HR and RPE responses [16].

Exercising with a large muscle mass will increase blood pressure for the same relative intensity, and this may affect blood flow in the working muscles [24, 28]. Based on the equation of blood flow (blood flow = mean arterial pressure (MAP) / total peripheral resistance), it is assumed that any increase in MAP will affect blood flow. Previous studies have shown that for the same % of VO_{2max} , systolic blood pressure was higher when exercising with a large muscle mass compared with the condition of exercising with a small muscle mass [29]. Hence, it is hypothesized that exercising at submaximal intensity with relatively large muscle groups may influence the level of occlusion pressure required to occlude the artery.

Therefore, the purpose of this study was to examine the physiological and perceptual responses during moderate intensity aerobic cycling exercise with or without blood flow restriction (MI and MI-BFR) at different levels of AOP. An additional aim was to compare these responses with those during high intensity aerobic exercise (HI). We hypothesized that i) MI-BFR will induce greater physiological and perceptual responses than MI, and ii) those responses in MI-BFR will be similar to those in HI.

MATERIALS AND METHODS

Subjects

Twenty-one moderately trained men (age: 24.6 ± 2.4 years, height: 1.76 ± 0.07 m, body mass: 74.2 ± 10.3 kg, body mass index: 23.8 ± 2.0 kg·cm⁻², mean \pm SD, training experience: more than 8 years) volunteered for this study. All subjects were free of injuries within the past 6 months and had been training for at least three times per week. Their physical activity was assessed with the PAR-Q

(Physical Activity Readiness Questionnaire) before the commencement of the study. Inclusion criteria were: normal BMI (< 30 kg·cm⁻²), no tobacco use, blood pressure < 140 mmHg and 90 mmHg [no hypertension [30]], and absence of heart disease and potential thrombosis. Following screening, it was confirmed that all subjects met the criteria. The participants were informed about the procedures involved in the tests, and signed informed consent was obtained. The study was approved by the Shanghai University of Sport ethical committee (code 2015018).

Exercise protocols

In the first visit, subjects’ thigh circumference was measured to determine the individual AOP. They also performed one maximal graded exercise test and became familiar with BFR cycling. In the following visits, they performed seven 5-min bouts of exercise of constant load on a cycle ergometer (Excalibur Sport, Lode, The Netherlands). Six of these exercise bouts were at low load and one at high load. The order of exercise bouts was randomized and they were performed with at least a 24-hour recovery period in between. The cadence in all cycling bouts was between 70 and 80 RPM. The time between the maximal test and the first submaximal bout was 2 weeks at the minimum.

Maximal graded exercise test

Subjects completed a maximal graded exercise test to determine the peak oxygen uptake (VO_{2peak}) and the peak power output (P_{peak}). After 5 min of warm-up at 100 W, they performed the ramp protocol consisting of 1 min at 60 W, followed by a ramp increase in power output of 25 W per 1 min (0.42 W per s). This was performed until subjective exhaustion or inability to maintain the requested cadence for more than 10 s. Verbal encouragement was given during the exercise. VO_{2peak} was defined as the highest average VO_2 value of 30 s in the test. The P_{peak} was determined by the formula: $P_{peak} (W) = (W) + [t (s) / \text{time per stage (s)} \times \text{incremental power per stage (W)}]$, where t was the time of an unfinished stage.

Submaximal exercise bouts

Subjects randomly performed seven exercise bouts of constant load: one low-load (moderate intensity) AE bout without BFR (MI, 40% P_{peak}), five moderate intensity AE bouts with BFR (MI-BFR, 40% P_{peak}), and one high load (high intensity) AE (HI, 70% P_{peak}) without BFR. The five different flow restriction pressures were 40%, 50%, 60%, 70% and 80% of the estimated arterial occlusion pressure. Each exercise bout consisted of a 5 min warm-up at 100 W, and 5 min cycling with constant load.

Estimated arterial occlusion pressure

Prior to MI-BFR, the thigh circumference was measured for each subject to estimate the individual arterial occlusion pressure as described before (Table 1) [24]. The average estimated AOP of our participants was 311 ± 31 mmHg. The elastic BFR cuffs we used

TABLE 1. Arterial occlusion pressure (AOP) applied in our study based on individual's thigh circumference (Based on [24]).

Thigh circumference (cm)	Pressure used (40% AOP)	Pressure used (50% AOP)	Pressure used (60% AOP)	Pressure used (70% AOP)	Pressure used (80% AOP)
< 45–50	80	100	120	140	160
51–55	100	125	150	175	200
56–59	120	150	180	210	240
> 60	140	175	210	245	280

(Kaatsu-Master, Kaatsu, Japan) had a width of 5 cm and were worn on the proximal portion of both legs. Prior to exercise, after other devices were worn, subjects were seated on a chair, and the BFR cuffs were repeatedly inflated (30 s) and deflated (10 s) from an initial pressure of 50 mmHg to the final pressure with increments of 40 mmHg. Once the cuffs were inflated to the target pressure, the cycling test started. The cuffs were applied during exercise and were released immediately after the end of exercise.

