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Research article

Blood Flow Restricted Cycling Impairs Subsequent Jumping But Not Balance Performance Slightly More Than Non-Restricted Cycling: An Acute Randomized Controlled Cross-Over Trial

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Abstract

Chronic blood flow restriction (BFR) training has been shown to improve drop jumping (DJ) and balance performance. However, the acute effects of low intensity BFR cycling on DJ and balance indices have not yet been examined. 28 healthy young adults (9 female; 21.8 ± 2.7years; 1.79 ± 0.08m; 73.9 ± 9.5kg) performed DJ and balance testing before and immediately after 20min low intensity cycling (40% of power at maximal oxygen uptake) with (BFR) and without BFR (noBFR). For DJ related parameters, no significant mode × time interactions were found ($p \geq 0.221$, $\eta_p^2 \leq 0.06$). Large time effects for DJ heights and the reactive strength index were observed ($p < 0.001$, $\eta_p^2 \geq 0.42$). Pairwise comparison revealed notably lower values for both DJ jumping height and reactive strength index at post compared to pre (BFR: -7.4 ± 9.4%, noBFR: -4.2 ± 7.4%). No statistically significant mode × time interactions ($p \geq 0.36$; $\eta_p^2 \leq 0.01$) have been observed for balance testing. Low intensity cycling with BFR results in increased ($p \leq 0.01$; SMD ≥ 0.72) mean heart rate (+14 ± 8bpm), maximal heart rate (+16 ± 12 bpm), lactate (+0.7 ± 1.2 mmol/L), perceived training intensity (+2.5 ± 1.6au) and pain scores (+4.9 ± 2.2au) compared to noBFR. BFR cycling induced acutely impaired DJ performance, but balance performance was not affected, compared to noBFR cycling. Heart rate, lactate, perceived training intensity, and pain scores were increased during BFR cycling.

Key words: Ischemic preconditioning, occlusion, PAP, post-activation potentiation, functional balance, vertical jump.

Introduction

Previous research has combined blood flow restriction (BFR) training with numerous different exercise variations, such as resistance training (Hughes et al., 2019), cycling (Abe et al., 2010), rowing (Held et al., 2020), balance exercises (Burkhardt et al., 2021), or jump training (Horiuchi et al., 2018). Thereby, numerous positive effects of BFR training such as increased strength, hypertrophy, and endurance adaptations have been identified (Abe et al., 2010; Horiuchi et al., 2018; Hughes et al., 2019; Held et al., 2020; Burkhardt et al., 2021).

In addition to these basic physical training indices, balance and jump performance were also recorded in several studies as additional outcomes (Clarkson et al., 2019). Thereby, the combination of (3 to 12 weeks) BFR with low load resistance training showed similar (Linero and Choi, 2021) to superior (Hughes et al., 2019) balance performance adaptations compared to low load resistance without BFR. Furthermore, in a different study, 8 weeks of low load resistance training with BFR induced comparable balance performance improvements as dynamic balance exercises without BFR (Yokokawa et al., 2008). Apart from these longitudinal findings, acute effects of BFR on balance performance have not yet been investigated. However, in a recent study of Burkhardt and colleagues (Burkhardt et al., 2021), dynamic balance performance with BFR was found to be impaired compared to the same testing without BFR. In this context, increased electromyography muscle activity of the vastus lateralis and soleus has been observed for dynamic balance exercises with BFR (Burkhardt et al., 2021).

