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Effectiveness of blood flow restriction training during a taper phase in basketball players

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ABSTRACT

This study investigates the effectiveness of blood flow restriction (BFR) training in maintaining athletic performance during a taper phase in basketball players. The taper phase aims to reduce external load while maintaining training intensity. Seventeen experienced basketball players were randomised into two groups: a placebo group ($n = 8$, 22.0 ± 2.1 years, mean ± SD) and BFR group ($n = 9$, 21.1 ± 1.5 years). The training schedule included strength trainings, team trainings, individual skill sessions and competitive games. During the 4-week taper period, lifting volume was reduced while either maintaining (placebo) or reducing (BFR) lifting load. The BFR group lifted with 60% arterial occlusion pressure at 25–30% of their 1RM, whereas the placebo group trained at 80% of their 1RM with BFR cuffs inflated to only 20%. Compared to the placebo group, BFR participants improved 5 m (−1.4 ± 1.5% mean ± 95% CI $p = 0.03$) and 10 m (−1.1 ± 0.5%, $p = <0.01$) sprint performance along with barbell back squat (9.6 ± 8.0%, $p = 0.013$) and counter-movement jump (1.1 ± 0.8%, $p = 0.0035$). BFR during the taper phase enabled a reduction in lifting load with no reduction in subsequent performance measures.

KEYWORDS

Blood flow restriction; resistance training; team athletes; taper

Introduction

Blood flow restriction (BFR) is a training method that partially restricts arterial inflow and fully restricts venous outflow in working musculature during exercise (Scott et al., 2015). The BFR technique involves applying an external pressure, typically using a tourniquet cuff, to the most proximal region of the upper and/or lower limbs (Patterson et al., 2019). When the cuff is inflated, mechanical compression of the vasculature occurs, leading to the desired restriction effects, with venous outflow being more severely impacted than arterial inflow (Patterson et al., 2019). This restriction leads to the accumulation of metabolites, such as lactic acid and hydrogen ions, which are hypothesised to stimulate the recruitment of additional muscle fibres beyond what is typical for low-intensity exercises, potentially mimicking the effects of high-intensity training (Loenneke et al., 2011; Yasuda et al., 2014).

Whilst the number of research groups and studies investigating BFR have grown, so too has the number of practitioners using this mode of training (Patterson et al., 2017). Some examples of its uses include rehabilitation, and athletic performance enhancement (Centner et al., 2019; Cognetti et al., 2022; Scott et al., 2017). BFR has been shown to improve countermovement jump and sprint times, increase maximal aerobic capacity and ventilation and maintain or increase strength in team sport athletes (Abe et al., 2005; Doma et al., 2020; Elgammal et al., 2020; Li et al., 2024). Further to this, resistance exercise with BFR (BFR-RE), has been beneficial in various studies, showing that low-load BFR-RE outperforms regular low-load resistance training, and at least equals high-load resistance training in enhancing strength and size (Lixandrão et al., 2018; Slysz et al., 2016). While not always superior in strength development to high-load training, low load-BFR-RE's advantage lies in allowing more frequent training with reduced mechanical stress (Cassidy et al., 2023). Unfortunately, while the use of BFR in team sports has increased, application of current theory on how to use BFR has not (Patterson et al., 2017). For example, a wide range of pressures applied by practitioners has resulted in unintended consequences such as numbness and pain following BFR (Patterson et al., 2017). Current recommendations for muscle strength and hypertrophy with BFR-RE suggests 4 sets (30, 15, 15, 15 reps) with cuff pressures of between 40% and 80% of limb restriction pressure and resting 30–60 s between sets (Scott et al., 2023). Training 2 to 3 times weekly is advised, similar to standard resistance training (Scott et al., 2023).

Given the importance of athletes reaching their maximal performance while simultaneously needing to decrease their training load to prevent fatigue during the taper phase, exploring the use of BFR training as a method to reduce external load while maintaining or enhancing performance levels could provide a valuable and innovative strategy for basketball athletes. Effective tapering balances sufficient load reduction to minimise fatigue without compromising the gains of prior training (Stone et al., 2023). Among the four commonly used tapering strategies, step taper, linear taper, exponential taper with slow decay, and exponential taper with fast decay, the step taper

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involves a sudden, consistent reduction in training load and has been shown to be particularly effective in team sports (Bosquet et al., 2007). Saleh et al. (2010) observed that a two-week step taper with a 50% reduction in training volume significantly improved strength outcomes in futsal players (Yakdhan Saleh et al., 2024). Similarly, Nunes et al. (2014) reported improvements in maximal strength and jumping power in elite female basketball players following a two-week step taper prior to an international competition.

We hypothesise that integrating BFR training into a tapering phase can enhance muscular strength while using lower external loads, effectively maintaining basketball athlete's performance during this critical period. By adopting this approach, athletes could achieve peak performance without the increased risk of overexertion or injury often associated with high-load training (Cassidy et al., 2023). Therefore, the aim of this study was to explore the use of blood flow restriction into a step taper as a method to reduce external load, but maintain, or even potentially enhance, performance levels in basketball athletes during their tapering phase, focusing specifically on variables such as strength, speed and explosive power. This approach could offer a novel and effective strategy for preparing athletes for the most demanding periods of their season.

Methods

Study design and overview

This single-blind randomised placebo controlled trial was conducted at a university in the Canterbury region of New Zealand between September and October 2023. The basketball players were at the end of the competition phase leading into a step taper block prior to playoffs. Participants reported for two 1-h testing sessions in the morning, 4 weeks apart, having fasted for 12 h, and abstained from strenuous physical activity and alcohol for 24 h. Following this we prepared the participants for the testing bout that took approximately 1 h to complete. The participants went through a warm-up protocol that included one set of 6–10 repetitions with a barbell for each strength-based exercise. After the warm-up, they completed attempts at 50%, 60%, 70%, 80%, and 90% of their estimated 1-repetition maximum (1RM) before their first attempt of 3. Their predicted 1RM was based on their previous scores from earlier in the season before the intervention. They took a 3–5-min-rest between attempts. The testing occurred in an air-controlled strength facility, and the participants wore lifting platform shoes and were on an Olympic-rated flooring designed for heavy lifting. All participants completed their attempt within the 3 tries allowed.

Participants

Using G*Power (G*Power 3.1.9.7) analysis, we calculated a priori sample size of 16 (8 per group) would be required using an effect size (ES = 0.7) found in the previous research on 1RM strength change after training with low-load BFR (Luebbers et al., 2019) and an alpha level of 0.05, and power (1-beta) of 0.80 with repeated measures Anova analysis (Luebbers et al., 2019).