Measurements

Thigh circumference

The thigh circumference of the dominant leg was measured with an anthropometric tape at the 33% position from the groin fold distance to the patella (knee cap) as previously suggested [24]. This was the position the BFR cuffs were applied.

Cardiopulmonary measures

A portable gas analyser was used to determine VO_2 breath by breath (K4b², Cosmed, Italy) during exercise. The instrument was calibrated according to standard procedures prior to each testing. Briefly, the system was warmed up for about 30 minutes before calibration. The gas analyser was calibrated with room air and a reference gas mixture (16% O_2 and 5% CO_2), whereas the volume transducer was calibrated using a 3-L syringe. Heart rate was continuously recorded using a heart rate belt (Polar Accurex Plus, Polar Electro Oy, Finland). The 30 s average HR before the end of the exercise was used for the analysis.

Blood lactate

10 μL of capillary blood was collected from the earlobe at rest, immediately prior to exercise, and at 1, 3, 5, 7, 10 min after the end of exercises, and further analysed with a blood lactate analyser (Biosen S_Line, EKF Diagnostic, Germany). The highest value during the recovery was reported as the peak BLA (BLA_{peak}).

Muscle oxygenation

Near-infrared spectroscopy (NIRS, Portalite, Artinis Medical Systems, Netherlands) was used to determine muscle tissue oxygen saturation [31, 32]. The Portalite consists of three light-emitting diodes,

positioned 30 mm, 35 mm and 40 mm from a single receiver, which transmitted infrared light at two wavelengths (760 nm and 850 nm). The received light at the device was calculated as the relative absorption of oxy-haemoglobin (O_2Hb), deoxy-haemoglobin (HHb), and total haemoglobin (tHb) presented as arbitrary units. These parameters were recorded continuously from a resting sitting position on a chair with a knee joint angle of 90° before exercise to the end of exercise with a sampling rate of 10 Hz. The probe was applied at the vastus lateralis of the dominant leg, approximately 16 cm above the knee joint [33], and the position of the probe was recorded using non-erasable ink. The probe was covered and secured with tape to prevent light interference and detachment during exercise. The relative tissue saturation index (ΔTSI) was calculated as: $[\text{O}_2\text{Hb}/(\text{O}_2\text{Hb}+\text{HHb})] \times 100$. ΔTSI was the average of 30 s before the end of exercise minus the resting average of 60 s before the exercise. The validity and reliability of continuous-wave NIRS with Portalite has been checked and found acceptable during orthostatic stress-induced shifts in lower leg blood volume [34], and the NIRS also has been applied in BFR studies, such as isometric contraction [35], knee extension [27] and arm cycling [36].

RPE

RPE was reported 10 s before the end of exercise using the Borg 6–20 scale [37]. All participants became familiar with the Borg scale before the commencement of the study.

Statistical analyses

IBM SPSS Statistics V25.0 (IBM Corp., Chicago, USA) and the level of significance was set at $p < 0.05$. The Shapiro-Wilk and Levene's tests were used to test the normality and homogeneity of the data, respectively. Only HR and TSI passed the two tests. For the non-normally distributed variables (VO_2 , BLA, RPE), the values were log-transformed before we performed a one-way ANOVA. When a significant interaction was found, the Bonferroni post hoc test was performed. In addition, the Cohen d effect size (ES) was calculated. The criteria to interpret the magnitude of the ES were: 0.0–0.2 considered as trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, > 2 very large [38]. Data are presented as mean \pm SD.

RESULTS

VO_{2peak} and P_{peak} of the subjects were $47.2 \pm 7.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $316 \pm 29 \text{ W}$, respectively. VO_2 was similar among MI and the MI-BFR bouts corresponding to 61.0–61.4% of VO_{2max} (Figure 1).

