ORIGINAL ARTICLE

The acute effect of blood flow restriction or ischemia on countermovement jump performance

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ABSTRACT

The aim of this study was to evaluate the effect of blood flow restriction (BFR) or ischemia (IS) used between countermovement jumps (CMJ) on power performance changes. Two groups of participants implemented two separate experimental protocols: BFR as protocol no. 1 and IS as protocol no. 2. Protocol no. 1 involved seventeens male (n = 14) and female (n = 3). Protocol no. 2 involved twenty-three active male (n = 15) and female (n = 8). During each experimental session, following a randomized crossover design, the subjects performed 4 sets of 2 repetitions of CMJ with a 7-minute rest interval. In protocol no.1, the subjects during the rest interval used the appropriate: BFR 60%AOP or 80%AOP or control condition. In protocol no.2 subjects during the rest interval used appropriate: IS 100%AOP or control condition. The two-way repeated measures ANOVA for protocol no.1 as well for protocol no.2 did not show statistically significant condition × set interaction for average force, average power, relative peak power, relative peak force and jump height. There was also no main effect of conditions for both protocols. The results of this study indicates that neither BFR nor IS, regardless of cuff pressure, do not led to improvements in jump performance.
Keywords: Sport medicine, Cuff, Occlusion, Jumping, Power performance.

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INTRODUCTION

Ischemia (IS) as well as blood flow restriction (BFR) are noteworthy training methods drawing significant research interest. Both of these concepts refer to controlled restriction of blood flow, however they differ in regard to the degree of closure of the blood flow. BFR refers to application of cuffs which cause compression in order to reduce the arterial blood flow, while during IS the arterial blood flow is fully blocked. The level of compression is commonly determined as % of arterial occlusion pressure (AOP) which is the individualized value of pressure at which the blood flow to a limb is ceased (the value of 100% AOP determine complete blockage of blood flow to a limb; Patterson et al., 2019). There are five primary BFR or IS methods, i.e.: pre-conditioning (used only before the exercise; Salagas et al. 2022), post-conditioning (used after the completion of the exercise; Daab et al., 2020), continuous (applied continuously during sets and rest intervals; Volga Fernandes et al., 2022; Wilk et al., 2020), intermittent (applied only during the exercise; Wilk et al., 2020) and intra-conditioning (used during only the rest intervals; Fostiak et al., 2022, Bichowska-Pawęska et al., 2024; Gawel et al., 2024).

Ischemic intra-conditioning stands out as a novel and relatively uncomplicated approach to the BFR method. The use of intra-conditioning BFR/IS method preserves the integrity of the movement structures during the exercise because the cuffs are applied only during rest intervals. Furthermore, this method reduces subjective rates of pain and discomfort (Fitschen et al., 2014), contrary to other methods of applying BFR (Schwiete et al., 2021). There is only study that has examined the effects of intra-conditioning BFR/IS in regards to acute changes in power output and bar velocity, however the research outcomes are contradictory (Wilk et al., 2021; Jarosz et al., 2021; Trybulski et al., 2023; Gawel et al., 2024). The differences in obtained study protocols may be explained by the variety of the BFR/IS variables such as the compression pressure, the duration of BFR/IS or the duration of reperfusion (Gawel et al., 2024).

The duration of BFR or IS in intra-conditioning lasted usually from 3 to 6.5 minutes, causing different acute responses (Jarosz et al., 2021; Salagas et al., 2022; Fostiak et al., 2022; Pugh et al., 2024; Bichowska-Pawęska et al., 2024; Gawel et al., 2024). The latest research indicates that also the duration of reperfusion may have a significant impact on acute metabolic responses (Trybulski et al., 2022; Gawel et al., 2024). Further exercise and particular variables (number of sets, repetitions, exercise type, limb circumference, sex, blood pressure) may be of importance as well (Loenneke et al., 2014; Vehrs et al., 2023; Montoye et al. 2023). Therefore, the assessment of the effect of BFR/IS requires taking into account both BFR, training and particular variables.

Currently scientific data suggests that intra-conditioning BFR may allow to increase acute power performance during resistance exercise performed with upper (Wilk et al., 2021) as well as lower limbs (Trybulski et al., 2022). Even a single cycle of IS (5-minute duration; 100% AOP; 60% 1RM; 5 sets; 3 repetitions) significantly increased bar velocity during the bench press exercise (Salagas et al., 2022). Interestingly, in case of progressive fatigue, the use of BFR allows for limiting the decrease in power output in subsequent sets of squats (Trybulski et al., 2022), but such an effect occurs after at least three BFR cycles. Therefore, the number of ischemia cycles also may be a factor influencing the efficiency of the intra-conditioning method (Bichowska-Pawęska et al., 2024; Salagas et al., 2022). Although, the studies regarding intra-conditioning BFR/IS are contradictory, even if some researches did not show positive changes, no study has demonstrated a decrease in performance justifying the continued research in this regard. Pugh et al. (2024) showed greater physiological stress resulting from ischemic conditioning, what enhanced adaptive mechanisms, improving performance and endurance in high-intensity sports. Therefore, applying ischemic intra-conditioning during rest periods may help sustain high levels of power by mitigating exercise-induced fatigue.

Power output of lower limbs which is often developed through resistance training (Cormie et al., 2007) has been shown to be of great significance for athletes. It is often necessary to generate maximal power output, especially in non-cyclical motions such as throws, leaps, kicks or jumps (Bayrakdaroglu et al., 2022). As generating high levels of power output seems crucial for athletic performance (Jandacka et al., 2011), intra-conditioning BFR/IS may serve as a potential tool to further enhance those adaptive changes, particularly among elite athletes (Wilk/Bogdanis et al, 2021; Salagas et al., 2022). Considering that the acute responses during resistance training with BFR may be dependent on the value of cuffs pressure (reference), we hypothesized that BFR (60% and 80%AOP) or IS (100%AOP) intra-conditioning applied between successive Countermovement Jumps (CMJ) improves the variables determining jump performance.