We recruited 20 elite basketball participants who had at least 9.6 ± 2.3 years playing experience and 12 played for higher-level representative teams (regional and national representatives). However, due to injury and testing unavailability, 17 participants (5 female and 12 male) completed data collection. All participants had strength training experience 5.1 years ±1.1 (mean ± SD) including 1RM testing in the barbell back squat, deadlift, bench press and prone row. All participants also had sprint testing and countermovement jump experience. Participants were randomly allocated to either the BFR or placebo group via a random number generation programme on Microsoft Excel. All subjects gave their written informed consent in accordance with the Declaration of Helsinki. The study was approved by the University Human Ethics Committee (HEC2022–25) and all participants provided written informed consent.

Measurements

Blood flow restriction pressure

One week before the start of the study, all participants had their arterial restriction pressure measured in a standing upright position by an experienced ultrasonographer blinded to the participants. A linear array probe (Lumify L12–4, Philips Healthcare, Amsterdam, the Netherlands) was placed over the popliteal artery just behind the knee to capture the auscultatory pulse. A standard blood pressure cuff (TheBFR.co, Queensland, Australia) 100 mm width and 740 mm length was wrapped around the participant's thigh at the inguinal fold region and inflated until the popliteal pulse disappeared and then slowly released until it appeared (arterial restriction pressure).

Test protocol

Prior to the first testing, anthropometric measures such as height (portable stadiometer, Seca 213, Seca GMBH, Hamburg, Germany), body mass (electronic scales, BWB-600, Tanita Corporation, Tokyo, Japan) and sum of 8 site skinfolds, i.e. triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf (Harpenden Skinfold Callipers, Baty International) were measured. Body mass was measured to the nearest 0.1 kg and height was measured without shoes and socks to the nearest 0.1 cm with the head in the Frankfort plane. Two days before and after the 4-week training period, all participants completed a series of tests including explosive power via the countermovement jump height (cm) and 1RM strength tests (i.e. back squat, a conventional deadlift, a bench press and a prone row), along with a 5, 10 and 20 m speed tests (Fusion Sport Timing Lights, Australia). All participants were familiar with these tests as they are a regular part of their testing routine. The tests were completed at the same time (13:00 hours) and in the same order, with a consistent 10-min rest period between each exercise to match both pre- and post-test conditions. Explosive power was measured using a jump mat (Fusion Sport Jump Mat, Australia) while 1RM testing used conventional 1RM protocols (Hamlin

& Deuchrass, 2024). All participants were given verbal encouragement during all tests.

Resistance training protocol

All participants performed three training sessions per week at their local training facility for 4-weeks, alongside their normal training routine, which included the same number of gym sessions, as in the previous 4-week competition phase. The programme was designed to target two distinct types of strength: maximal strength, which focuses on lifting heavy weight with low repetitions, and speed strength, which emphasises moving lighter weights quickly to develop power. Maximal strength days were scheduled for Monday (Day 1), and Tuesday (day 2), with speed strength scheduled Thursday (Day 3). Each session lasted 1 h, during which each player was assigned a specific time each day for each week they trained. All players performed a warm-up lasting 10 min, consisting of a light jog, followed by dynamic movements tailored to the type of strength day being trained. The BFR group was introduced to a new 4-week tapered programme that included low resistance BFR and low volume training, while the placebo group engaged in traditional high resistance low volume training. Once the participants were assigned to a group, they either had the cuff on and inflated to 60% of their individual restriction pressure (BFR Group) or to 20% of restriction pressure (placebo group), using the same cuff that was used to measure their arterial restriction pressure.

During day 1 (Monday), the BFR group completed 3 sets of 10 reps using a 25–30% 1RM load for barbell back squats. After the squats, the cuffs were removed, and the participants performed additional ancillary exercises. On day 2 (Tuesday), the BFR group again completed 3 sets of 10 reps on the trap bar deadlift before removing the cuffs and performing further ancillary exercises. On day 3 (Thursday), both groups engaged in a combination of speed and ancillary-based movements without using BFR cuffs. On days 1 and 2 the placebo group performed 3 sets of 10 reps at approximately 80% 1RM load followed by ancillary exercises. The reason for maintaining the same repetitions as the BFR group was to equalise the strength training stimulus between groups, ensuring that any performance differences between groups were not due to variations in training volume but rather the specific interventions used.

Participants had a 2-min rest between sets and after their final set. Importantly, the cuff remained on the leg throughout the exercises and remained inflated (60% of arterial restriction pressure) not only during the sets but also throughout the inter-set periods for the BFR group resulting in a total restriction time of approximately 12–15 min each training day. Immediately following each set, the cuff pressure for the BFR group was checked and adjusted if necessary to the required pressure. Bar velocity was monitored across all major lifts, including the squat, deadlift, bench press and prone row, via a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia). Participants were required to maintain a velocity between 0.75 and 1.0 m/s to stay within their strength-speed force velocity curve range.

Physiological measures

Players heart rate and arterial oxygen saturation ($Sp0_2$) (Sport-Stat; Nonin Medical, Minneapolis, Minnesota, USA) were recorded immediately after each set on all training days.

Subjective measures

Rate of perceived exertion (RPE) was measured using Borg's category-ratio (CR10) scale where 0 is no exertion at all, and 10 is maximal exertion. Players were asked to rate their exertion on the scale immediately after every set.

Total weekly load calculation

The total weekly physical load was calculated by summing the arbitrary units (AU) from various training sessions, including two team trainings, one skill training, three gym sessions, and one game per week. For strength training sessions, the load was determined by multiplying the weight lifted (in kilograms) by the number of repetitions and sets, with the BFR group using 25–30% of their 1RM with cuffs inflated to only 20%. The load from team training sessions, skill sessions, and games was calculated by multiplying the session RPE (sRPE) by the duration of the session in minutes. These values were then summed to provide the total weekly load, which was used to compare differences between the BFR and placebo groups. This same method of total weekly load calculation was applied during the competition phase that took place before the intervention study, allowing for a direct comparison of the training load between phases. These values were then summed to provide the total weekly load, which was used to compare differences between the BFR and placebo groups.