A recent systematic review on jumping performance concluded that positive adaptation of vertical jump performance might be expected after 8+ weeks of BFR training (Clarkson et al., 2019). However, few studies showed no (≤10 weeks low load resistance training) (Scott et al., 2017), comparable (6 weeks soccer-specific training) (Hosseini Kakhak et al., 2020), or even inferior (4 weeks jump training) (Horiuchi et al., 2018) countermovement jump (CMJ) adaptations following BFR training. Apart from these heterogeneous chronic responses of BFR training on jump performance, also acute effects of BFR on jumping performance showed high variability (Doma et al., 2020; Lindner et al., 2021). For example, Doma and colleagues (Doma et al., 2020) reported improvements in jumping height and reactive strength index values of drop jumps (DJ) using a BFR-based post-activation potentiation approach (lunges with BFR, 3 sets, 8 reps, 2 min rest). In this context, the reactive strength index quantifies the utilization of the reactive force capabilities during DJ (Struzik et al., 2016). Previous research revealed accelerated fatigue response of slow-twitch muscle fibres via BFR, which elicited an earlier onset of fast-twitch muscle fibre recruitment (Takarada et al., 2000). As the recruitment of higher threshold motor units is one proposed mechanism of post-activation potentiation (Sweeney et al., 1993), Doma and colleagues (Doma et al., 2020) concluded BFR approaches as a suitable means for inducing post-activation potentiation effects. In contrast to these BFR findings related to post-activation potentiation (Doma et al., 2020), passive ischemic preconditioning revealed no effects on acute DJ and CMJ performance (Lindner et al., 2021).

Against this background we sought to examine acute effects of low intensity cycling with and without BFR on DJ and balance performance. Thereby, the increased electromyography muscle activation (Burkhardt et al., 2021) and

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the earlier onset of fast-twitch muscle fibre recruitment (Takarada et al., 2000) via BFR could affect balance and jump performance. Since balance performance is impaired, if corresponding testing is performed with BFR (Burkhardt et al., 2021), and low (Hill et al., 2015) to moderate (Stemplewski et al., 2012) intensity cycling could impair acute balance performance, we assumed decreased balance performances immediately after cycling with BFR. Furthermore, we assumed an increased DJ performance directly post BFR cycling. Our results may have a noticeable impact on the conceptualization of BFR training approaches. In addition, the knowledge of acute effects induced by BFR could be improved, which might be used for designing BFR based training approaches.

Methods

Participants and study design

Assuming moderate effect sizes ($\eta_p^2 = 0.11$, $f = 0.35$), a priori conducted power analysis ($\alpha = 0.05$, study power ($1-\beta$-error) = 0.95, $r = 0.6$; G*Power, Version 3.1.9.6) revealed a required sample size of $n = 24$. Based on previous research with a similar study design (Rappelt et al., 2021), a low to moderate dropout rate was assumed. Therefore, 28 young healthy participants (9 females, age: 21.8 ± 2.7 years; height: 1.79 ± 0.08 m; mass: 73.9 ± 9.5 kg; weekly training: 6.4 ± 1.2 h; Maximal aerobic capacity; oxygen uptake (VO_2max): 56.0 ± 7.6 mL/kg/min; Power at VO_2max (PVO2MAX): 275 ± 35W) were enrolled in this acute randomized controlled crossover trial. Inclusion criteria were no medical condition such as neurological and orthopedical issues that potentially impede the completion of all testings. The study was approved by the local ethical committee (183/2021) and all participants signed an informed written consent after receiving all relevant study information prior to start of the study.

The study required three lab visits over three weeks as follows: (I) anthropometric assessment, ramp cycling test with initial familiarization with BFR (about 5 min cycling at <100W with 80% occlusion pressure) plus familiarization of neuromuscular performance testing (Drop jump (DJ), and Posturomed (Haider Bioswing, Germany)); (II and III in randomized order) cycling with BFR and without BFR (noBFR) plus jump and balance testing prior and post cycling. All lab visits were conducted one week apart. Participants were instructed to avoid any strenuous exercise 48h before each testing session. A standardized low intensity 10-minute warm up (5 min low intensity cycling at 100W with 80 rpm, individual dynamic stretching, 2 CMJ, 2 DJ) was performed prior to each lab visit. In order to control for potential circadian effects on neuromuscular performance, all measurements were conducted at similar times of the day for each participant. Jump and balance testing were always performed in the same order (DJ, Posturomed) before, and immediately after the cycling exercise. All tests were completed after about 3 - 4 min.