MATERIALS AND METHODS

Study design

The study was conducted according to a randomized crossover design in which two different groups of participants underwent separate experimental protocols, one with blood flow restriction (P-no. 1), and the second with ischemia (P-no. 2). Each protocol was preceded by a familiarization session conducted one week before the main measurements. In both protocols, the participants performed 4 sets of 2 repetitions of the CMJ with a 7-minute rest interval. In each experimental protocol, the effects of BFR or IS applied only during the rest intervals between sets were assessed. Experimental protocol no. 1 included 3 conditions: BFR60%AOP, BFR80%AOP or a control condition and involved the use of cuffs before the first and between each set of CMJs. Experimental protocol no. 2 included 2 conditions, i.e. 100%AOP and a control condition and involved the use of cuffs before the first, 2nd and 4th set of the CMJ. All testing sessions were performed in the Physical Effort Laboratory at the University of Physical Education and Sport in Gdansk, Poland.

Participants

Experimental protocol no. 1 - BFR

Experimental protocol no. 1 involved 17 volunteers and consisted of 14 males and 3 females (age = 22.18 ± 2.01 years; body mass = 80.44 ± 9.43 kg; height = 181.06 ± 6.49 cm; 100%AOP = 192.94 ± 12.22 mmHg; 80%AOP = 154.35 ± 9.78 mmHg 60%AOP = 115.76 ± 7.33 mmHg).

Experimental protocol no. 2 – IS

Experimental protocol no. 2 involved 23 active volunteers and consisted of 15 males and 8 females (age = 23.48 ± 5.07 years; body mass = 75.83 ± 17.59 kg; height = 177.87 ± 9.41 cm; 100%AOP = 199.14 ± 18.86 mmHg).

The inclusion criteria for both groups were: no cardiovascular diseases (including atrial fibrillation, hypertension, thrombosis, heart failure) and no musculoskeletal injuries 6 months prior to the start of the study (personal declaration). The subjects did not change their basic diet, also they did not use any additional supplements or drugs throughout the duration of the study. Before the beginning of the experimental sessions, the subjects were informed and were aware of the potential risks of participating in the research and they signed a written informed consent. The study was approved by the Bioethics Committee at the University of Physical Education and Sport in Gdansk, Poland (no 3, 13.03.2024), in accordance with the ethical standards of the Declaration of Helsinki, 1983. No participants withdrew from the study.

Procedures

Familiarization session

One week before the main experiment began, the participants from both groups performed a familiarization session. During the familiarization session, the subjects from both groups performed the same warm-up which included jogging (5-min) and dynamic exercises (10-min) such as the gluteal stretch walk (10 repetitions (reps)), quadriceps grab walk (10 reps), bouncing on the spot (double leg) (28 reps), gluteal run (14 reps per leg), walking lunges (6 reps) and CMJ (4 reps) (O'Grady et al., 2021). Then, the participants performed 4 sets of 2 repetition of the CMJ with BFR (60% AOP) applied before the first and between each set of the CMJ.

Experimental session

One week before the start of each experimental protocols, participants from both groups completed a familiarization session. During each familiarization session, subjects from both groups performed 4 sets of 2 repetitions of the CMJ with a 7-minute rest interval, while BFR/IS were applied for 5 minutes, with additional ~60 s for cuff inflation and ~60 s for deflation. Experimental protocol no. 1 involved the use of BFR before the first and between each set of the CMJ with cuff pressure set to 60% or 80%AOP. Experimental protocol no. 2 involved the use of IS before the 1st, 2nd and 4th set of CMJ with cuff pressure set to 100%AOP. The warm-up before each main experimental protocol was the same as that performed in the familiarization session. To assess jumping variables, we used a 75 cm x 75 cm Kistler (Germany) tensometric platform. Participants performed a dynamic CMJ and to isolate leg performance during the CMJ jump, the upper limbs were stabilized at the hip.

BFR/ischemic intra-conditioning procedure

For the BFR and IS, pressure cuffs were applied bilaterally, as high as possible to the femoral groin area. The experiment utilized Fit Cuffs (Fit Cuffs, Denmark) with a 10 cm width. To determine each participant's AOP, after the completion of the warm-up and a 5-minute rest interval a handheld Doppler was used (Edan SD3, Sonoline C doppler with 8 MHz probe, Contec, China).

Participants remained seated during the measurement, and the probe was positioned over the posterior tibial artery to identify the blood pressure at which the auscultator pulse ceased. This procedure, as detailed in previous research (Wilk DOI 626915, Trybulski 2023?), was conducted twice for each limb to ensure accuracy. During the BFR protocol, cuff pressure was set to 60% and 80%AOP AOP (115.76 ± 7.33 mm Hg; 154.35 ± 9.78 Hg, respectively) whereas for the IS protocol cuff pressure was set to 100% AOP (199.14 ± 18.86 mmHg). During both protocols BFR/ischemia were applied for 5 minutes, with additional 60s for cuff inflation and 60 s for deflation.

Statistical analysis

All statistical analyses were performed using Statistica 9.1. Results are presented as means and standard deviations. The Shapiro-Wilk as well as the Levene and Mauchly's tests were used in order to verify the normality, homogeneity and sphericity of the sample data variances. respectively. Differences between the conditions for experimental protocol no.1 were examined using two-way repeated measures ANOVA [3 conditions (BFR 60% AOP vs. BFR 80% vs. control) × 4 sets of CMJ].