Statistical analysis

Descriptive data are given as the mean ± SD. We used a mixed ANOVA test (group × day × set) to examine the differences in training parameters for both groups over 8 days with 3 sets of exercises on each day. Normal distribution of the data was analysed with the Shapiro–Wilk test. For the mean assumption of homogeneity of variance, we applied Mauchly's test of sphericity, and for violations, we used the Greenhouse – Geisser correction. The significance level was accepted as $p < 0.05$. We used the Statistical Package for Social Sciences (version 29) (SPSS Inc. Chicago, IL, USA) for the mixed ANOVA. We also used a repeated measures analysis to investigate the differences in the performance test from pre- to post-training between groups (Hopkins, 2006). The differences in performance variables that showed statistically significant change over time (e.g. 1RM squat, 5 m and 10 m sprint) were compared between groups and Cohen's value of 0.2 of the between-subject standard deviation was used to assess the smallest worthwhile change (Hopkins, 20020044). The test–retest reliability of all performance measures (measured using the coefficient of variation between baseline and post-intervention tests) indicated good reliability (squat 6.1%, trap bar deadlift 3.4%, bench press 3.5%, prone row 3.2% and countermovement jump 0.6%).

Results

Physical characteristics and performance

We found no significant differences in the physical characteristics of the participants in the 2 groups who were all experienced basketball players (Table 1). Compared to the placebo group, participants undertaking 4 weeks of BFR training improved their barbell squat (9.6 ± 8.0% mean ±95% confidence interval, $p < 0.05$, ES = 0.54), countermovement jump (1.1 ± 0.8%, $p < 0.05$, ES = 0.47) and bench press (4.5 ± 4.8%, $p < 0.05$, ES = 0.32) strength. Other strength parameters did not improve but were maintained over this period (Table 2). Performance in the 5 m and 10 m sprints improved in the BFR group compared to the placebo group (1.4 ± 1.5%, $p < 0.05$ and 1.1 ± 0.5%, $p < 0.05$, respectively).

Table 1. Physical characteristics of the placebo group and blood flow restriction.

	Placebo group ($n = 9$)	BFR group ($n = 8$)
Male/Female	5/3	7/2
Age (yr)	22.0 ± 2.1	21.1 ± 1.5
Height (cm)	185.4 ± 10.7	186.1 ± 10.5
Body Mass (kg)	82.8 ± 12.9	81.1 ± 11.4
Sum of 8 Skinfolds (mm)	96.9 ± 23.4	72.5 ± 26.3
Years Playing Basketball	9.4 ± 2.6 years	9.8 ± 2.1 years
Years Strength Training	5.8 ± 0.7	5.3 ± 1
Training volume (h/week)	10	10

Data are mean ± SD. Sum of 8 skinfolds included triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf.

Not all participants responded similarly to the interventions, with considerable individual variation found in the performance variables. Individual differences can be found in Figures 3 and 4, which illustrate the percentage change in performance metrics. Figure 1 shows that the BFR participants increased in back squat performance from 5% to 25%. On the other hand, the placebo group showed a much more modest improvement, mostly under 5%. BFR participants increased in countermovement jump performance from 1.2% to 3.5%, whereas the placebo groups improvements were smaller, between 0.2% and 2.3% (Figure 2). Similarly, Figure 3 shows the BFR participants experienced large variations in 5-m sprint time change (from −1% to −6%), while the placebo group showed less variation but ultimately smaller sprint time decrements. Additionally, Figure 4 indicates that BFR participants improved their sprint times by −1.5% to −2.4%, whereas the placebo group showed smaller decreases ranging from 0% to −1.

Training parameters

For SpO_2, there was a significant main effect of set ($p < 0.001$; ES = 0.89) and all 3 sets were significantly different from each other (Set 1: 96%, Set 2: 94.8%, Set 3: 93.8%, $p < 0.001$, Figure 5). In addition, a group main effect for SpO_2 was found to be significant ($p < 0.001$; ES = 0.95). The BFR mean SpO_2 (91.5%) was significantly lower than the placebo group (98.2%, $p < 0.001$). There was a significant interaction between set and group ($p < 0.001$; ES = 0.88) and all 3 sets were significantly different from each other in the BFR group (Set 1: 93.7%, Set 2: 91.3%, Set 3: 89.4%, $p = <0.001$).

We found a significant main effect for set with RPE ($p < 0.001$; ES = 0.96, Figure 5) and all three RPE sets were significantly different from each other (Set 1: 7.0, Set 2: 7.7, Set 3: 8.4, $p < 0.001$). We also found a significant main effect for

Table 2. Performance parameters in basketball players before (pre) and after (post) 4 weeks of taper training in the placebo and blood flow restriction groups.

	Placebo Group ($n = 8$)				Blood Flow Restriction Group ($n = 9$)					
	Pre	Post	Post-Pre change %	ES	Pre	Post	Post-Pre change %	ES	Between group Post-Pre % change; 95% CI, and clinical inference	ES
BB Back Squat (kg)	112.2 ± 21.1	114.2 ± 22.8	1.5	0.23	110.6 ± 28.8	123.4 ± 33.1	10.7*	0.89	9.6; 8.0# Very likely beneficial	0.54
Trap Bar Deadlift (kg)	122.8 ± 22.5	128.3 ± 22.4	4.7	0.86	127.5 ± 21.7	136.3 ± 30.7	6.1	0.64	1.3; 5.5 Unclear	0.22
BB Bench Press (kg)	69.2 ± 14.4	71.7 ± 15.6	3.3*	0.69	67.2 ± 18.9	72.8 ± 21.9	8.0*	0.80	4.5; 4.8 Likely beneficial	0.32
BB Prone Row (kg)	69.7 ± 12.2	72.2 ± 11.6	3.8*	0.90	66.6 ± 18.2	71.3 ± 17.0	7.2*	0.73	3.3; 5.1 Likely beneficial	0.21
CMJ (cm)	52.0 ± 10.6	52.6 ± 10.8	1.1	0.85	49.4 ± 11.6	50.4 ± 11.8	2.1*	0.93	1.1; 0.8# Possibly beneficial	0.47
5 m time (sec)	1.06 ± 0.1	1.05 ± 0.1	1.1	0.83	1.04 ± 0.1	1.01 ± 0.1	2.5*	0.86	1.4; 1.5# Possibly beneficial	0.48
10 m time (sec)	1.81 ± 0.09	1.80 ± 0.09	0.6	0.75	1.80 ± 0.11	1.77 ± 0.12	1.8*	0.99	1.1; 0.5# Very likely beneficial	0.76
20 m time (sec)	3.09 ± 0.16	3.07 ± 0.17	0.6	0.83	3.11 ± 0.19	3.08 ± 0.18	0.9	0.88	0.3; 0.5 Very likely trivial	0.19

Pre and post are mean ± SD. Within-group and between-group post-pre change is in %; 95% confidence interval along with the clinical inference. BB = Barbell. CMJ = Countermovement Jump. ES = Effect size. * Significant difference within group pre-post test ($p < 0.05$).
#significant difference between groups ($p < 0.05$).