Testing procedures

VO_2max was assessed using a ramp testing protocol on a standard cycle ergometer (SRM Ergo, SRM Training Systems GmbH, Germany) until voluntary exhaustion was reached. The test consisted of 120 s with 100 W at a cadence of ~80 rpm, with subsequent load increments of 15 W every 30 s. During the ramp test, respiratory gas exchanges were continuously recorded employing a validated breath-by-breath spiroergometric system (Metamax 3b, Cortex Biophysics, Leipzig, Germany; technical error of the measurement <2%) (Macfarlane and Wong, 2012). The system was calibrated prior to each test following the manufacturer's recommendations. The highest consecutive oxygen uptake values averaged over 30 s were considered as VO_2max. The PVO2MAX was determined as the average power during this time-interval. VO_2max and objective exhaustion were verified by employing the criteria as suggested by Midgley and colleagues (Midgley et al., 2007). All athletes were verbally encouraged in a standardized manner until exhaustion.

Vertical jumping was evaluated employing the DJ test (0.40m drop height) on a force plate at 500 Hz (Quattro jump, Kistler, Switzerland; reliability: ICC = 0.998; CV < 2,7 %; random errors ± 2.8 cm) (Glatthorn et al., 2011). During testing, the arms had to be placed on the hips (akimbo). Three trials of DJ were performed before and immediately after the cycling (~20 s of rest between attempts). Jump height was determined via integrating the ground reaction forces (Baca, 1999). In addition, the utilization of the reactive force capabilities within the DJ were quantified using the reactive strength index (Struzik et al., 2016). The reactive strength index was calculated as jump height divided by ground contact time (Struzik et al., 2016). The average of the two best trials of reactive strength index with corresponding DJ heights and ground contact durations were included into further analyses.

Postural sway upon medio-lateral perturbation was tested using a two-dimensional platform (Posturomed). The platform is suspended in each corner on two independent springs, allowing a sway of up to 70 mm from its neutral position in all directions. Initially, the plate was laterally deviated by 30 mm and magnetically fixated. The participants were instructed to take a stable position on the center of the plate in tandem stance (dominant leg behind, toes and heels touching the center of the plate), to place the hands akimbo and to focus the gaze on a wall (~3 m distance, at 1.75 m height). Limb dominance was determined following the lateral preference inventory (Coren, 1993). The fixation of the platform was released 2−3 s after taking in the initial position. Participants were asked to reduce the induced oscillation as quickly as possible and then to maintain a steady and stable position. The amplitude of the oscillations was recorded at a rate of 100 Hz. Total postural sway (distance) was calculated for the duration of 10 s. In addition, maximal deviation was measured as maximal amplitude during oscillation. The reliability of postural sway tests with unexpected perturbation on the Posturomed is considered to be good to very good (ICC = 0.71 - 0.97) (Schmidt et al., 2015). The average of the two best trials of postural sway (distance) with corresponding maximal amplitude were used for further analyses.

Acute intervention protocol

Adapted from Abe and colleagues (2010), participants performed 20 min cycling (SRM Ergo, SRM Training Systems GmbH, Germany) at low intensity (40%

PVO2MAX, 110 ± 35 W, 80 rpm) with (BFR) and without BFR (noBFR). BFR was applied at the proximal part of both lower limbs using pneumatic BFR bands (Occlusion Cuff Elite, The Occlusion Cuff, Belfast, United Kingdom). The occlusion pressure was initially measured via an ultrasound doppler (vascular Doppler probe PD1 + Combi, Ultrasound Technologies Ltd, Caldicot, UK): At first, the BFR cuffs were inflated to the maximum and then subsequently slowly deflated until the pulse wave was detectable via the ultrasound doppler. Finally, 80% of this occlusion pressure was used during training (193 ± 14 mmHg).