For experimental protocol no. 2 the differences between the conditions were examined using two-way repeated measures ANOVA [2 conditions (IS 100% vs. control) × 4 sets of CMJ]. Effect sizes (ES) for main effects and interactions in both protocols were determined by partial eta squared ($\eta 2$). Partial eta squared values were classified as small (0.01–0.059), moderate (0.06–0.137) and large (>0.137). Post hoc comparisons using Tukey's test were conducted to locate the differences between mean values when the main effect or an interaction was found. For pairwise comparisons. ESs were determined by Cohen's d which was characterized as large (d > 0.8), moderate (d between 0.8 and 0.5), small (d between 0.49 and 0.20) and trivial (d < 0.2). Percent changes with 95% confidence intervals (95CI) were also calculated. Statistical significance was set at $p < .05$.

RESULTS

Experimental protocol no. 1

The two-way repeated measures ANOVA [3 conditions (BFR at 60% AOP vs. BFR at 80% vs. control) × 4 sets of CMJ] for average force [N], average power [W], relative peak power [W/kg], relative peak force [N/kg] and jump height [m] did not show a statistically significant condition × set interaction (conditions × sets; $p = .21$; $\eta^2 = 0.08$; $p = .39$; $\eta^2 = 0.06$; $p = .81$; $\eta^2 = 0.03$; $p = .52$; $\eta^2 = 0.05$; $p = .91$; $\eta^2 = 0.02$. respectively; tables 1-5). There was also no main effect of conditions ($p = .67$; $\eta^2 = 0.02$; $p = .38$; $\eta^2 = 0.05$; $p = .11$; $\eta^2 = 0.13$; $p = .76$; $\eta^2 = 0.02$; $p = .21$; $\eta^2 = 0.09$, respectively; tables 1-5).

Table 1. Average force [N] during countermovement jumps under three experimental conditions (experimental protocol no. 1).

Condition	CMJ set 1 [N] (95%CI)	CMJ set 2 [N] (95%CI)	CMJ set 3 [N] (95%CI)	CMJ set 4 [N] (95%CI)	*p*-value for interaction	*p*-value for main effect of condition
Control	1532 ± 262 (1398 to 1667)	1511 ± 270 (1373 to 1650)	1524 ± 272 (1384 to 1664)	1500 ± 266 (1363 to 1637)	.21	.67
BFR 60%AOP	1519 ± 274 (1377 to 1660)	1510 ± 264 (1375 to 1646)	1509 ± 263 (1374 to 1644)	1484 ± 255 (1353 to 1615)		
BFR 80%AOP	1506 ± 263 (1371 to 1641)	1522 ± 279 (1379 to 1666)	1494 ± 268 (1356 to 1632)	1496 ± 269 (1358 to 1635)		
ES Cohen's						
CON vs. BFR 60%AOP	0.05	0.00	0.06	0.06		
CON vs. BFR 80%AOP	0.10	0.04	0.11	0.01		
BFR 60%AOP vs. BFR 80%AOP	0.05	0.04	0.06	0.05		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; BFR = blood flow restriction; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; N = newton.

Table 2. Average power [W] during countermovement jumps under three experimental conditions (experimental protocol no. 1).

Condition	CMJ set 1 [W] (95%CI)	CMJ set 2 [W] (95%CI)	CMJ set 3 [W] (95%CI)	CMJ set 4 [W] (95%CI)	*p*-value for interaction	*p*-value for main effect of condition
CON	2199 ± 505 (1939 to 2458)	2134 ± 539 (1857 to 2411)	2156 ± 523 (1887 to 2425)	2130 ± 546 (1849 to 2411)	.39	.38
BFR 60%AOP	2176 ± 521 (1908 to 2444)	2152 ± 522 (1884 to 2421)	2130 ± 503 (1871 to 2389)	2070 ± 477 (1825 to 2315)		
BFR 80%AOP	2117 ± 504 (1857 to 2376)	2130 ± 523 (1861 to 2399)	2094 ± 535 (1819 to 2369)	2074 ± 518 (1808 to 2340)		
ES Cohen's						
CON vs. BFR 60%AOP	0.04	0.03	0.05	0.12		
CON vs. BFR 80%AOP	0.16	0.01	0.12	0.11		
BFR 60%AOP vs. BFR 80%AOP	0.12	0.04	0.07	0.01		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; BFR = blood flow restriction; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; W = watt.

Table 3. Relative peak power [W] during countermovement jumps under three experimental conditions (experimental protocol no. 1).

Condition	CMJ set 1 [W/kg] (95%CI)	CMJ set 2 [W/kg] (95%CI)	CMJ set 3 [W/kg] (95%CI)	CMJ set 4 [W/kg] (95%CI)	CMJ set 5 [W/kg] (95%CI)	*p*-value for interaction	*p*-value for main effect of condition
CON	50.2 ± 8.3 (46.0 to 54.5)	48.9 ± 8.3 (44.6 to 53.2)	48.5 ± 7.9 (44.4 to 52.5)	48.5 ±9 .6 (43.5 to 53.4)	47.7 ±7.8 (43.7 to 51.7)	.81	.11
60%AOP	49.9 ± 9.0 (45.2 to 54.5)	48.6 ± 8.6 (44.2 to 53.0)	47.9 ± 8.0 (43.8 to 52.0)	46.8 ± 7.8 (42.8 to 50.7)	47.2 ± 7.3 (43.4 to 50.9)		
80%AOP	48.8 ± 8.0 (44.7 to 52.9)	48.2 ± 7.8 (44.2 to 52.2)	47.3 ± 8.3 (43.0 to 51.5)	46.9 ± 7.9 (42.9 to 51.0)	46.9 ± 8.0 (42.8 to 51.0)		
ES Cohen's							
CON vs. 60%AOP	0.03	0.04	0.08	0.19	0.07		
CON vs. 80%AOP	0.17	0.09	0.15	0.18	0.10		
60%AOP vs. 80%AOP	0.13	0.05	0.07	0.01	0.04		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; BFR = blood flow restriction; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; W = watt.