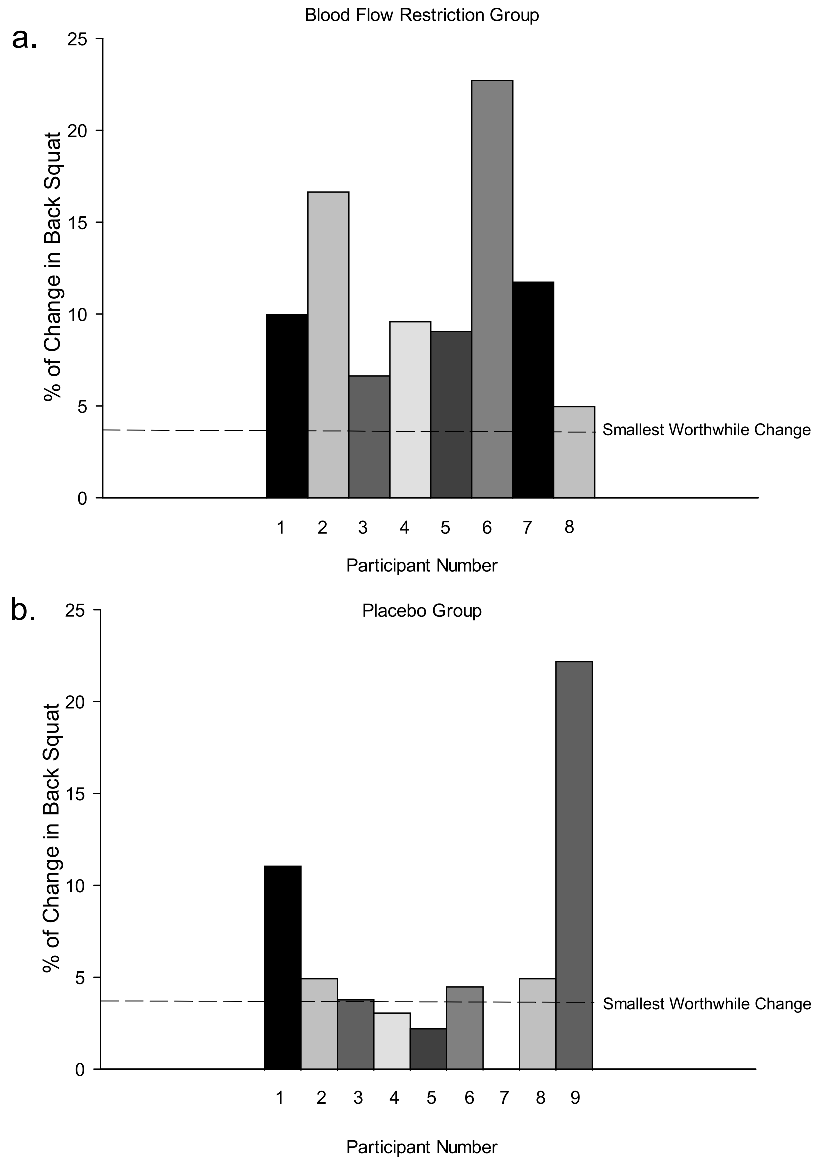

Figure 1. Percentage change in back squat from baseline in the BFR (A) and placebo (B) groups in back squat with Cohen's smallest worthwhile change.

group ($p = 0.027$; ES = 0.29). Overall, the BFR group RPE (8.0) was significantly higher than control group RPE (7.4, $p < 0.05$). For heart rate we found a significant main effect for day ($p < 0.001$; ES = 0.021). Day 4 (145 b/min) was found to be significantly lower than day 7 (148 b/min, $p = 0.036$). There was a significant main effect for set ($p < 0.001$; ES = 0.91) and all 3 sets were significantly different from each other (Set 1: 135 b/min, Set 2: 149 b/min, Set 3: 157 b/min, $p < 0.001$).

Total weekly load difference between BFR and placebo groups

The BFR group had a significantly lower physical load (−21.6%, $p < 0.001$) compared to the placebo group (Figure 6). The average physical load for the BFR group was 12,490.3 ± 411.6 arbitrary units (au) while the placebo group had an average physical load of 15,246.9 ± 389.8 au. Physical load was determined based on two team training sessions, one skill training session, three gym sessions and one game. Moreover, the BFR group experienced a significantly lower strength training load −24.8%, $p < 0.001$) compared to the placebo group. Specifically, the average 4-weekly strength training load for the BFR group was 10,100.6 ± 368.1 au, whereas the placebo group had an average 4-weekly strength physical load of 12,961.0 ± 444.0 au. Further to this, the BFR group and placebo group had a significantly higher physical load during the competition phase prior to the intervention (18285.6 ± 541.9 au and 18,249.0 ± 368.7 au, respectively, $p < 0.001$). Additionally, both groups exhibited significantly higher 4-weekly strength training loads compared to the taper phase (15446.8 ± 486.8 au and 15,197.6 ± 349.5 au, respectively, $p < 0.001$).

