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RESEARCH

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Effects of blood flow restriction moderate intensity interval training on aerobic and anaerobic capabilities and lower extremity performance in male college basketball players

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Abstract
This study investigated whether blood flow restriction moderate-intensity interval training (BFR-MIIT) could achieve or surpass the training effects of high-intensity interval training (HIIT) at lower training intensities. A total of 33 male college basketball players completed the trial and were randomly assigned to the BFR-MIIT group ($n = 17$) and the HIIT group ($n = 16$). Both groups performed the 4×4 "Norwegian" training method, with the BFR-MIIT group engaging in moderate-intensity training and the HIIT group in high-intensity training. Assessments included the Wingate Anaerobic Power Test, the multistage 20-meter shuttle run test, and tests of jumping ability (countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ)), sprinting ability (30-meter sprint), and change of direction ability (505 test). Post-intervention, both the BFR-MIIT group ($p < 0.001$, ES=-1.199) and the HIIT group ($p = 0.02$, ES=-0.526) showed significant and equivalent improvements in VO_{2max}. However, neither group significantly improved peak power (PP) or relative peak power (PP/kg). The BFR-MIIT group demonstrated superior improvements in lower extremity performance compared to the HIIT group in CMJ ($p = 0.007$; ES=-0.570), SJ ($p < 0.001$; ES=-0.537), DJ ($p < 0.001$; ES=-0.805), and the 505 test ($p < 0.001$; ES = 1.708). Additionally, across four measurements of the Rate of Perceived Exertion (RPE), the BFR-MIIT group reported significantly lower RPE than the HIIT group ($p < 0.05$). In conclusion, compared to HIIT, BFR-MIIT can achieve equivalent improvements in aerobic capacity at lower training intensities and perceived exertion while yielding better improvements in lower extremity performance.

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Keywords Blood flow restriction, Moderate intensity interval training, Aerobic capacity, Anaerobic capacity, Lower extremity performance

Introduction

Basketball is an intermittent team sport with many high-intensity sprints, accelerations, decelerations, changing directions, jumps, and specialized technical actions during matches [1–6]. Typically, basketball players run a distance of approximately 6.4–7.6 km on the court during a game, including 1.7 km of high-intensity exercise and 1.6 km of moderate-intensity exercise [6, 7]. As reported, Elite athletes jump an average of 44 ± 7 times and perform an average of 997 ± 83 sprints and changes of direction per game [8, 9]. Therefore, to maintain high-level performance throughout the game, having excellent aerobic and anaerobic capacities and sprinting, jumping, and changing direction abilities appear to be increasingly essential prerequisites for top-level athletes [8, 10–13].

High-intensity interval training (HIIT) is a training method that involves exercise at intensities exceeding 90% of maximum oxygen uptake (VO_{2max}) or maximum heart rate (HRmax), lasting between 10 s and 5 min, with inadequate rest intervals [14, 15]. It is commonly used to improve the cardiorespiratory function of basketball players [16]. It has been shown to positively affect abilities such as jumping, sprinting, and change of direction under specific conditions [17, 18]. However, the exceptionally high intensity of HIIT sessions may lead to excessive fatigue in athletes [19, 20]. Symptoms of excessive fatigue can manifest during or immediately after HIIT training and, in some cases, persist until the next HIIT session [19, 20]. In basketball seasons, HIIT-induced excessive fatigue may have detrimental effects on performance, particularly in activities such as dribbling, shooting, passing, sprinting, and jumping [21–23]. Therefore, there is a pressing need for a training method to achieve equal or superior effects to high-intensity training at lower intensities.

Blood Flow Restriction Training (BFRT), initially applied in the realm of sports rehabilitation, particularly in the early stages of recovery to enhance muscle mass and muscle circumference [24], has shown promising rehabilitation outcomes for patients with anterior cruciate ligament ruptures [25], Achilles tendon ruptures [26], and ankle instabilities [27]. Over the past decade, BFRT has increasingly been incorporated into sports science, commonly used in resistance training to develop muscle strength, and has been demonstrated to improve muscle circumference and strength [28, 29]. Most notably, BFRT is a training method that can achieve the effects of high-intensity training at a lower intensity [30]. Meta-analysis results by Lixandrão et al. [31] indicate that resistance training under blood flow restriction can achieve 70–92% of the strength training effects of a one-repetition maximum (1RM) with only 10–40% of 1RM. Beyond its application in resistance training, BFRT has also been applied to aerobic training, typically combined with walking [32], jogging [33], and cycling [34], to study its impact on aerobic metabolism. Research suggests that despite the lower training intensity, BFRT remains an effective method for enhancing aerobic capacity and performance [35]. For example, Oliveira et al. [30] combined low-intensity interval training with BFRT, and their findings indicated that wearing a compression band during aerobic training improves aerobic capacity and positively affects muscle strength. However, most research has concentrated on combining blood flow restriction with low-intensity aerobic exercises, mainly targeting the elderly and adolescents. There is a relative dearth of research on BFRT in athletes, especially studies integrating it with moderate-intensity interval training(MIIT). Furthermore, to avoid the potential for sports injuries associated with high-intensity interval training, there is a need for a training approach that combines external loads to achieve high-intensity training outcomes while reducing the intensity of the training. In essence, we need a training method that reconciles training effectiveness with the risk of sports injuries.