Table 4. Relative peak force [N/kg] during countermovement jumps under three experimental conditions (experimental protocol no. 1).

Condition	CMJ set 1 [N/kg] (95%CI)	CMJ set 2 [N/kg] (95%CI)	CMJ set 3 [N/kg] (95%CI)	CMJ set 4 [N/kg] (95%CI)	*p*-value for interaction	*p*-value for main effect of condition
CON	231 ± 23 (219 to 243)	226 ± 26 (213 to 239)	229 ± 20 (216 to 242)	227 ± 20 (214 to 240)	.52	.76
BFR 60%AOP	230 ± 24 (217 to 242)	227 ± 21 (216 to 238)	228 ± 22 (217 to 240)	225 ±21 (215 to 236)		
BFR 80%AOP	226 ± 23 (214 to 238)	228 ± 24 (215 to 240)	225 ± 20 (211 to 239)	226 ± 26 (212 to 239)		
ES Cohen's						
CON vs. BFR 60%AOP	0.04	0.04	0.05	0.10		
CON vs. BFR 80%AOP	0.22	0.08	0.20	0.04		
BFR 60%AOP vs. BFR 80%AOP	0.17	0.04	0.14	0.04		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; BFR = blood flow restriction; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; N = newton; kg = kilograms.

Table 5. Jump height [m] during countermovement jumps under three experimental conditions (experimental protocol no. 1).

Condition	CMJ set 1 [m] (95%CI)	CMJ set 2 [m] (95%CI)	CMJ set 3 [m] (95%CI)	CMJ set 4 [m] (95%CI)	*p*-value for interaction	*p*-value for main effect of condition
CON	0.34 ± 0.07 (0.18 to 0.45)	0.33 ± 0.07 (0.15 to 0.44)	0.33 ± 0.07 (0.17 to 0.46)	0.32 ± 0.07 (0.16 to 0.43)	.91	.21
BFR 60%AOP	0.33 ± 0.07 (0.16 to 0.42)	0.32 ± 0.07 (0.16 to 0.41)	0.32 ± 0.07 (0.15 to 0.42)	0.31 ± 0.07 (0.15 to 0.41)		
BFR 80%AOP	0.32 ± 0.07 (0.18 to 0.45)	0.32 ± 0.07 (0.17 to 0.46)	0.32 ± 0.08 (0.16 to 0.46)	0.32 ± 0.07 (0.16 to 0.43)		
ES Cohen's						
CON vs. 60%AOP	0.14	0.14	0.14	0.14		
CON vs. 80%AOP	0.29	0.14	0.14	0.00		
60%AOP vs. 80%AOP	0.14	0.00	0.00	0.14		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; BFR = blood flow restriction; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; m = meters.

Experimental protocol no. 2

The two-way repeated measures ANOVA [2 conditions (ischemia 100% AOP vs. control) × 4 sets of CMJ] for average force [N], average power [W], relative peak power [W/kg], relative peak force [N/kg] and jump height [m] did not show statistically significant condition × set interaction (conditions × sets; $p = .94$; $\eta^2 = 0.01$; $p = .30$; $\eta^2 = 0.05$; $p = .41$; $\eta^2 = 0.04$; $p = .97$; $\eta^2 = 0.01$; $p = .35$; $\eta^2 = 0.04$. respectively; tables 6-10). There was also no main effect of conditions ($p = .07$; $\eta^2 = 0.13$; $p = .06$; $\eta^2 = 0.14$; $p = .22$; $\eta^2 = 0.06$; $p = .28$; $\eta^2 = 0.05$; $p = .42$; $\eta^2 = 0.02$, respectively; tables 6-10).

Table 6. Average force [N] during countermovement jumps under two experimental conditions (experimental protocol no.2).

Condition	**CMJ set 1**	**CMJ set 2**	**CMJ set 3**	**CMJ set 4**	***p*-value for interaction**	***p*-value for main effect of condition**
	[N] (95%CI)	[N] (95%CI)	[N] (95%CI)	[N] (95%CI)		
CON	1498 ± 369 (960 to 2155)	1461 ± 371 (957 to 2161)	1446 ± 360 (935 to 2193)	1446 ± 379 (958 to 2288)	.94	.07
IS 100%AOP	1468 ± 387 (885 to 2350)	1438 ± 390 (901 to 2350)	1422 ± 367 (922 to 2065)	1411 ± 363 (918 to 2113)		
ES Cohen's						
CON vs. IS 100%AOP	0.08	0.06	0.07	0.10		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; IS = ischemia; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; N = newton.

Table 7. Average power [W] during countermovement jumps under two experimental conditions (experimental protocol no.2).

Condition	**CMJ set 1**	**CMJ set 2**	**CMJ set 3**	**CMJ set 4**	***p*-value for interaction**	***p*-value for main effect of condition**
	[W] (95%CI)	[W] (95%CI)	[W] (95%CI)	[W] (95%CI)		
CON	2124 ± 651 (1207 to 3135)	2040 ± 648 (1186 to 3010)	2016 ± 626 (1174 to 2948)	2031 ± 671 (1150 to 3156)	.30	.06
IS 100%AOP	2030 ± 625 (1153 to 2824)	1973 ± 632 (1162 to 2820)	1983 ± 654 (1059 to 3034)	1980 ± 656 (1047 to 2931)		
ES Cohen's						
CON vs. IS 100%AOP	0.15	0.10	0.05	0.08		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; IS = ischemia; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; W = watt.