Discussion

The major findings from this study shows that eight sessions of BFR training designed to taper the athletes performance significantly improved 5-m sprint, barbell back squat and barbell

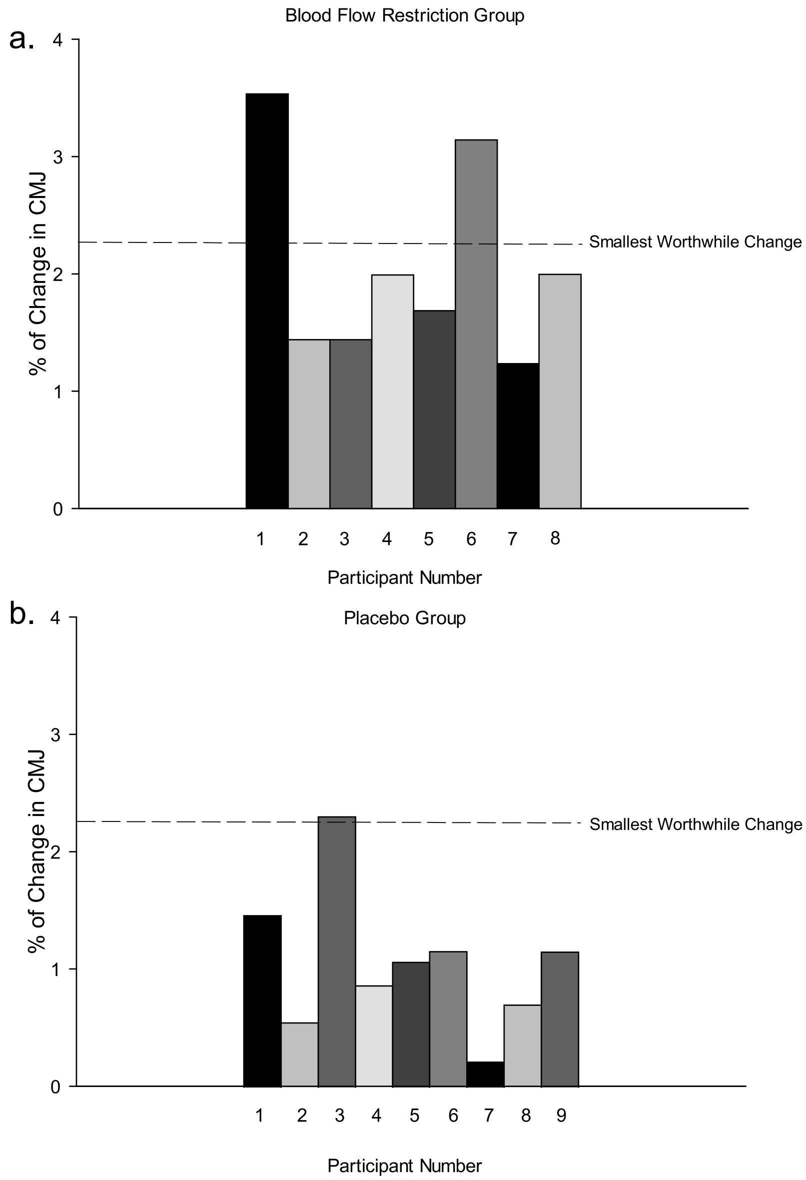

Figure 2. Percentage change in countermovement jump (CMJ) from baseline in the BFR (A) and placebo (B) groups in CMJ with Cohen's smallest worthwhile change.

bench press performance compared to a traditional high resistance taper. Importantly, performance in the other measures including trap bar deadlift, prone row and countermovement jump were maintained in the BFR participants during this period of reduced loading, indicating a reduction in physical but an increase in metabolic loading via BFR is beneficial for performance during a taper period.

Previous research has also found that BFR training showed greater improvements in 1RM barbell back squat performance (2.0 ± 0.6%) compared to a placebo group, during a 3-week resistance training intervention (Cook et al., 2014). However, unlike Cook et al. (2014), who employed intermittent restriction with the cuff inflated only during exercise and deflated during the inter-set and inter-exercise rest periods, the current study applied continuous pressure throughout the inter-set periods, potentially influencing muscle adaption differently resulting in an overall higher strength adaptation (e.g. 9.6% for the barbell squat). Additionally, while Cook et al. (2014) used a generalised cuff pressure of 180 mmHg for all participants, which might have limited the precision dosage needed for adaption, the current study individualised cuff pressures to align more closely with each participant's specific limb anatomy, as highlighted in previous research (Lorenz et al., 2021). This approach underlines the importance of personalised occlusion pressure in enhancing training efficacy.

Interestingly, although not directly part of the BFR training which was lower body limbs only, we found upper body strength also improved (barbell bench press increased by 5.6% and barbell prone row by 4.7%). Previous research has also reported this cross-over effect and have attributed this to local physiological adaptions (Cook et al., 2014). In a study by Takarada et al. (2000), the authors suggest improved neuromuscular efficiency may be involved where BFR training could enhance the efficiency of neural recruitment patterns, not just in the muscles directly under restriction, but throughout the body (Takarada, Takazawa, et al., 2000). Given that our training program lasted only 4 weeks, we believe that the improvements in strength gains in both lower and upper body muscles