Considering the potential risk of excessive fatigue associated with HIIT and the significant effects of BFRT on improving training efficiency, this study designed an experiment to verify whether blood flow restriction moderate intensity interval training (BFR-MIIT) can achieve or even surpass the training effects of HIIT at lower training intensities and fatigue levels. Specifically, this study hypothesizes that both BFR-MIIT and HIIT can significantly improve the aerobic and anaerobic capacities of the participants. In terms of lower extremity performance, the effects of BFR-MIIT may be superior to HIIT. By comparing the effects of the two training modalities, this study aims to provide a more scientific and efficient training method for athletes.

Methods

Experimental approach to the problem

A randomized controlled design was employed in this study to investigate the effects of twice-weekly (Tuesdays and Thursdays) BFR-MIIT on the aerobic and anaerobic capabilities and lower extremity performance of male college basketball athletes over six weeks. Participants were assigned randomly to either the BFR-MIIT or HIIT group. Prior to the intervention, all participants underwent one familiarization session and two testing sessions, which included the Wingate Anaerobic Power Test (WAnT), the multistage 20-meter shuttle run test, as well as tests of jumping ability, sprinting ability, and change of direction ability.

Participants

The sample size of this study was estimated using G-power software, with a significance level (α) of 0.05, a statistical power (1-β) of 0.85, and an effect size (ES) of 0.95, which was based on the research findings of Lu et al. [36]. The estimation result showed that a minimum total sample size of 29 participants was required for this study. Considering a potential dropout rate of 20%, 34 male college basketball players were recruited for the experiment. The inclusion criteria for the participants were: (1) good physical health; (2) Athletes with a national level-2 ranking or above, equivalent to Tier 3: Highly Trained/National Level in the Participant Classification Framework proposed by McKay et al. [37]; (3) no participation in BFRT; (4) experience with aerobic training; (5) no injury history in the previous six months; and (6) no cardiovascular diseases. After completing the initial testing, the participants were randomly assigned to either the BFR-MIIT or HIIT group. Participants who missed more than two training sessions or suffered injuries during the training process were excluded from the study. All participants voluntarily participated in the experiment and signed an informed consent form.

Procedure and evaluation

To reduce the influence of circadian rhythms, both groups of participants were required to attend two testing sessions at the same time of day. Prior to the pre-test, a familiarization session was provided to the participants, which included the following: (1) an explanation of the experimental procedure, including the timing of the tests and interventions, as well as the testing items and intervention methods; (2) an experience of wearing the KAATSU devices (Kaatsu-Master, KAATSU Global, Japan) during aerobic exercise and becoming familiar with the Heart Zone Moves team heart rate monitor (Heart Zone Moves, Upbeat Workouts, USA); (3) instruction on the proper execution of each training movement; and (4) an explanation of the use of the rating of perceived exertion (RPE) scale. At the end of the familiarization session, the participants were informed of the precautions for the study. During the intervention period, the precautions were as follows: (1) all participants were required to wear basketball apparel; (2) all participants were required to arrive at the testing site on time; (3) while participating in the experiment, participants were allowed to engage in other physical activities, but not other experimental interventions; and (4) participants were required to ensure sufficient sleep during the intervention period. During the testing period, the precautions were as follows: (1) Participants should refrain from engaging in high-intensity exercise for 48 h prior to the testing period.; (2) all participants were required to ensure sufficient sleep and avoid staying up late; (3) alcohol, caffeine, tobacco, and other stimulants should be avoided for at least six hours prior to testing; and (4) the equipment worn during pre- and post-tests should be as similar as possible.

Testing

Day 1

Height and weight, Height and weight measurements were taken from all participants prior to the commencement of any testing. Height and weight were measured with participants barefoot to ensure accuracy. Additionally, during weight measurements (Inbody, Seoul, South Korea), participants did not wear any clothing to minimize potential sources of measurement error that could lead to significant discrepancies. These measurements were conducted at baseline and solely used to report participants' basic information and randomization grouping.

Countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ), The jumping performance was assessed using the testing protocol of the National Strength and Conditional Association(NSCA) [38], and the SmartJump (SmartJump, Fusion Sport, Australia) device was used to obtain jump parameters, including the height of countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ). Each participant performed two trials of each jump test, with a 5-second rest period between each trial. After all participants completed the tests, the next set of tests was conducted. For each jump test, the participants placed their hands on their waist and jumped as high as possible. During the CMJ test, the participants were required to maintain an upright posture at the peak of the jump. During the SJ test, the knee angle for each participant was set at 90 degrees, and they were instructed to jump when they heard the starting signal from the tester. The height of the box for the DJ test was set at 30 cm, and the participants were required to jump off the box and then jump as high as possible upon landing on the ground. The best score from each participant was selected for further analysis.