Table 8. Relative peak power [W/kg] during countermovement jumps under two experimental conditions (experimental protocol no.2).

Condition	**CMJ set 1**	**CMJ set 2**	**CMJ set 3**	**CMJ set 4**	***p*-value for interaction**	***p*-value for main effect of condition**
	[W/kg] (95%CI)	[W/kg] (95%CI)	[W/kg] (95%CI)	[W/kg] (95%CI)		
CON	50.0 ± 8.5 (35.3 to 65.0)	48.4 ± 7.9 (34.0 to 61.0)	47.3 ± 8.1 (32.8 to 59.8)	47.5 ± 7.8 (32.4 to 59.4)	.41	.22
IS 100%AOP	48.8 ± 8.2 (33.7 to 61.7)	48.3 ± 8.5 (32.6 to 61.6)	47.1 ± 8.7 (29.7 to 58.9)	47.2 ± 8.8 (32.8 to 61.7)		
ES Cohen's						
CON vs. IS 100%AOP	0.14	0.01	0.02	0.04		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; IS = ischemia; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; W = watt; kg = kilograms.

Table 9. Relative peak force [N/kg] during countermovement jumps under two experimental conditions (experimental protocol no.2).

Condition	**CMJ set 1**	**CMJ set 2**	**CMJ set 3**	**CMJ set 4**	***p*-value for interaction**	***p*-value for main effect of condition**
	[N/kg] (95%CI)	[N/kg] (95%CI)	[N/kg] (95%CI)	[N/kg] (95%CI)		
CON	245 ± 33 (194 to 337)	241 ± 29 (187 to 295)	238 ± 28 (191 to 297)	239 ± 28 (189 to 296)	.97	.28
IS 100%AOP	241 ± 27 (201 to 296)	238 ± 31 (193 to 312)	236 ± 32 (192 to 308)	235 ± 32 (184 to 310)		
ES Cohen's						
CON vs. IS 100%AOP	0.13	0.10	0.07	0.13		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; IS = ischemia; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; N = newton; kg = kilograms.

Table 10. Jump height [m] during countermovement jumps under two experimental conditions (experimental protocol no.2).

Condition	CMJ set 1 [m] (95%CI)	CMJ set 2 [m] (95%CI)	CMJ set 3 [m] (95%CI)	CMJ set 4 [m] (95%CI)	*p*-value for interaction	*p*-value for main effect of condition
CON	0.32 ± 0.08 (0.21 to 0.45)	0.32 ± 0.08 (0.20 to 0.45)	0.31 ± 0.08 (0.20 to 0.44)	0.32 ± 0.08 (0.20 to 0.43)	.35	.42
IS 100%AOP	0.32 ± 0.08 (0.21 to 0.48)	0.32 ± 0.08 (0.20 to 0.47)	0.31 ± 0.08 (0.17 to 0.43)	0.31 ± 0.08 (0.20 to 0.45)		
ES Cohen's						
CON vs. IS 100%AOP	0.00	0.00	0.00	0.13		

Note. All data are presented as mean with standard deviation [SD]; CI = confidence interval; IS = ischemia; CMJ = Countermovement Jump; AOP = arterial occlusion pressure; CON = control condition; m = meters.

DISCUSSION

The main finding of this study was that intra-conditioning BFR as well as intra-conditioning IS did not increase variables related to jump performance, i.e.: average force, average power, relative peak power, relative peak force and jump height. The lack of significant differences occurred across each compression pressures 60% AOP; 80%; 100% AOP. Therefore, it may be concluded that regardless of the cuff pressure, as well as the number of ischemia cycles the intra-conditioning BFR or IS did not influence acute jump performance, which is in contrast to our hypothesis. Although, the obtained results indicate no increases in jump performance, however it must be emphasized that also no decrease in jump performance was recorded in successive sets of the CMJ.

To the best of the authors knowledge, the present study is the first to evaluate the effects of BFR/IS used during rest periods on CMJ performance which limits the possibility of comparison with other studies. To date, the application of intra-conditioning BFR and/or IS was primarily used during resistance exercise (Teixeira et al., 2018; Torma et al. 2021; Jarosz et al., 2021; Wilk et al. 2021). Previous research has indicated that BFR used between sets of resistance exercises may be a significant factor leading to acute power performance changes (Wilk et al., 2021; Trybulski et al., 2022). For instance, Wilk et al. (Wilk et al., 2021) reported significant increases in power output and bar velocity when intra-conditioning BFR was used during the bench press exercise (5 minutes duration; 80%AOP; 60% 1RM; 5 sets; 3 repetitions). Likewise, Salagas et al. (2022) showed an increase in mean and peak bar velocity when a single cycle of IS was applied before the bench press exercise (5-min duration; 100%AOP; 60% 1RM). Therefore, 5-minutes of BFR or IS in the above-mentioned studies was suitable to induce positive changes, but when the same procedure was performed between the CMJs such a positive effect was not observed. It is worth considering the importance of external loading when intra-conditioning BFR. Most studies that showed a positive effect of intra-conditioning BFR used external loading. However, studies using a protocol without external loading did not show such changes (Fostiak et al., 2022). For example, in Wilk et al. (2021) and Salagas et al. (2022) studies, a load of 60% of 1RM was used. On the contrary, a study analysing the intra-conditioning BFR (5-min duration; 60% and 80% AOP) during a running protocol (without external load) did not show any changes in performance (Fostiak et al., 2022) what is similar to the results of our study. Taking this into consideration, it might be concluded that changes in the results after BFR or IS intra-conditioning occurred when high muscle tension was observed caused by external load. Conversely, in the absence of an external load stimulus, no such changes were observed.