Mean (HRmean) and maximal heart rate (HRmax) were recorded using a chest strap (Polar, H7, Polar Electro Inc., Bethpage, NY, USA) during cycling. In addition, capillary blood samples from the earlobe were collected immediately after cycling cessation for lactate analysis (EBIOplus; EKF Diagnostic Sales, Magdeburg, Germany). Perceived training intensity (RPE, CR-10 scale) (Foster et al., 2001) and BFR induced pain scores (PS, CR-10 scale) (Lau et al., 2015) were also collected immediately post cycling.

Statistical analyses

Data are presented as means ± standard deviation. All data were initially assessed for normal distribution via shapiro-wilk-tests and variance homogeneity via plotting residuals. To examine protocol differences (BFR vs. noBFR) for the respective internal load measures (HRmean, HRmax, lactate, RPE, and pain scores) paired t-tests were separately conducted. Furthermore, two separately conducted 2 (mode: BFR vs. noBFR) × 2 (time: PRE vs. POST) rANOVA were separately calculated for all DJ and balance outcome measures. Effect sizes for rANOVA were given as partial eta squared (η_p^2) with ≥0.01, ≥0.06, ≥0.14 indicating small, moderate, and large effects, respectively (Cohen, 1988). In case of significant mode × time interactions, Bonferroni post-hoc tests were subsequently computed. For pairwise effect size comparison, standardized mean differences (SMD) were calculated as differences between means divided by the pooled standard deviations (trivial: $SMD < 0.2$, small: $0.2 \leq SMD < 0.5$, moderate: $0.5 \leq SMD < 0.8$, large $SMD \geq 0.8$) (Cohen, 1988). The smallest worthwhile changes (SWC) were calculated as 30% of noBFR standard deviation (Hopkins, 2004) in order to address meaningful changes. All statistical analyses were performed using R (version 4.0.5) in its integrated development environment RStudio (version 1.4.106).

Results

Jumping performance

For DJ floor contact time, no significant mode × time interaction ($p = 0.95$, $\eta_p^2 < 0.001$) or main effects for neither mode ($p = 0.59$, $\eta_p^2 = 0.01$) nor time ($p = 0.23$, $\eta_p^2 = 0.06$) were found. Similarly, for both DJ jumping height and DJ reactive strength index no significant mode × time interaction effects ($p = 0.22$, $\eta_p^2 = 0.06$ & $p < 0.31$, $\eta_p^2 = 0.05$) were found. However, analysis of time revealed a statistically significant time effect with large effect sizes for both DJ jumping height ($p < 0.001$, $\eta_p^2 = 0.42$) and DJ reactive strength index ($p < 0.001$, $\eta_p^2 = 0.50$). Pairwise comparison of time points revealed notably lower values for both DJ jumping height and reactive strength index at post compared to pre (Table 1).

Perturbed balance performance

In addition, rANOVA revealed non-significant mode × time interactions ($p \geq 0.36$; $\eta_p^2 \leq 0.01$) for both total distance (BFR: 2608 ± 870 mm (PRE) to 2665 ± 1135 mm (POST); +5.0 ± 36.9 mm; SMD = 0.06; noBFR: 2801 ± 1055 mm (PRE) to 2721 ± 855 mm (POST); +0.3 ± 30.2 %; SMD = 0.08) and maximal derivation (BFR: 39 ± 7 mm (PRE) to 38 ± 6 mm (POST); +0.4 ± 11.8 %; SMD = 0.15; noBFR: 37 ± 6 mm (PRE) to 38 ± 5 mm (POST); +3,5 ± 15.1 %; SMD = 0.18) of perturbed balance performance testing.

Internal load

Low intensity cycling with BFR resulted in increased ($p \leq 0.01$; $SMD \geq 0.72$; see Figure 1) HRmean (132 ± 19 bpm vs. 117 ± 20 bpm), HRmax (146 ± 19 bpm vs. 130 ± 18 bpm), lactate (1.8 ± 1.5 mmol/L vs. 1.0 ± 0.5 mmol/L), RPE (5.1 ± 1.9 au vs. 2.7 ± 1.1 au) and pain score (5.4 ± 2.2 au vs. 0.4 ± 0.8 au) compared to low intensity cycling without BFR.