The multistage 20-meter shuttle run test, the maximal oxygen uptake was estimated using the multistage 20-meter shuttle run test, using the testing protocol developed by Leger and Lambert [39]. Each participant performed the test once, and it was stopped when the participant could no longer keep up with the pace or felt unable to continue. The number of laps completed by the participant was recorded, and this value was used in a formula to calculate the maximal oxygen uptake.

$$\text{speed} = 8 + 0.5\,\text{stage no. and age (A, year)}$$

$$\mathrm{Y} = 31.025 + 3.238\,\mathrm{X} - 3.248\mathrm{A} + 0.1536\mathrm{AX}$$

Day 2

30-meter sprint, the 30-meter sprint test was performed using an electronic timing device (Timing Systems, Brower, USA). The device was placed 0.8 m above the ground (level with the hip joint) during the test. Participants were instructed to sprint as fast as possible upon hearing the "go" command and complete the designated sprint distance. Each participant performed two trials of the test, with a 2-minute rest period between each trial. The best score from the two trials was selected for further statistical analysis.

505 agility test, The 505 agility test was administered using the Brower Timing System equipment and following the testing protocol of the NSCA [38]. Participants were given a 10-meter acceleration distance and timing began once they passed through the light gate. They then sprinted forward to the marked line, touching it with one foot before immediately returning to the light gate, where the timing stopped. Each participant completed the test twice, with a 2-minute rest period between trials, and the best score from the two attempts was used for statistical analysis.

Wingate Anaerobic Power Test, The Wingate anaerobic power test was used to assess the anaerobic capacity of the participants. Prior to the test, all participants were informed of the testing procedure, and their weight was measured using an electronic scale. Participants were given a 2-minute slow-speed warm-up on a stationary bicycle before the actual test. Testing personnel added a load equivalent to 7.5% of each participant's body weight prior to the test [40]. At the start of the test, participants pedaled as fast as possible for 3 s without any load, and then pressed a button to add the load for the remaining 30 s of the test. Participants were instructed to exert maximum effort during the 30-second test period, and peak power and relative power were ultimately included in the analysis.

RPE and Heart Rate Monitoring, this study will utilize the Borg Rating of Perceived Exertion (RPE) scale to monitor the exertion level of the participants [41]. Participants were asked to rate their training intensity on the scale during the activity, taking into account all sensations, physical stress, and exertion, and disregarding any single factors such as leg pain or shortness of breath, while focusing on their overall exertion level [42]. The RPE scale was recorded immediately after each training session by the testing personnel. Heart rate is the most intuitive method for monitoring the training intensity of the participants in this study. Participants will wear Heart Zone Moves team heart rate monitor before each training session and have their heart rate monitored in real-time during the intervention. The heart rate zone for the BFR-MIIT group will be controlled at 70-75% of their maximum heart rate, while the HIIT group's heart rate zone will be controlled at 85–95% of their maximum heart rate. Maximum heart rate will be calculated as 220 minus the participant's age [43].

Training program

The BFR-MIIT and HIIT groups performed a standard 8-minute warm-up prior to each training session, which consisted of 5 min of dynamic stretching followed by 3 min of core activation. After the warm-up, participants underwent approximately 20 min of training intervention, which followed the 4×4 "Norwegian" training method [44, 45]. Each training was performed for 1 min in the sequence of A-B-C-D (Fig. 1), with 1 min of rest following each training. The entire set comprised four trainings, totaling 4 min of training time. Two training sets were performed during each intervention session, with a 2-minute rest period between sets [30, 46]. After completing the intervention training, all participants engaged in a standardized 60-minute basketball-specific training program, including basketball skills, tactics, offensive techniques, and defensive strategies. The basketball-specific sessions were consistently conducted by the same specialized basketball coach (W.H). Both the BFR-MIIT and HIIT groups participated in the same basketball-specific training sessions, ensuring minimal discrepancies in training intensity and total training duration among all participants.

During the training intervention, the BFR-MIIT group controlled their movement frequency using different metronome frequencies to achieve a moderate-intensity training level. Participants wore KAATSU devices around the lower extremities, with the pressure controlled between 180-200mmHg [47]. The training intensity was monitored using a team heart rate monitor (Heart Zone Moves), with the target range set at 70–75% of maximum heart rate [48]. In contrast, the HIIT group also controlled their training intensity using different metronome frequencies to achieve a high-intensity training level. However, unlike the BFR-MIIT group, the HIIT participants did not wear KAATSU devices.The training intensity was monitored using a team heart rate monitor, with the target range set at 85-95% of maximum heart rate [49]. Figure 2 displays the heart rate profiles and heart rate zone distribution during the intervention period for the BFR-MIIT and HIIT groups, based on a single training intervention from one participant per group. As