Attention should also be paid to the direction of the intra-conditioning BFR effect. Some studies show an increase in power output following intra-conditioning BFR, while others studies show a beneficial effect on decreasing power output loss during multiple sets of resistance exercise. Trybulski et al. (2022), on the contrary to other studies did not find any increases of performance following intra-conditioning BFR, however reported significantly lower decline in power output during the squat exercise. Perhaps, for BFR or IS to be effective, it likely requires effort that generates fatigue, which did not occur during the CMJ. In our protocol of CMJ tests the extended rest periods (7 minutes) allowed for full recovery. The possible influence of IS/BFR on the development may be further supported by the lack of decline in CMJ performance across subsequent sets also under control conditions. Furthermore, recent studies have shown that body position significantly affects the baseline measurement of 100%AOP (Queiros et al., 2024). Higher mean AOP occurs in measurements taken in the standing position compared to the supine and sitting position. Therefore, in order to standardize BFR pressure, Queiros et al. (2024) suggest that baseline measurement of 100%AOP should be performed in the same body position in which the effort will be executed. In the conducted studies, the AOP measurement was performed in the sitting position and the exercise in the standing position, which could have a significant impact on the actual cuff pressure. However, it should be emphasized that none of the cuff pressures applied in our protocol did not show significant changes in CMJ test results.

Another factor that should be taken into account is the area in which the cuffs are applied. All previous studies that have shown improved power output following intra-conditioning BFR have involved the use of a protocol that included upper body exercise. However, the acute effect of BFR may vary between the upper and lower limbs (Trybulski et al., 2022; Trybulski et al., 2023). For example, Gepfert et al. (2020) showed that to induce positive changes after ischemia, the lower limbs require a significantly higher pressure value (150% AOP) compared to the upper limbs. Also, a recent study by Queiros et al. (2024) demonstrated significant differences in AOP measurements between the lower and upper extremities. The authors have shown that the lower limbs require higher cuff pressure to achieve the same degree of BFR compared to the upper limbs. Additionally, as Enko et al. (2011) points out, as the application of BFR cycles increases, the blood vessels progressively widen, attaining their peak diameter after the third cycle. Hence, it appears advisable to incorporate more than one BFR cycle within an intra-conditioning method of training. Thus, based on previous research, it can be concluded that the number of cycles of BFR and IS (5 and 4 respectively) used in our study was sufficient to have a positive effect on jumping variables. However, the results of this study do not confirm these expectations, even though different cuff pressures were used in both protocols (60%, 80%, 100%AOP).

To fully appreciate the scope and implications of the study, it is crucial to consider its primary limitations, which may influence the observed outcomes. Above all, this is the first study to examine the effect of BFR and IS intra-conditioning on jump performance, which is limited by the lack of generalizability or comparison of results across different research protocols. Moreover, while intra-conditioning IS positively impacted power performance when 100% of AOP was used (Pugh et al., 2024), our study shows no significant improvements (60%, 80%, 100%AOP) in body-weight movement such as jumping, suggesting that factors other than % of arterial occlusion pressure may determine the effectiveness of this method. As Spitz et al. (2020) points out, varying body positions, such as seated, supine, and standing can lead to significant differences in the pressure required to achieve effective arterial occlusion, as each position alters blood flow dynamics and limb positioning. In our study, AOP was measured in a seated position with extended legs, which does not reflect the standing position used during jump exercises, therefore composing the main limitation of our study. This variability underscores the importance of aligning the AOP measurement position with that used in the exercise to ensure consistency and accuracy (de Queiros et al., 2024) when BFR/IS method was used. In addition, BFR applied during physical exercise causes a higher level of motor unit activity (Yasuda et al., 2013), increased cell swelling (Loenneke et al., 2012), as well as increased muscle protein synthesis (Fujita et al., 2007) and satellite cell proliferation (Nielsen et al., 2012) compared to exercise without BFR. BFR has been shown to positively impact post-exercise growth hormone concentration (Takarada et al., 2000; Suga et al., 2009) and insulin-like growth factor IGF-1 compared to control conditions (Takano et al., 2005). Thus, despite no improvement in jump performance in our study following the BFR/IS intervention, we may assume that such a training intervention may have a beneficial effect on acute metabolic and hormonal responses. However, in the present study, the physiological and metabolic responses were not determined on an acute basis. Thus, future research should explore the above mentioned factors and their linkage in order to better understand the conditions under which intra-conditioning BFR and IS might enhance athletic performance, particularly in dynamic, lower-limb exercise.

CONCLUSIONS

The results of this study demonstrate that neither BFR nor IS, regardless of cuff pressure (60%, 80%, 100%AOP), led to improvements in jump performance variables such as average force, average power, relative peak power, relative peak force and jump height. The absence of performance enhancement in this study suggests that the effects of BFR and IS may be exercise-specific and more pronounced in contexts involving mechanical overload, such as resistance training, rather than dynamic, unloaded movements like jumping. However, despite the lack of performance gains, BFR/IS intra-conditioning effectively maintained jump performance levels without the progressive decline typically seen over successive sets. This maintenance of performance may facilitate chronic muscle adaptations while minimizing acute performance trade-offs. Thus, future research should focus on examining the underlying physiological mechanisms and testing alternative protocols, including body position during AOP measurements and external load incorporation, to clarify the potential of BFR and IS in enhancing performance in dynamic lower-limb activities.