Discussion

This is the first randomized controlled acute cross-over trial that investigated the immediate effects of low intensity cycling with and without BFR on selected neuromuscular performance indices in young active adults. We aimed at elucidating whether BFR or non-BFR cycling differently affect drop jump as well as perturbed balance performance. We found notable impairments of drop jump performance following both training conditions, whereas postural sway after perturbation was neither relevantly affected after low intensity cycling with nor without BFR. In addition, BFR revealed increased heart rate, lactate, perceived training intensity, and pain scores compared to cycling without BFR.

Table 1. **Drop-Jump height (DJ height), Drop-Jump floor contact time (DJ contact time), and Drop-Jump reactive strength index (DJ RSI) for training session with blood flow restriction (BFR) and without blood flow restriction (noBFR) during PRE and POST testing.**

Parameter	Condition	PRE	POST	POST-PRE		rANOVA *p*-value (η_p^2)		
				%DELTA	SMD	Time	Mode	Time × Mode
DJ height [cm]	BFR	25.7 ± 5.3	24.0 ± 5.4	-6.9 ± 8.7	0.33	<0.001	0.21	0.22
	noBFR	26.2 ± 5.9	25.1 ± 5.8	-3.4 ± 8.8	0.18	(0.42)	(0.07)	(0.06)
DJ contact time [msec]	BFR	181 ± 25	182 ± 27	0.8 ± 4.7	0.05	0.23	0.59	0.95
	noBFR	180 ± 23	181 ± 25	0.9 ± 6.0	0.07	(0.06)	(0.01)	(0.00)
DJ RSI [cm·s^{-1}]	BFR	145.3 ± 36.6	135.3 ± 37.8	-7.4 ± 9.4	0.27	<0.001	0.14	0.31
	noBFR	148.9 ± 42.8	141.6 ± 39.6	-4.2 ± 7.4	0.18	(0.50)	(0.09)	(0.05)