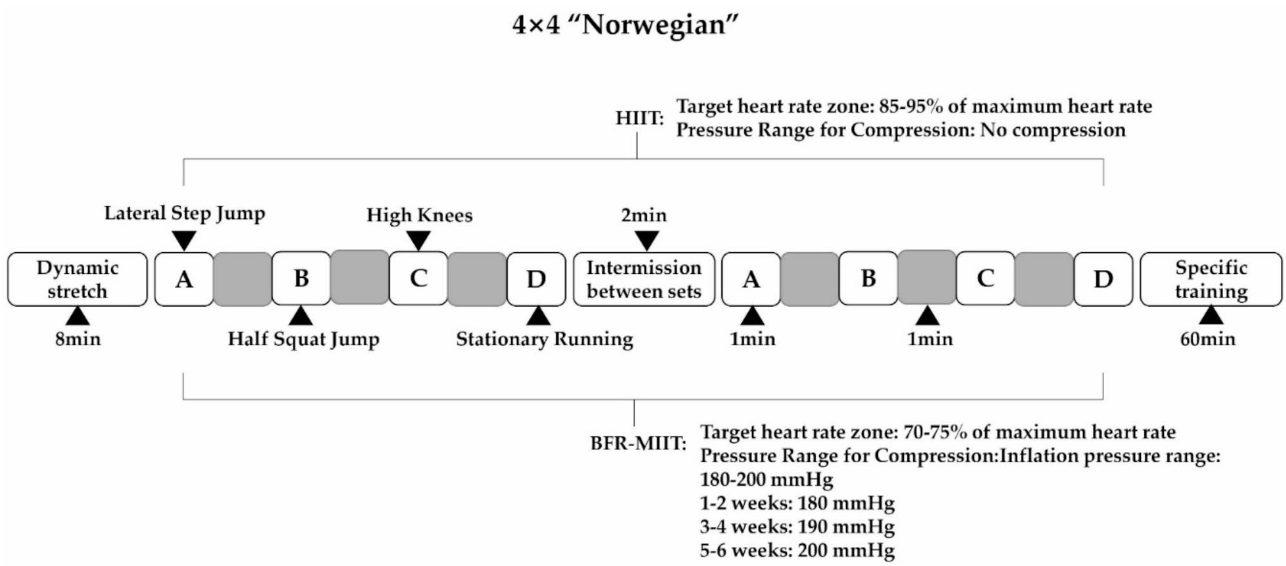

Fig. 1 Flowchart of the intervention protocols for the BFR-MIIT and HIIT groups

participants wore heart rate monitors during the warm-up period, the heart rate trace shows the dynamic warm-up phase up to approximately eight minutes, followed by the formal experimental intervention.

Statistical analysis

All variables were tested for normality using the Kolmogorov-Smirnov test, and homogeneity of variances was determined using Levene's test. Mean and standard deviation were used to present the data in the text. Data analysis was performed using JASP software [JASP Team (2020). JASP (Version 0.14.1)]. A repeated measures ANOVA with a 2 (pre-post intervention) × 2 (experimental group-control group) design was used to evaluate differences in changes between and within groups. The effect size (η_p^2) was used to measure the size of the intervention effect, with cut-off values of small ($0.01 \le \eta_p^2 \le 0.06$), moderate ($0.06 \le \eta_p^2 < 0.14$), or large ($\eta_p^2 \ge 0.14$) [50]. If significant interaction or main effects were observed in the analysis, Post Hoc Tests were conducted, and p-values were adjusted using the Bonferroni method to determine differences. In cases where the assumption of sphericity was violated, Greenhouse-Geisser correction was applied. The baseline characteristics of the study participants were compared using independent samples T-tests. The RPE between the two groups was assessed using the Mann-Whitney U test. Cohen's d was used to measure the effect size (ES) for within-group pre-post comparisons and baseline characteristics compared to RPE between groups, with the following criteria: ES < 0.2 = trivial, 0.2 ≤ ES ≤ 0.6 = small, 0.6 ≤ ES < 1.2 = moderate, 1.2 ≤ ES < 2.0 = large, 2.0 ≤ ES < 4 = very large, and ES ≥ 4 = extremely large [51]. A p-value < 0.05 was considered statistically significant.

Results

Participants analysis

One participant withdrew from the study due to missing more than two training sessions, resulting in 33 participants (BFR-MIIT = 17, HIIT = 16) completing all training sessions. Table 1 displays the baseline characteristics of the participants, and no significant differences were observed between the two groups.

Aerobic capacity

Aerobic capacity was assessed using VO_{2max}. Statistical results indicated a significant main effect of time ($F = 55.782$, $p < 0.001$, $\eta_p^2 = 0.643$) and a significant interaction effect for time * group ($F = 8.503$, $p = 0.007$, $\eta_p^2 = 0.215$) regarding VO_{2max} (Table 2). After the training period, both the BFR-MIIT group (ES=-1.199, 95%CI: -1.815 to -0.583, $p<0.001$) and the HIIT group (ES=-0.526, 95%CI: -1.022 to -0.029, $p=0.02$) showed significant improvements in VO_{2max}. However, there was no significant difference between the two groups (ES=0.627, 95%CI: -0.367 to 1.621, $p = 0.479$).

Anaerobic capacity

Anaerobic capacity was evaluated using peak power (PP) and relative peak power (PP/kg) (Table 2). The statistical analysis revealed no significant main effect of time for peak power ($F = 0.031$, $p = 0.861$, $\eta_p^2 = 0.001$), no significant main effect of group ($F = 0.035$, $p = 0.853$, $\eta_p^2 = 0.001$), and no significant interaction effect ($F = 0.01$, $p = 0.92$, $\eta_p^2 < 0.001$). Relative peak power also showed no significant main effect of time ($F = 0.629$, $p = 0.434$, $\eta_p^2 = 0.02$), no significant main effect of group ($F = 0.241$, $p = 0.627$, η_p^2