AUTHOR CONTRIBUTIONS

Study design, MB-P. Data collection, MB-P, KF, ES and RT. Statistical analysis, MB-P and MW. Data interpretation, MB-P and MW. Manuscript preparation, MB-P, DG, RT and MW. Literature search, MB-P, DG, DIA. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Bayrakdaroglu, S., Can, I., Ulutasdemir, N. (2022). A Comparison of Optimal Training Load for Maximal Power Output in Upper and Lower Body Exercises According to Different Sports. P J M H S, Vol. 16, No.02; 433-437. https://doi.org/10.53350/pjmhs22162433

Bichowska-Paweska, M., Gawel, D., Trybulski, R., Jarosz, J., Losinska, K., Fostiak, K., Vieira, J.G. (2024). The effect of a single cycle of ischemia on bar velocity during bench press exercise. Balt J Health Phys Act, 16(1):Article10. https://doi.org/10.29359/BJHPA.16.1.10

Cormie, P., McCaulley, G.O., Triplett, N.T., McBride, J.M. (2007). Optimal loading for maximal power output during lower body resistance exercises. Medicine and Science in Sports and Exercise, 39(2), 340-349. https://doi.org/10.1249/01.mss.0000246993.71599.bf

Daab, W., Bouzid, M. A., Lajri, M., Bouchiba, M., Rebai, H. (2020). Brief cycles of lower-limb occlusion accelerate recovery kinetics in soccer players. The Physician and Sportsmedicine, 49(2), 143-150. https://doi.org/10.1080/00913847.2020.1785260

de Queiros, V.S., Rolnick, N., Kamiş, O., Formiga, M.F., Rocha, R.F.C., Alves, J.C.M., Vieira, J.G., Vianna, J.M., Wilk, M., Fostiak, K., Cabral, B.G.A.T. and Dantas, P.M.S. (2024). Body position and cuff size influence lower limb arterial occlusion pressure and its predictors: implications for standardizing the pressure applied in training with blood flow restriction. Front. Physiol, 15:1446963. https://doi.org/10.3389/fphys.2024.1446963

Enko, K., Nakamura, K., Yunoki, K., Miyoshi, T., Akagi, S., Yoshida, M., et al. (2011). Intermittent arm ischemia induces vasodilatation of the contralateral upper limb. J. Physiol. Sci. 61, 507-513. https://doi.org/10.1007/s12576-011-0172-9

Fitschen, P. J., Kistler, B. M., Jeong, J. H., Chung, H. R., Wu, P. T., Walsh, M. J., et al. (2014). Perceptual effects and efficacy of intermittent or continuous blood flow restriction resistance training. Clin. Physiol. Funct. Imaging 34, 356-363. https://doi.org/10.1111/cpf.12100

Fostiak, K., Bichowska, M., Trybulski, R., Trabka, B., Krzysztofik, M., Rolnick, N. et al. (2022). Acute effects of ischemic intra-conditioning on 30 m sprint performance. Int J Environ Res Public Health. 2022 Oct 3;19(19):12633. https://doi.org/10.3390/ijerph191912633

Fujita, S., Abe, T., Drummond, M.J., Cadenas, J.G., Dreyer, H.C., Sato, Y., Volpi, E., Rasmussen, B.B. (2007). Blood flow restriction during low-intensity resistance exercise increases S6K1 phosphorylation and muscle protein synthesis. J Appl Physiol, 103: 903-910. https://doi.org/10.1152/japplphysiol.00195.2007

Gawel. D,, Jarosz, J., Trybulski, R. et al. (2024). Effects of different ischemic pressures on bar velocity during the bench press exercise: A randomized crossover trial. Biol Sport, 41(3):89-96. https://doi.org/10.5114/biolsport.2024.133004

Gepfert, M., Krzysztofik, M., Kostrzewa, M., Jarosz, J., Trybulski, R., Zajac, A., et al. (2020). The acute impact of external compression on back squat performance in competitive athletes. Int J Environ Res Public Health, Jun 29;17(13):4674. https://doi.org/10.3390/ijerph17134674

Jandacka, D., Beremjiski, P. (2011). Determination of strength exercise intensities based on the load-power-velocity relationship. Journal of Human Kinetics, 28: 33-44. https://doi.org/10.2478/v10078-011-0020-2

Jarosz, J., Trybulski, R., Krzysztofik, M., Tsoukos, A., Filip-Stachnik, A., Zajac, A. et al. (2021). The effects of ischemia during rest intervals on bar velocity in the bench press exercise with different external loads. Front Physiol, Aug 10;12:715096. https://doi.org/10.3389/fphys.2021.715096

Loenneke, J.P., Fahs, C.A., Rossow, L.M., et al. (2012). Effects of cuff width on arterial occlusion: implications for blood flow restricted exercise. Eur J Appl Physiol, 112(8):2903-2912. https://doi.org/10.1007/s00421-011-2266-8

Loenneke, J.P., Allen, K.M., Mouser, J.G., Thiebaud R.S., Kim D., Abe T., Bemben, M.G. (2014). Blood flow restriction in the upper and lower limbs is predicted by limb circumference and systolic blood pressure. Eur J Appl Physiol, Feb;115(2):397-405. https://doi.org/10.1007/s00421-014-3030-7

Nielsen, J.L., Aagaard, P., Bech, R.D., Nygaard, T., Hvid, L.G., Wernbom, M., et al. (2012). Proliferation of myogenic stem cells in human skeletal muscle in response to low-load resistance training with blood flow restriction. J. Physiol, 590, 4351-4361. https://doi.org/10.1113/jphysiol.2012.237008

Patterson, S.D., Hughes, L., Warmington, S., Burr, J., Scott, B.R., Owens, J., Abe, T., Nielsen, J.L., Libardi, C.A., Laurentino, G., Neto, G.R., Brandner, C., Martin-Hernandez, J. and Loenneke, J. (2019). Blood Flow Restriction Exercise: Considerations of Methodology, Application, and Safety. Front. Physiol. 10:533. https://doi.org/10.3389/fphys.2019.00533

Montoye, A.H.K., Neph, S.E., Plouffe, A.A., Vondrasek, J.D., Nordbeck, J.T., Cox, B.A., & Vranish, J.R. (2023). Understanding lower limb blood flow occlusion parameters for use in field-based settings. Journal of Sports Sciences. https://doi.org/10.1080/02640414.2023.2240995