Heart rate, BLa_{peak} , and RPE were higher in MI-BFR bouts compared to MI, irrespective of the occlusion pressure ($p < 0.05$; ES: moderate to very large). There was no difference in those responses between the experimental conditions with the various BFR levels. VO_2 during

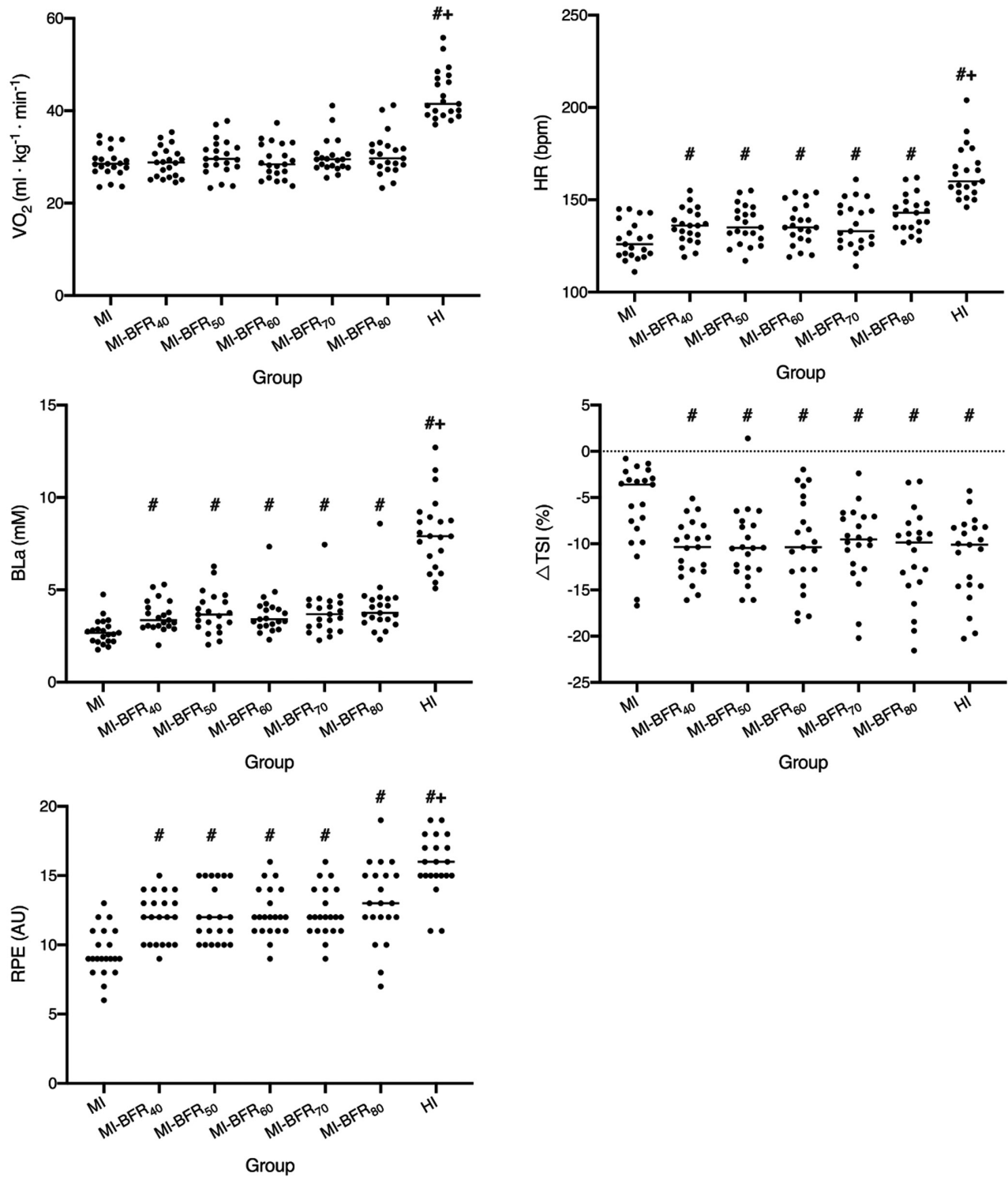


FIG. 1. Individual values and means (represented with a bar) for the physiological and perceptual responses during MI, MI-BFR and HI. Note: MI: moderate intensity aerobic exercise (40% of peak power), MI-BFR: moderate intensity aerobic exercise with BFR, HI: high intensity aerobic exercise (70% of peak power). VO_2 , oxygen uptake; HR, heart rate; BLa , blood lactate; TSI, tissue saturation index; RPE, rate of perceived exertion. # $p < 0.05$ for the difference compared to MI and + $p < 0.05$ for the difference of HI with any of MI-BFR conditions.

HI exercise corresponded to 91.4% of VO_{2max} and was higher compared to all MI exercise bouts ($p < 0.05$). HR was higher by 42 beats/min in HI compared to MI and by 23–31 beats/min compared to MI-BFR. BLa_{peak} concentration was 6.8 mmol/l greater in HI compared to MI and 4.1–4.5 mmol/l higher compared to the BFR conditions. RPE was 7 a.u. higher in HI compared to MI and by 3–4 a.u. compared to all MI-BFR conditions ($p < 0.05$; ES: large to very large). With regards to ΔTSI , its % change was greater in MI-BFR compared to MI ($p < 0.05$, ES: moderate to large; Figure 1). Finally, the ΔTSI was similar between MI-BFR_{40/50/60/70/80} and HI (MI-BFR_{40/50/60/70/80} range: $-10.0 \pm 4.2\%$ to $-11.3 \pm 4.9\%$, HI: $-11.5 \pm 4.5\%$).