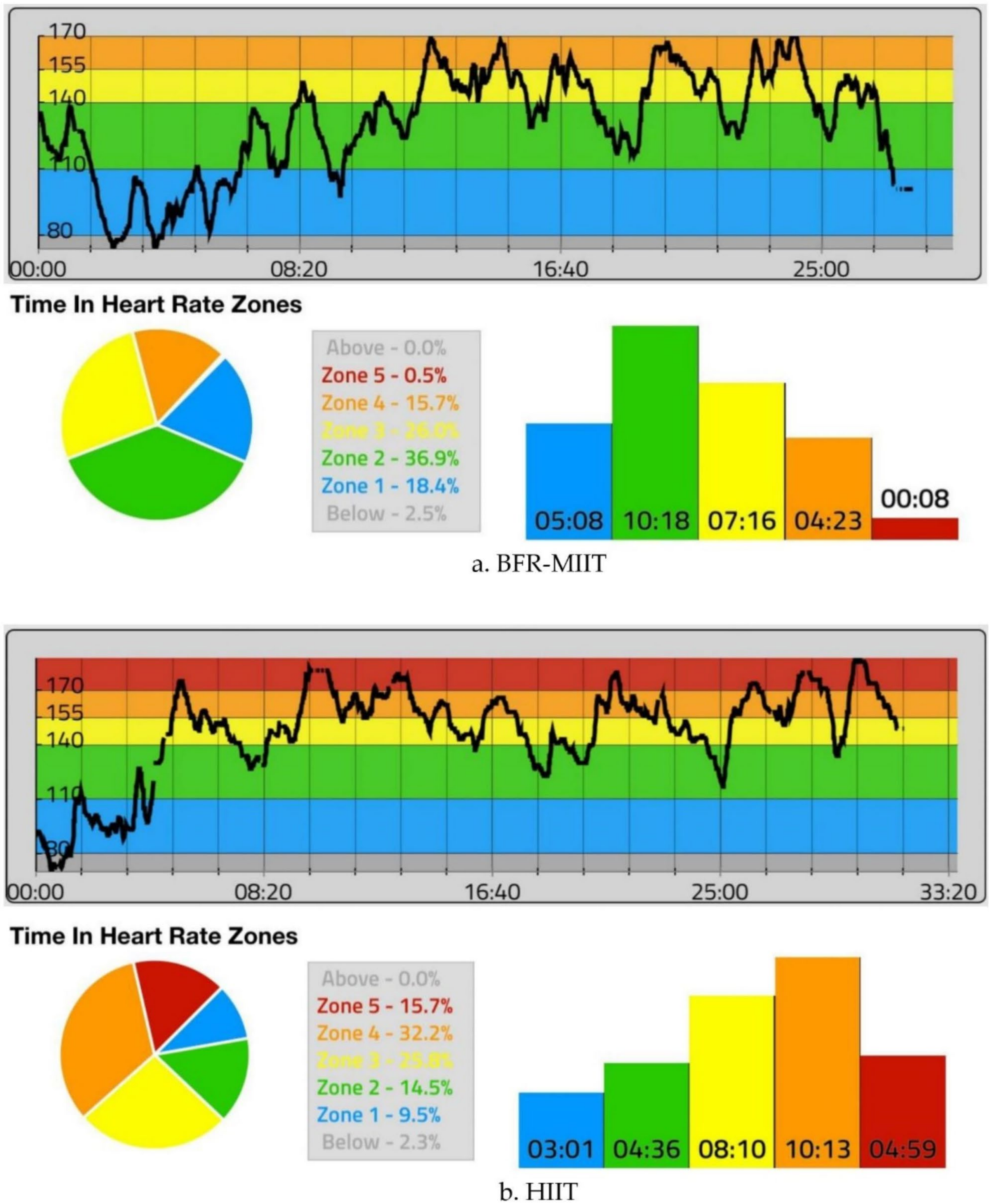

Fig. 2 Visual representations of heart rate profiles and heart rate zone distributions during the intervention period for the BFR-MIIT and HIIT groups, based on a single participant per group

Table 1 Basic information of participants

groups		Mean ± SD (range)	p	Effect Size
Age, y	BFR-MIIT	19.70 ± 1.31(17–22)	0.708	-0.131
	HIIT	19.87 ± 1.25(18–22)		
Height, cm	BFR-MIIT	183.11 ± 2.93(178–188)	0.996	-0.002
	HIIT	183.12 ± 4.74(176–193)		
Weight, kg	BFR-MIIT	77.97 ± 8.59(69.3–93.0)	0.889	0.044
	HIIT	77.54 ± 10.81(59.3–103.0)		
BMI	BFR-MIIT	22.14 ± 2.10(18.9–26.8)	0.637	0.166
	HIIT	22.79 ± 2.15(19.6–26.3)		

BFR-MIIT = blood flow restriction moderate intensity interval training group; HIIT = high intensity interval training group

Table 2 Comparison between pre-tests and post-tests (mean ± standard deviation) of the BFR-MIIT group and HIIT group