O'Grady, M.W., Warren B.Y., Scott W.T., David, G.B. (2021). Does the warm-up effect subsequent post activation performance enhancement? The Journal of Sport and Exercise Science, Vol. 5, Issue 4, 302-309. https://doi.org/10.36905/jses.2021.04.08

Pugh, C.F., Paton, C.D., Ferguson, R.A., Driller, M.W., Beaven, M. (2024). Acute physiological responses of blood flow restriction between high-intensity interval repetitions in trained cyclists. Eu J Sport Sci, 1-11. https://doi.org/10.1002/ejsc.12107

Salagas, A., Tsoukos, A., Terzis, G., Paschalis, V., Katsikas, C., Krzysztofik, M. et al. (2022). Effectiveness of either short-duration ischemic pre-conditioning, single-set high-resistance exercise, or their combination in potentiating bench press exercise performance. Frontiers, 13:1083299. https://doi.org/10.3389/fphys.2022.1083299

Schwiete, C., Franz, A., Roth, C. anBehringer, M. (2021). Effects of Resting vs. Continuous Blood-Flow Restriction-Training on Strength, Fatigue Resistance, Muscle Thickness, and Perceived Discomfort. Front. Physiol, 12:663665. https://doi.org/10.3389/fphys.2021.663665

Spitz, R.W., Bell, Z.W., Wong, V., Viana, R.B., Chatakondi, R.N., Abe, T., et al. (2020). The position of the cuff bladder has a large impact on the pressure needed for blood flow restriction. Physiol. Meas, 41 (1), 01NT01. https://doi.org/10.1088/1361-6579/ab64b8

Suga, T., Okita, K., Morita, N., et al. (2009). Intramuscular metabolism during low-intensity resistance exercise with blood flow restriction. J Appl Physiol, 1985 106: 1119-1124. https://doi.org/10.1152/japplphysiol.90368.2008

Takano, H., Morita, T., Iida, H., Asada, K. I., Kato, M., Uno, K., ... & Nakajima, T. (2005). Hemodynamic and hormonal responses to a short-term low-intensity resistance exercise with the reduction of muscle blood flow. European journal of applied physiology, 95, 65-73. https://doi.org/10.1007/s00421-005-1389-1

Takarada, Y., Nakamura, Y., Aruga, S., Onda, T., Miyazaki, S., and Ishii, N. (2000). Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. J Appl Physiol, 88: 61-65. https://doi.org/10.1152/jappl.2000.88.1.61

Teixeira, E. L., Barroso, R., Silva-Batista, C., Laurentino, G. C., Loenneke, J. P., Roschel, H., & Tricoli, V. (2018). Blood flow restriction increases metabolic stress but decreases muscle activation during high-load resistance exercise. Muscle & Nerve, 57(1), 107-111. https://doi.org/10.1002/mus.25616

Torma, F., Gombos, Z., Fridvalszki, M., Langmar, G., Tarcza, Z., Merkely, B., ... & Radak, Z. (2021). Blood flow restriction in human skeletal muscle during rest periods after high-load resistance training down-regulates miR-206 and induces Pax7. Journal of sport and health science, 10(4), 470-477. https://doi.org/10.1016/j.jshs.2019.08.004

Trybulski, R., Jarosz, J., Krzysztofik, M., Lachowicz, M., Trybek, G., Zajac, A., et al. (2022). Ischemia during rest intervals between sets prevents decreases in fatigue during the explosive squat exercise: a randomized, crossover study. Sci Rep, Apr 8;12(1):5922. https://doi.org/10.1038/s41598-022-10022-4

Trybulski, R., Bichowska, M., Piwowar, R., Pisz, A., Krzysztofik, M., Filip-Stachnik, A., et al. (2023). The effects of ischemia during rest intervals on strength endurance performance. PLoS ONE, 18(4):e0280231. https://doi.org/10.1371/journal.pone.0280231

Vehrs, P. R., Blazzard, C., Hart, H. C., Kasper, N., Lacey, R., Lopez, D., Richards, S., & Egget, D.L. (2023). Comparison of two cuff inflation protocols to measure arterial occlusion pressure in males and females. Applied Sciences, 13, 1438. https://doi.org/10.3390/app13031438

Volga Fernandes, R., Tricoli, V., Soares, A.G., Miyabara, E.H., Aoki, M.S., Laurentino, G. (2022). Low-Load Resistance Exercise with Blood Flow Restriction Increases Hypoxia-Induced Angiogenic Genes Expression. Journal of Human Kinetics, Volume 84/2022, 82-91. https://doi.org/10.2478/hukin-2022-0101

Wilk, M., Gepfert, M., Krzysztofik, M., Stastny, P., Zajac, A., Bogdanis, G.C. (2020). Acute effects of continuous and intermittent blood flow restriction on movement velocity during bench press exercise against different loads. Front Physiol, 11:569915. https://doi.org/10.3389/fphys.2020.569915

Wilk, M., Krzysztofik, M., Jarosz, J., Krol, P., Leznicka, K., Zajac, A., Stastny, P., Bogdanis, G.C. (2021). Impact of Ischemic Intra-Conditioning on Power Output and Bar Velocity of the Upper Limbs. Front Physiol, Feb 25:12:626915. https://doi.org/10.3389/fphys.2021.626915

Yasuda, T., Loenneke, J.P., Ogasawara, R., et al. (2013). Influence of continuous or intermittent blood flow restriction on muscle activation during low-intensity multiple sets of resistance exercise. Acta Physiologica Hungarica, Volume 100 (4), 419-426. https://doi.org/10.1556/APhysiol.100.2013.4.6