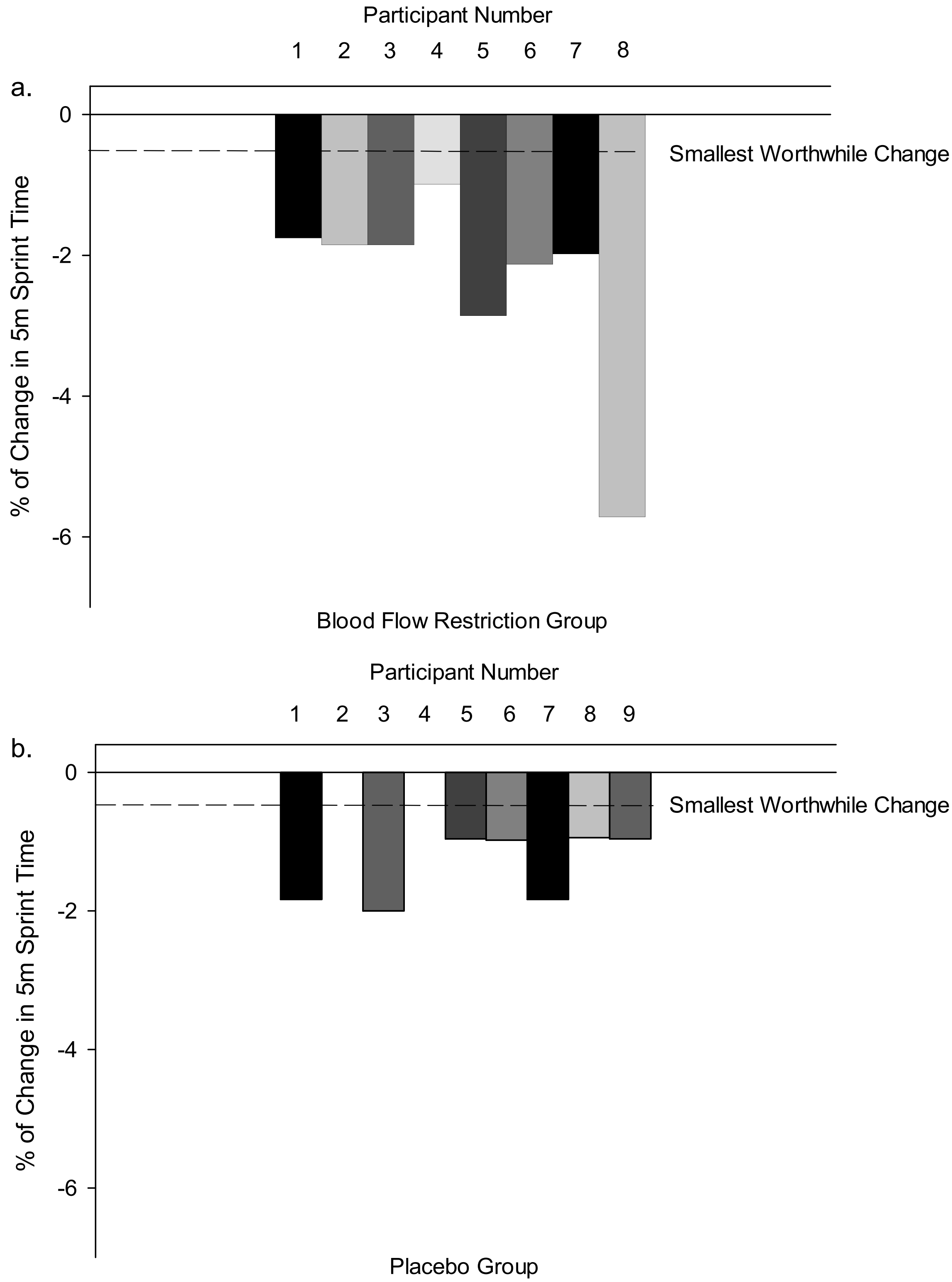

Figure 3. Percentage change in 5 m sprint time from baseline in the BFR (A) and placebo (B) groups with Cohen's smallest worthwhile change.

were probably more neural adaptations rather than hypertrophic changes, however, this assumption will remain speculative until further research can support this hypothesis.

Sprint running, segmented into an initial acceleration phase (0–10 m), achieving maximal speed (10–40 m) and maintaining maximal speed (40 m onwards), is enhanced by specific training modalities (Abe et al., 2005). The current study found that the BFR group, compared to the placebo group, increased sprint performance over 5, 10 and 20 m, (although not statistically significant for 20 m). Earlier findings from Cook et al. (2014) and

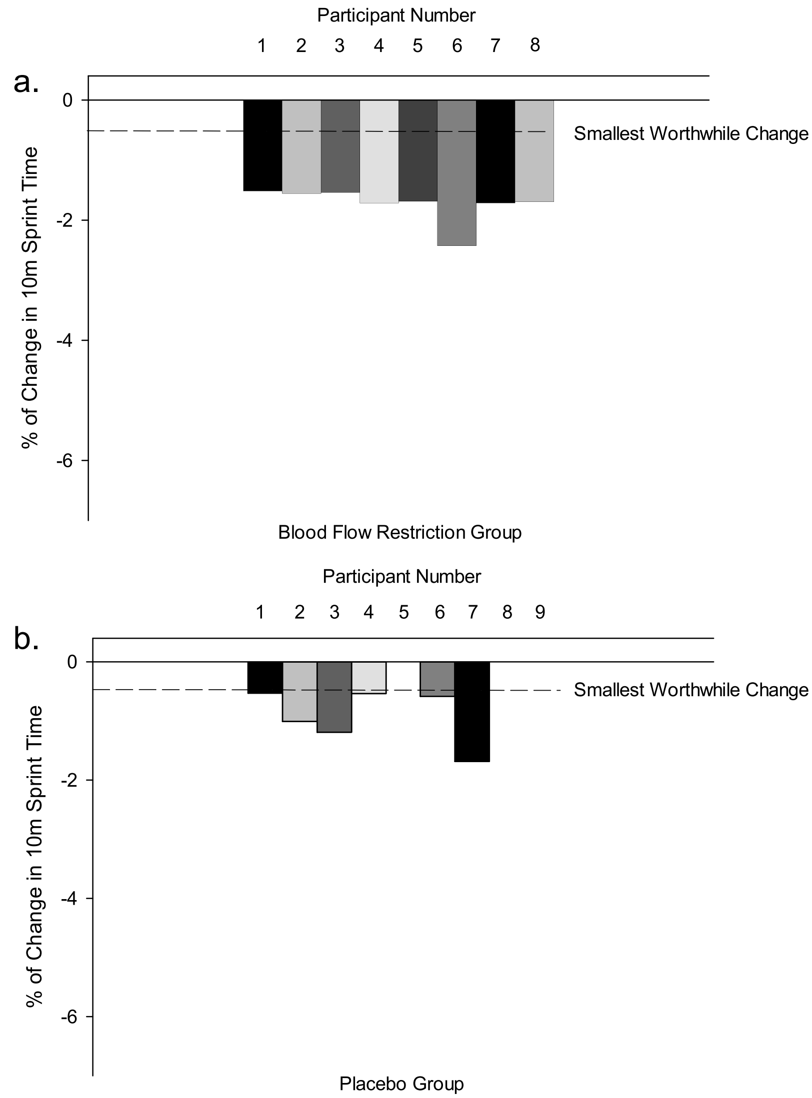

Figure 4. Percentage change in 10 m sprint time from baseline in the BFR (A) and placebo (B) groups with Cohen's smallest worthwhile change.

Abe et al. (2005) similarly showed improvements in short sprint phases after BFR training, particularly in the first 10 m, supporting the notion that specific training like BFR enhances the initial acceleration phase of sprinting (Abe et al., 2005; Cook et al., 2014). However, discrepancies appear in longer sprints as Scott et al. (2017) found no differences between BFR and control groups over 40 m distance, potentially due to inadequate control over training intensity and the effects of residual fatigue from pre-season training demands (Scott et al., 2017). The current study also found no statistically significant improvement in the longer sprint (20 m) and while speculative it may suggest that BFR training can significantly improve shorter sprints, but its effectiveness may diminish as distances increase, reflecting a concentrated benefit in the early, explosive phases of sprinting.