Measures	PRE	POST	Effect Size	Time	Group	Time * group
VO_{2max}						
BFR-MIIT	39.48 ± 6.22	44.48 ± 4.77§	-1.199 (-1.815, -0.583)	P<0.001	p = 0.384	P = 0.007
HIIT	39.75 ± 6.92	42.82 ± 5.21§	-0.526(-1.022, -0.029)			
PP						
BFR-MIIT	767.74 ± 108.60	768.81 ± 107.98	-0.008(-0.427, 0.411)	P = 0.861	p = 0.853	P = 0.920
HIIT	774.48 ± 153.33	778.45 ± 155.51	-0.030(-0.461, 0.401)			
PP/KG						
BFR-MIIT	9.86 ± 1.02	10.01 ± 1.13	-0.122(-0.720, 0.475)	P = 0.434	P = 0.627	P = 0.997
HIIT	10.05 ± 1.19	10.21 ± 1.64	-0.124(-0.739, 0.492)			
CMJ						
BFR-MIIT	43.06 ± 6.39	46.29 ± 6.52§	-0.570(-1.055, -0.085)	P = 0.007	P = 0.7	P = 0.04
HIIT	43.72 ± 3.54	46.18 ± 5.55	-0.083(-0.538, 0.372)			
SJ						
BFR-MIIT	42.27 ± 6.27	44.34 ± 5.38§	-0.537(-0.909, -0.165)	P<0.001	P = 0.842	P = 0.026
HIIT	43.61 ± 3.91	44.40 ± 4.61	-0.153(-0.487, 0.180)			
DJ						
BFR-MIIT	36.16 ± 5.94	39.52 ± 5.02§	-0.805(-1.355, -0.255)	P<0.001	P = 0.747	P = 0.045
HIIT	37.41 ± 3.69	39.70 ± 7.08	-0.297(-0.794, 0.200)			
505 Test						
BFR-MIIT	2.45 ± 0.17	2.27 ± 0.15§	1.708(0.790, 2.627)	P<0.001	P = 0.109	P = 0.037
HIIT	2.52 ± 0.16	2.31 ± 0.16§	0.909(0.122, 1.696)			
30 Sprint						
BFR-MIIT	4.30 ± 0.15	4.20 ± 0.23	0.449(-0.064, 0.963)	P = 0.03	p = 0.195	P = 0.21
HIIT	4.35 ± 0.21	4.33 ± 0.22	0.126(-0.379, 0.631)			

BFR-MIIT, blood flow restriction moderate intensity interval training group; HIIT, high-intensity interval training group, VO2max, maximum oxygen uptake; PP, Peak power; PP/kg, relative peak power; CMJ, countermovement jump; SJ, squat jump; DJ, drop jump; * Significant difference compared with HIIT, $p < 0.05$. § Significant difference compared with the pre-test, $p < 0.05$. Time * group: interaction of time and group

=0.008), and no significant interaction effect (F=0.001, p=0.997, η_p^2=0.001).

Lower extremity performance

Lower extremity performance was evaluated through CMJ, SJ, DJ, 505 test, and 30-meter sprint, corresponding to measures of jumping ability, change of direction ability, and sprinting ability, respectively (Table 2).

In terms of jumping ability, statistical results indicated a significant main effect of time for CMJ (F = 8.235, p = 0.007, η_p^2=0.21) and a significant interaction effect (F=4.595, p=0.04, η_p^2=0.129). After the training period, the BFR-MIIT group (ES=-0.570, 95%CI: -1.055 to -0.085, p = 0.007) showed a significant improvement in CMJ, while the HIIT group (ES=-0.153, 95%CI: -0.487 to 0.180, p=1.000) did not, with no significant difference between the two groups (ES=0.372, 95%CI: -0.607 to 1.350, p = 1.000). For SJ, there was a significant main effect of time (F=17.774, p<0.001, η_p^2=0.364) and a significant interaction effect (F=5.493, p=0.026, η_p^2=0.151). The BFR-MIIT group (ES=-0.537, 95%CI: -0.909 to -0.165, p<0.001) experienced a significant enhancement in SJ, but the HIIT group (ES=-0.153, 95%CI: -0.487 to 0.180, p=1.000) did not, with no significant difference observed between the groups (ES=0.124, 95%CI: -0.852 to 1.100,

Table 3 Comparison of RPE values for the 1st, 4th, 8th, and 12th intervention sessions between the BFR-MIIT and HIIT groups

	Mean ± standard deviation	Z	*p*
BFR-MIIT(1)	16.58 ± 0.71	-2.097	0.036
HIIT(1)	17.43 ± 1.54		
BFR-MIIT(4)	15.11 ± 0.33	-5.013	<0.001
HIIT(4)	17.12 ± 0.88		
BFR-MIIT(8)	14.91 ± 0.89	-4.242	<0.001
HIIT(8)	16.68 ± 0.94		
BFR-MIIT(12)	14.76 ± 0.66	-5.087	<0.001
HIIT(12)	16.75 ± 0.44		

BFR-MIIT, blood flow restriction moderate intensity interval training group; HIIT, high-intensity interval training group

p=1.000). DJ also demonstrated a significant main effect of time (F=20.457, p<0.001, η_p^2=0.398) and a significant interaction effect (F=4.344, p=0.045, η_p^2=0.123). The BFR-MIIT group (ES=-0.805, 95%CI: -1.355 to -0.255, p<0.001) saw a significant improvement in DJ, whereas the HIIT group (ES=-0.297, 95%CI: -0.794 to 0.200, p=0.596) did not, with no significant difference between the groups (ES=0.360, 95%CI: -0.616 to 1.336, p=1.000).