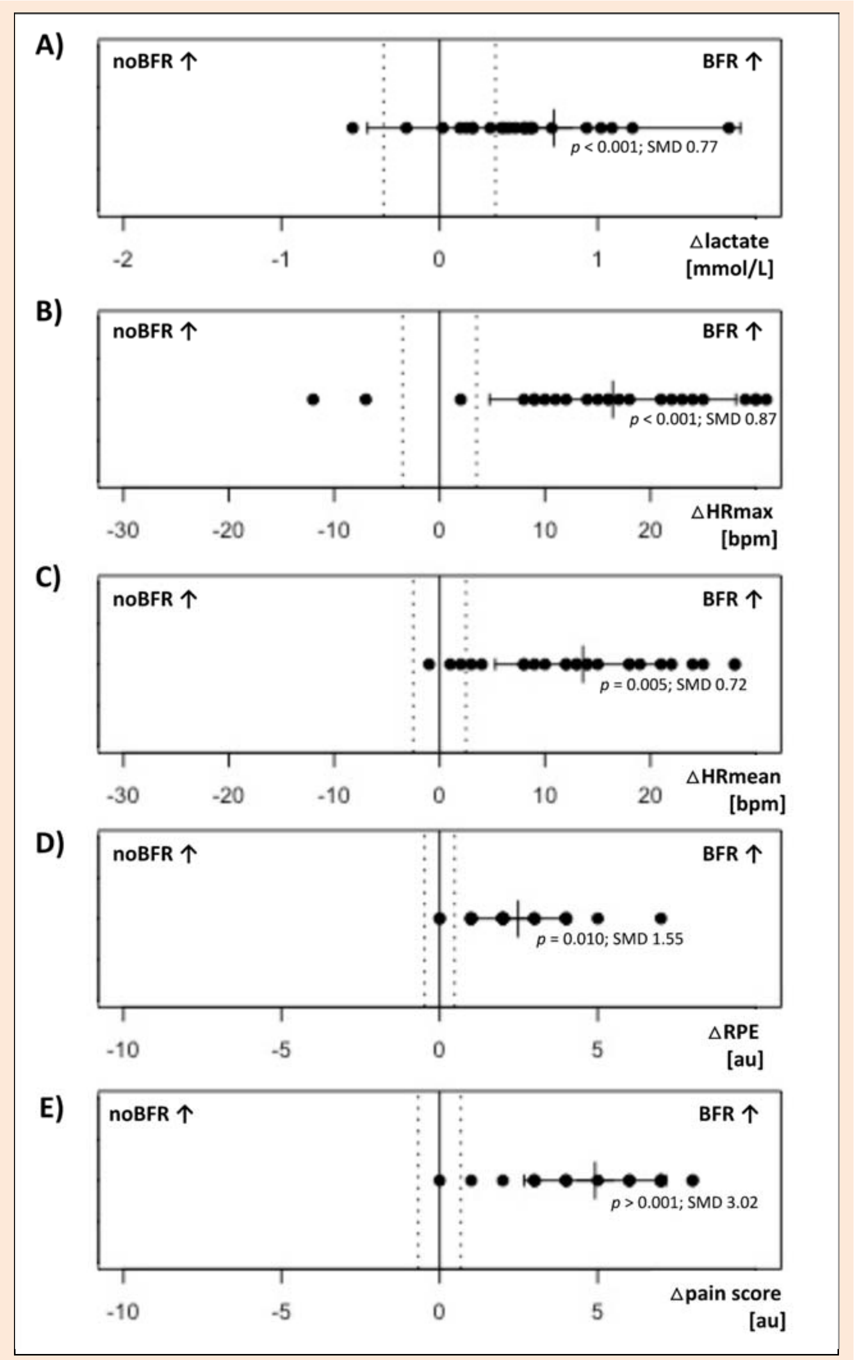

Figure 1. Mean change scores (with standard deviation and individual values) of post lactate (A); maximal heart rate (HRmax, B); mean heart rate (HRmean, C); perceived training intensity (RPE, D); and pain scores (C) between low intensity cycling with BFR and without BFR (noBFR). The range of the smallest worthwhile change (30% of noBFR standard derivation) [Hopkins, 2004] were marked with dashed lines. In addition, paired t-test significances (p) and pairwise effect size (SMD: standard mean difference) are presented.

Although passive ischemic preconditioning has been shown to result in increased acute sprint performance in cycling (Cruz et al., 2016), no performance enhancements effects on drop and countermovement jump performance were observed (Lindner et al., 2021). Furthermore, our data revealed performance decrements of both cycling with and without BFR on subsequent drop jump performance. Whether impaired drop jump performance via non-BFR cycling was induced by fatigue cannot be conclusively clarified based on the current data. This should be considered in future research. In contrast to our findings, a BFR-based post-activation potentiation approach (lunges with BFR, 3 sets, 8 reps, 2 min rest) resulted in improved drop jump performances (Doma et al., 2020). Post-activation potentiation refers to preconditioning exercises, which increase muscular power and athlete's performance acutely (Tillin and Bishop, 2009). Thereby, the effectiveness of the post-activation potentiation approach depends on the net balance between fatigue and potentiation (Clark et al., 2006). Optimal post-activation potentiation for subsequent power output occurs between 5 and 10 min following dynamic muscular contractions performed at (near) maximal, efforts (Wilson et al., 2013). Accordingly, in our research setting, neither the optimal rest duration (immediate post vs. 5-10 min), nor the optimal contraction type (low-intensity cycling vs. maximal or near maximal contractions) were fulfilled. Thus, post-activation potentiation effects are not to be expected in our study. In addition, observed higher lactate concentrations, heart rate, RPE and pain scores during BFR may indicate increased fatigue. Therefore, the fatiguing effects may exceeded potential potentiation effects. However, as fatigue was not directly measured here, this point remains speculative.