The likely improvements in sprinting and explosive power (as measured with the CMJ) may be related to neuromuscular adaptation induced by blood flow restriction (Xiaolin et al., 2023). This adaption promotes a heightened neuromuscular drive with studies by Moritani et al. (1992) and Takarada et al. (2000) demonstrating that BFR leads to earlier and more significant recruitment of fast-twitch fibres, due to insufficient oxygen supply to slow-twitch muscle fibres. This increased recruitment of fast-twitch fibres can also enhance force production in 1RM strength training (Moritani et al., 1992; Takarada, Nakamura, et al., 2000).

In the current study, CMJ performance increased significantly in the BFR group compared to the placebo group and reached statistical significance between groups. Similarly, Cook et al. (2014) observed a significant increase in CMJ in the BFR group compared to the placebo group (1.8 ± 0.7%) (Cook et al., 2014). However, Scott et al. (2017), found no between-group difference in CMJ performance (Scott et al., 2017). These differences could be attributed to variations in study design. Scott et al. (2017) had participants in both the BFR and placebo group complete 4 sets of 30-15-15-15 reps after 5 sets of normal resistance training, 3 times a week with sets performed at up to 30% 1RM of barbell back squat. The BFR group used elastic powerlifting knee wraps on the upper thigh with a continuous restriction of a 7–10 reported pressure rating (Scott et al., 2017). In contrast, the current study implemented 3 sets of 10 reps with continuous restriction at 60% for the BFR group and 20% for the placebo group, performed twice a week. Scott et al.

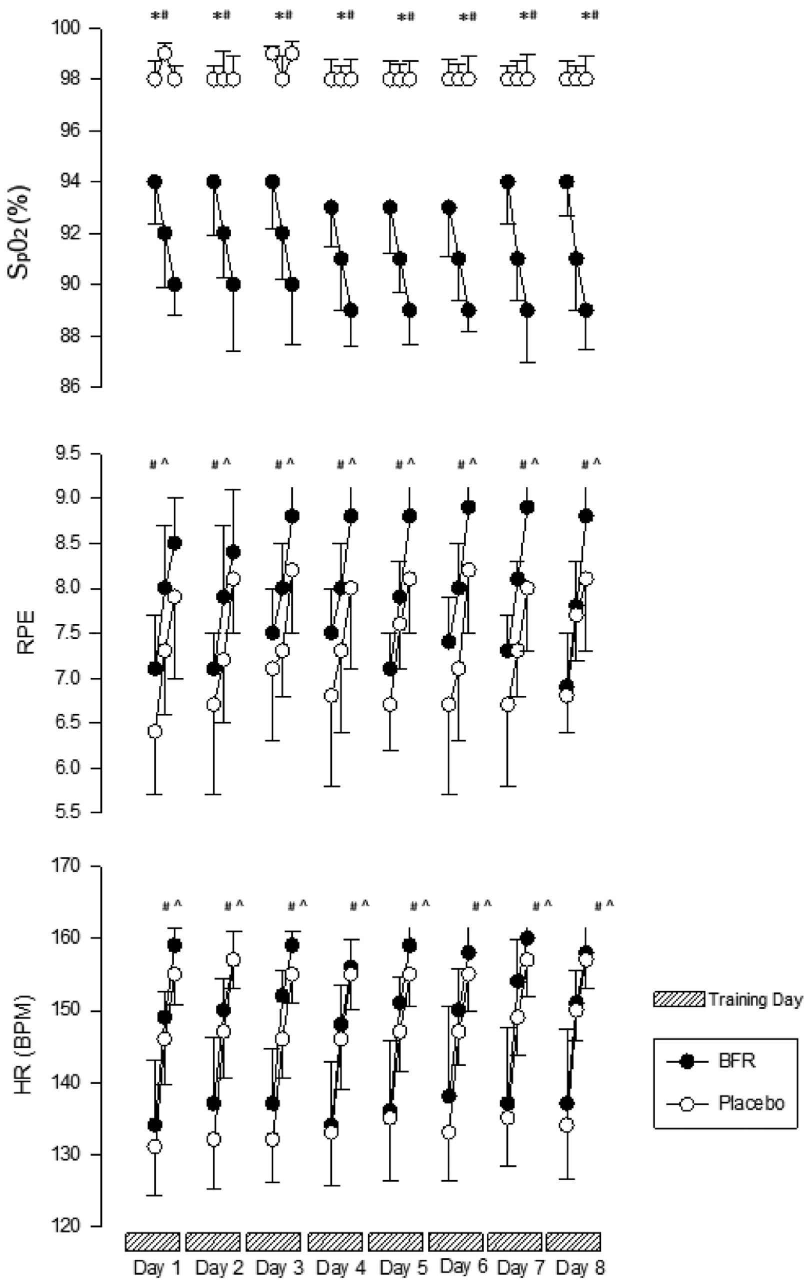

Figure 5. Physiological parameter changes during 3 sets of strength training in the blood flow restriction and placebo groups over a 4-week taper period. * significant difference between groups ($p < 0.05$). # significant difference within BFR group from set 1 – set 3 ($p < 0.05$). ^ significant difference within placebo group from set 1 – set 3 ($p < 0.05$).

(2017), implemented the BFR protocol as an additional component at the end of the participant's regular resistance training sessions, whereas the current study integrated the BFR protocol into the overall training regimen (Scott et al., 2017). Additionally, Scott et al. (2017) did not have any reliable measures of restriction, such as SpO_2 or heart rate during the BFR protocol, limiting direct comparisons with the current study (Scott et al., 2017). Furthermore, the use of gold standard methods to measure occlusion pressures in the current study ensured accurate and reliable application of BFR, contributing to the strength of the findings.

In the current study, SpO_2 levels taken from the finger, of BFR participants were significantly lower compared to the placebo group, which needs some explanation as the blood flow restriction occurred on the lower not upper limbs. This observation is also supported by other researchers who noted decreased muscle oxygenation during BFR exercise (Neto et al., 2016; Tanimoto et al., 2005). In contrast, McKee et al. (2024) reported no significant differences in SpO_2 levels between BFR and non-BFR groups (McKee et al., 2024). Similar to our study, Campbell-Simpson, (2024), observed that SpO_2 levels during exercise were significantly lower in the BFR group (Campbell-Simpson et al., 2024). The primary effect of BFR is the restriction of venous blood flow while allowing arterial inflow, creating a hypoxic environment in the restricted limb (Kilgas et al., 2019). This restriction leads to a significant reduction in venous return from the leg, which impacts overall circulation dynamics (Kilgas et al., 2019). The reduced blood