Regarding change of direction ability, statistical results indicated a significant main effect of time for the 505 test (F = 51.172, p < 0.001, η_p^2=0.623) and a significant interaction effect (F=4.766, p=0.037, η_p^2=0.133). After the training period, both the BFR-MIIT group (ES=1.708, 95%CI: 0.790 to 2.627, p<0.001) and the HIIT group (ES=0.909, 95%CI: 0.122 to 1.696, p=0.01) showed significant improvements in the 505 test, with no significant difference between the two groups (ES=-0.889, 95%CI: -1.894 to 0.116, p=0.082).

In terms of sprinting ability, statistical results indicated no significant interaction effect for the 30-meter sprint (F = 1.639, p = 0.21, η_p^2=0.05), but there was a significant main effect of time (F=5.196, p=0.03, η_p^2=0.144). After the training period, neither the BFR-MIIT group (ES=0.449, 95%CI: -0.064 to 0.963, p=0.094) nor the HIIT group (ES = 0.126, 95%CI: -0.379 to 0.631, p=1.000) showed a significant improvement in the 30-meter sprint.

Subjective exertion

Non-parametric tests, specifically the Mann-Whitney U test, were utilized to assess differences in RPE between the BFR-MIIT group and the HIIT group at the 1st, 4th, 8th, and 12th intervention sessions (Table 3). The statistical findings indicated that there were significant differences in RPE between the BFR-MIIT and HIIT groups at the 1st (Z = -2.097, p = 0.036), 4th (Z = -5.013, p < 0.001), 8th (Z = -4.242, p < 0.001), and 12th (Z = -5.087, p < 0.001) intervention sessions, with the BFR-MIIT group exhibiting significantly lower RPE compared to the HIIT group.

Discussion

This study aimed to investigate whether BFR-MIIT could achieve comparable or superior improvements in aerobic, anaerobic capabilities, and lower extremity performance at lower training intensities and perceived exertion compared to HIIT. The findings revealed that both BFR-MIIT and HIIT effectively enhanced the aerobic capacity of college male basketball players. In terms of lower extremity performance, BFR-MIIT outperformed HIIT, while the latter showed no significant improvements except for the 505 test. Additionally, neither BFR-MIIT nor HIIT groups exhibited improvements in anaerobic capacity. The four measurements of RPE indicated that BFR-MIIT was significantly lower than HIIT, suggesting that BFR-MIIT achieved better improvements in aerobic capacity and lower extremity performance at lower training intensities and perceived exertion compared to HIIT.

Aerobic capacity

HIIT is recognized as an effective method for enhancing aerobic capacity, a conclusion supported by numerous experimental studies and meta-analysis [14, 52, 53]. However, there is a dearth of research findings on achieving superior improvements in aerobic capacity by combining blood flow restriction with reduced HIIT training intensities. BFRT appears to be a specific “catalyst” for enhancing aerobic capacity and is applicable to various populations [54–57]. The meta-analysis results by Formiga et al. [56] serve as compelling evidence; their research indicates that while low to moderate-intensity aerobic training can effectively improve aerobic capacity, this improvement is more pronounced under conditions of blood flow restriction. A study by Amani et al. [58], which is similar to the present study in its use of BFR-MIIT, demonstrated that moderate-intensity interval training without blood flow restriction resulted in a 1.43% increase in VO_{2max}. In contrast, under blood flow restriction, there was a 3.66% increase in VO_{2max}. Thus, blood flow restriction seems to be an effective “catalyst” for enhancing aerobic capacity in moderate-intensity aerobic exercise. According to the results of this study, even when blood flow restriction is applied in moderate-intensity interval training, it can achieve similar improvements in aerobic capacity compared to HIIT.

Anaerobic capacity

Basketball is a high-intensity sport that requires players to frequently perform rapid sprints, jumps, and other high-intensity movements during games, necessitating excellent anaerobic capacity to ensure sustained high performance [59]. However, this study did not observe significant improvements in anaerobic capacity in either the BFR-MIIT or HIIT groups. Similar results were reported in the experimental study by Elgammal et al. [60], which, despite employing Repeated Sprint Training(RST) with BFRT, still indicated that the combination of BFRT and RST did not enhance the anaerobic capacity of basketball players. From the perspective of training intensity, anaerobic metabolism primarily relies on high-intensity muscle contractions, which the moderate-load training used in the BFR-MIIT group may not achieve, thus failing to effectively activate anaerobic metabolic pathways [61]. Analyzing the intervention method itself, it may be due to the work-rest ratio; the intervention method used in this study had a work-rest ratio of 1:1, whereas Mykolas et al. [62] found that anaerobic capacity was improved with a work-rest ratio of 1:8, but not with a ratio of 1:3, suggesting that ratios below 1:8 may not positively affect anaerobic capacity enhancement and could even have negative effects [62]. Given that each movement in this study's single training session lasted 1 min, the aerobic system gradually becomes involved after 25s [63], and during the recovery period, phosphofructokinase is inhibited by the resynthesis of ATP. Additionally, the recovery time for ATP/PCr is between 90 and 120 s; the short recovery time in this study (60s) prevented the timely recovery of ATP/PCr, thus necessitating more aerobic metabolism to fuel subsequent training sessions, which limited the improvement of anaerobic capacity [64, 65].