In addition to jumping performance, we initially assumed that balance performance would be affected after BFR cycling, as an increased electromyography muscle activity (Burkhardt et al., 2021) and an earlier onset of fast-twitch muscle fibre recruitment (Takarada et al., 2000) has been observed previously in BFR conditions. However, despite findings of (i) improved balance performance adaptations after (3 to 12 weeks) of low load resistance training with BFR (Linero and Choi, 2021); (ii) balance performance adaptations comparable to direct dynamic balance exercise after 8 weeks of BFR-based low load resistance training (Yokokawa et al., 2008); (iii) reduction of dynamic balance performance when testing was performed with BFR (Burkhardt et al., 2021); and (iv) balance performance reduction immediately after low (Hill et al., 2015), moderate (Stemplewski et al., 2012) and high intensity (Rappelt et al., 2021) cycling bouts; we did not observe an acute effect of low-intensity cycling with and without BFR on balance performance. Accordingly, we need to reject our initial assumption of impaired balance performance immediately post low-intensity cycling with BFR. In contrast to our findings, short (3min) knee/upper tight flossing revealed (acutely) improved balance performance (Chang et al., 2021), applying an Y-Balance Test (Powden et al., 2019). Flossing consists of tightly wrapping part of a limb or a joint with a thick elastic band, resulting in fractional vascular occlusion of the blood flow distal to the wrapped area (Vogrin et al., 2020). In flossing, the wrapping is usually applied over a very large area across the corresponding limb (Wortman et al., 2021). In general, the necessary occlusion pressure decreases with the increase of the occlusal surface (McEwen et al., 2019). Accordingly, the occlusion pressure used in flossing, in contrast to BFR, can hardly be quantified. However, flossing approaches could produce a localized effect of vascular occlusion and blood flow restriction (Wortman et al., 2021). In the context of the improved (acute) Y-balance performance via flossing, the corresponding authors (Chang et al., 2021) postulated the following two reasons: (i) increased range of motion (via relaxed soft tissues, increased muscle elasticity, and reduced joint tightness) results in increased Y-Balance Test performance (Aslan et al., 2018); and (ii) the improvements in Y-Balance Test performance and isokinetic quadriceps strength are related (Lee et al., 2018). However, neither reasoning is valid for our findings since we tested balance via perturbed balance performance using the Posturomed (Schmidt et al., 2015) instead of Y-Balance Testing (Powden et al., 2019). Therefore, future research should examine different occlusion methods (i.e., BFR vs. flossing), exercise intensities and balance testing procedures (e.g., static vs. dynamic).

In line with previous research (Thomas et al., 2018), we observed noticeable increased (mean and maximal) heart rate, lactate, and perceived training intensity during low intensity cycling (at 30 - 40% of peak power during graded exercise tests or power at VO_2max) with BFR compared to same exercise modularity without BFR. Interestingly, we additionally observed considerably increased pain scores during BFR cycling. Overall, these increased psycho-physical measures suggest an increased cardiovascular load via BFR cycling compared to non-BFR cycling. These findings may provide an explanation for previously observed improved VO_2max adaptations via low intensity cycling with BFR (Abe et al., 2010).

Conclusion

In conclusion this randomized controlled cross-over testing revealed impaired drop jump performance directly post low intensity cycling with and without BFR. Despite increased heart rate, lactate, perceived training intensity, and pain scores during BFR cycling, perturbed balance performance was neither relevantly affected after low intensity cycling with nor without BFR.

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Key points

- Impaired drop jump performances after both BFR and no BFR cycling.
- No influence on functional balance after BFR and no BFR cycling.
- Increase lactate, heart rate, RPE and pain score via BFR cycling.

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