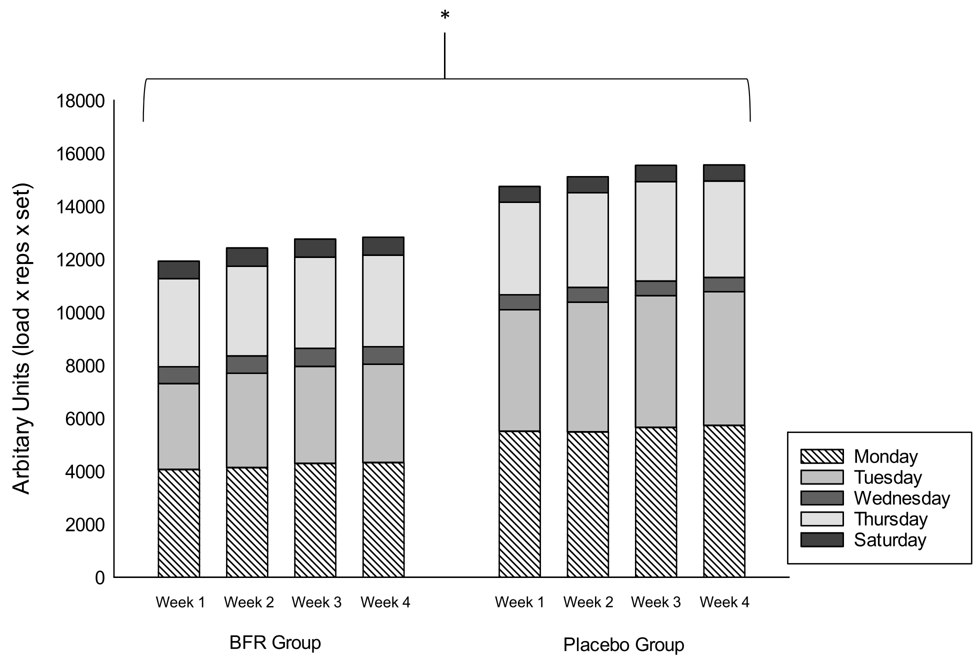

Figure 6. Total weekly load in arbitrary units during strength training between BFR and Placebo groups over a 4-week taper period. * significant difference between groups ($p < 0.05$).

flow results in less oxygenated blood reaching the peripheral extremities, including the fingers, which is detected by the pulse oximeter as lower SpO_2 levels (Campbell-Simpson et al., 2024).

We found a statistically significant main effect for both set and group RPE variables, with the BFR group exhibiting significantly higher RPE levels compared to the placebo group, despite the fact that these individuals had reduced mechanical load. These findings resonate with the results of a previous investigation by Neto et al. (2016), who observed increased RPE in the BFR compared to the placebo group after each set (Neto et al., 2016). Similarly, a study conducted by Loenneke et al. (2010), supports these observations, indicating that RPE scores were significantly higher in the BFR group compared to the placebo group after every set (Loenneke et al., 2010). Hughes and Patterson, (2020) suggest that BFR reduces oxygen delivery to muscles, creating an anaerobic environment that leads to the buildup of metabolic byproducts such as carbon dioxide and hydrogen ions, decreasing pH levels (Hughes & Patterson, 2020). This acidic environment stimulates pain receptors, enhancing sensations of pain and discomfort (Hughes & Patterson, 2020). Additionally, cellular swelling from fluid accumulation and increased muscle fibre recruitment under BFR contribute to greater sensations of exertion and fatigue (Saraf et al., 2022). The sympathetic nervous system further amplifies these sensations by triggering mechanoreceptors and prompting hormone release, such as growth hormone (Saraf et al., 2022). The higher RPE levels observed in the BFR group align with previous research, confirming that blood flow restriction leads to increased perceived exertion despite reduced mechanical load.

The results of this study did not show a significant difference in heart rate between groups, but there was a significant difference between sets of each session indicating an increased metabolic stress throughout the 3 training sets. We were surprised that given the femoral constriction which causes alterations in the metaboreflex increasing CNS mediated output (Kaur et al., 2016), we found no difference in heart rate between BFR and placebo groups. One potential explanation for the lack of significant difference in heart rate could be the individual responses to BFR training, as some individuals may experience more pronounced hemodynamic responses than others due to genetic factors and sensitivity of baroreceptors and chemoreceptors involved in cardiovascular regulation (Miller et al., 2021). Additionally, this study's duration, intensity and specific BFR protocol (i.e. cuff pressure, repetitions and sets) might not have been sufficient to elicit a distinguishable difference in heart rate between the groups. Previous research has suggested that while BFR can lead to acute increases in heart rate and blood pressure due to enhanced muscle afferent feedback and sympathetic nervous system activation, the overall cardiovascular response can be modulated by compensatory mechanisms such as peripheral vasodilation and enhanced venous return (Neto et al., 2016). While heart rate is a commonly used measure of cardiovascular strain, it may not provide a comprehensive view of the localised effects of exercise, such as muscular fatigue or metabolic stress, especially in the context of resistance training with BFR (Loenneke et al., 2012). Heart rate reflects the overall workload of the heart and the systemic demand for oxygen, which may not increase significantly if the exercise does not broadly tax the cardiovascular system or if the systemic physiological compensation does not match the local stress on the muscles (Miller et al., 2021). Furthermore, heart rate may remain unchanged due to compensatory increases in stroke volume or more efficient oxygen utilisation by non-restricted muscles, potentially masking increases in cardiovascular strain.

Practical applications

This study demonstrated that bilateral lower-limb BFR training was more beneficial than traditional resistance training in terms of increasing strength and speed measures in trained basketball athletes over a relatively short 4-week taper block. These results are suggestive of an advantage of combining restriction with moderate resistance loads (25–30% 1RM) in eliciting strength and speed gains during a deload training phase.

Conclusion

Implementing BFR to maintain exercise intensity while reducing overall work volume has shown to not only be effective in sustaining performance levels during a taper phase, but this type of training can increase performance in many cases, possibly allowing greater gains from lower loading that could be of benefit during high training loads, in competitive seasons. The clear improvement in bench-press strength resulting from lower-body restriction suggests a systemic effect of BFR training. Future research should now investigate whether a concomitant improvement in game-specific measures accompanies such improvements in out-of-game fitness test measures.

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Data deposition

The data that support the findings of this study are available on request from the corresponding author, [HKS]. The data are not publicly available due to privacy issues.

Ethics statement

This study was approved by the Universities Ethics Committee (HEC2022–25) and in accordance with the Declaration of Helsinki.

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