DISCUSSION

Our findings showed that 1) moderate intensity exercise with an individualized occlusion pressure was more demanding given that heart rate, blood lactate and RPE responses were higher compared to moderate intensity exercise without BFR, 2) compared to high intensity, moderate intensity exercise with blood flow restriction produced a similar level of TSI decline, which is an indirect index of muscle hypoxia, and 3) arterial occlusion pressure of 40% is sufficient to produce a comparable decline in tissue oxygenation when exercising at moderate intensity with a relatively large muscle mass.

The similarity in TSI decline between MI-BFR and HI may indicate a similar level of muscle hypoxia between the two conditions despite the fact that exercise intensity is much lower in the former (40% P_{peak}) compared to the latter (70% P_{peak}). Previous studies have shown a decline in muscle blood flow as a result of external pressure application [26, 28]. In the former study, as the external pressure applied on the thigh increased from 0% to 100% of occlusion pressure, blood flow and mean blood velocity in the posterior tibial artery decreased in a linear manner [26]. In contrast, Crossley et al. [28] reported a non-linear decline in muscle blood flow characterized by an abrupt rate of decline in muscle blood flow as the occlusion pressure increased from 80% to 100%. One point relevant to our study is that, to our best knowledge, no data exist on the relationship between different levels of occlusion pressure and muscle blood flow while exercising with relatively large muscle groups.

What is interesting in our study is that although we adopted five different blood flow restriction levels, from 40% to 80% arterial occlusion pressure, 40% of arterial occlusion pressure during moderate intensity exercise was adequate to produce a similar decline in TSI compared to HI despite the lower relative exercise intensity. Ours is one of the very few studies showing this effect when exercising at submaximal intensity with a large pressure scale and a large muscle mass. Previous studies have used small muscle mass exercise tasks such as plantar flexion and knee extension [27, 28]. In the latter study, an occlusion pressure of 40% provided an ischemic stimulus comparable to that of 80% occlusion pressure during plantar flexion [28]. In knee extension, BFR of 40% AOP reduced TSI to the same degree compared with 60% and 80% AOP [27]. Our results

in cycling confirm the previous findings during exercise with much smaller, compared to our study, muscle mass involved.

Another interesting finding of our study is the large individual differences in TSI responses (Figure 1). This variability occurred despite the fact that we applied an AOP based on individual characteristics and employed similar relative exercise intensity. Both physiological and methodological factors can explain our findings. The occlusion pressure required to reduce blood flow could have been affected by the individual's systolic blood pressure, as previously reported [25]. Similarly, the estimation of AOP is based on resting measurements, and this could be a source of error. Barnett et al. [39] reported that mean arterial occlusion pressure during upper-body exercise with a small muscle mass (elbow flexion) was about 13% higher compared to that at rest. These results were confirmed later during lower-body exercise with a small muscle mass (plantar flexion [28]). Whether this is also the case during lower body exercise with a large muscle mass, as in our study, remains to be investigated. In addition to the above-mentioned factor, the potential differences in occlusion pressure between the legs, as shown before [28], could also have affected our results. Furthermore, due to lack of detectors to measure blood flow, AOP was estimated based on thigh circumference in our study, and this could also be a reason for the variability in TSI change. Indeed, for the same thigh circumference a difference in fat thickness could have affected the NIRS signal [40]. It is also possible that the NIRS signal was derived from differently affected small vessels in our study's participants. We assume that the microcirculation may be affected in a slightly different pattern among individuals [40].

CONCLUSIONS

In conclusion, our study shows that greater pressure could not increase the acute physiological and perceptual responses. The blood flow restriction equal to 40% of arterial occlusion pressure is sufficient to reduce TSI during moderate intensity exercise with relatively large muscle groups. This BFR level seems to stress the physiological mechanisms at the muscular level adequately, and there is no need for higher external pressure application. This level of BFR can also produce local hypoxia similar to that during HI. Therefore, moderate intensity exercise with BFR could be an alternative exercise mode for individuals who are unable to perform high intensity exercise. Our study is one of the few that have examined the effect of BFR when exercising at moderate intensity with relatively large muscle groups in a common exercise model (cycling). Therefore, our findings are more applicable to a real-life setting, and this differentiates our study from the previous ones.

Acknowledgements

Funding source: Ministry of Science and Technology of the People's Republic of China, 2018YF0300901; Shanghai Science and Technology Commission, TP2017063; State Sports Administration of China, Basic 17-30

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