Lower extremity performance

Excellent sprinting, jumping, and COD abilities are fundamental to the athletic performance of basketball players [12]. Although studies have demonstrated the positive impact of BFRT on lower extremity performance [66, 67], there remains considerable debate due to the variety of pressurization interventions [68–71]. For instance, Horiuchi et al. [69] conducted an experimental study on adult males that indicated jump training with blood flow restriction had no significant effect on improving jump performance. While the interventions used in this study also involved plyometric training, the differences in training movements and the experimental population may account for the discrepancies between this study and that of Horiuchi et al. [69]. Analyzing the intervention actions, it can be posited that most of the actions employed in this study included plyometric training (lateral jumps, half squat jumps), which encompass a complete stretching-shortening cycle, potentially exerting a slight influence on BFR-MIIT or HIIT interventions. The characteristics of plyometric training, which involve many consecutive jumps, can to some extent enhance central nervous system adaptation and lower extremity muscle strength [72], and may be the underlying reason for the improved lower extremity performance in both the BFR-MIIT and HIIT groups.

Subjective exertion

It is widely believed that, compared to high-intensity training, lower-intensity training can be completed with greater ease. This notion is supported by the research of Maaloul et al. [73] and Wiehlhove et al. [74], MIIT with HIIT and found that all-out sprint interval training resulted in stronger pain sensations than prolonged submaximal heart rate interval training. This may be attributed to the fact that high-intensity training leads to elevated levels of muscle damage markers, thereby increasing perceived pain and soreness after exercise [75]. In the field of BFRT, most studies have focused on the impact of creating a blood flow restriction environment on athletes' subjective feelings under the same training intensity. Multiple studies have indicated that, compared to non-pressurized conditions, the degree of fatigue significantly increases under pressurized conditions [76, 77]. However, unlike previous studies, this study compares the fatigue levels between high-intensity interval training and moderate-intensity interval training under blood flow restriction conditions with different training intensities. Despite this, an interesting finding of this study is that, compared to HIIT, BFR-MIIT can achieve similar improvements in aerobic capacity at lower training intensities and fatigue levels and can also provide additional benefits for lower extremity performance.

It must be acknowledged that this study is preliminary. Although we have demonstrated the efficacy of BFR-MIIT based on extremity performance and its advantages over HIIT in terms of lower load and fatigue, we do not recommend BFR-MIIT as a direct alternative to HIIT. We have not measured indices such as neuromuscular adaptations, lactate tolerance, and proprioception. Instead, consider BFR-MIIT as a complement to HIIT or, in specific circumstances, as an auxiliary regimen. For instance, BFR-MIIT may be a potential training option for athletes who require recovery, wish to avoid overtraining, or for individuals with contraindications to high-intensity training. Furthermore, the ecological validity of BFRT may be limited, as it necessitates real-time monitoring of the cuffs and the athlete's immediate condition during the practical application, which undoubtedly increases the complexity of the operation. Additionally, the cost of BFRT is relatively high, encompassing equipment purchase and the labor costs associated with the operation. Therefore, when promoting BFR-MIIT, it is essential to consider these factors and make reasonable training program choices based on actual conditions.

Limitation

The subjects of this study were collegiate basketball athletes, not professional athletes, which raises questions about the applicability of BFR-MIIT during the competitive season. Furthermore, the efficacy of applying the same intervention protocol to other populations must be clarified, thus limiting the generalizability of the findings. Secondly, due to limitations in experimental equipment, this study could not employ the Ankle-Brachial Index to assess lower extremity arterial occlusive pressure, which presents potential limitations in the personalized determination of cuff inflation pressure. Additionally, when measuring maximum heart rate, the study relied solely on the traditional "220-age" formula, which may have limitations regarding accuracy and personalization.

Conclusion

This study confirmed the research hypothesis that, compared to high-intensity interval training, blood flow restriction combined with moderate-intensity interval training can achieve a similar level of aerobic capacity improvement at a lower training intensity and with less perceived fatigue while also enhancing lower extremity performance to a greater extent than high-intensity interval training.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01100-x.

Supplementary Material 1

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Author contributions

L.C.: Methodology, Data curation, Statistical analysis, Visualization, Writing, and Editing. Z.Z.: Methodology, Investigation. W.Q.: Critical revision, Methodology. W.H.: Data curation, Investigation and Providing professional basketball players as subjects. J.S.: Revising, Visualization. X.D.: Topic Selection, Methodology, Writing, Revising. D.L.: Topic Selection, Methodology, Writing, Revising. All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study has been approved by the Ethics Committee of Guangzhou Sport University (Registration number: 2022LCLL-33). The randomized controlled trial protocol was prospectively registered with the CONSORT Statement (Registration number: ChiCTR2300069760). All procedures involving human participants were conducted in accordance with the ethical principles of the Declaration of Helsinki. Informed consent was obtained from all participants, and all participants voluntarily took part in this experiment.

Consent for publication

We agree to submit the manuscript titled " Effects of Blood Flow Restriction Moderate Intensity Interval Training on Aerobic and Anaerobic Capabilities and Lower Extremity Performance in Male College Basketball Players" to BMC Sports Science, Medicine and Rehabilitation for publication. We declare that this manuscript is our original work and has not been published in any other journal or publication, nor is it under consideration for publication elsewhere. All listed authors have made significant contributions to this manuscript and have jointly approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

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