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Effects of a post- activation performance enhancement protocol combined with blood flow restriction at submaximal 1rm percentages on countermovement jump performance

Abstract

Purpose: Post-activation performance enhancement (PAPE) is a strategy used to acutely enhance explosive performance; however, the effectiveness of combining it with blood flow restriction (BFR) remains unclear. The aim of this study was to examine the acute effects of a PAPE protocol based on back squat exercise (90% 1RM) combined with different levels of arterial occlusion pressure (AOP) (80% and 100%) on countermovement jump (CMJ) performance.

Methods: Seven resistance-trained athletes completed a randomized, repeated-measures crossover design across three conditions: (1) without occlusion (WO), (2) 80% AOP, and (3) 100% AOP. The conditioning activity consisted of two sets of two repetitions of the back squat at 90% 1RM. Jump height (HGT), power output (POT), and Reactive Strength Index (RSI) were assessed 5 min post-activation using a contact platform. Data were analyzed using repeated-measures ANOVA.

Results: Significant main effects were observed for HGT, POT, and RSI (all $p \leq 0.011$). Post hoc comparisons indicated that only the 100% AOP condition differed significantly from WO ($p \leq 0.042$); the 80% AOP condition did not differ significantly from either WO or 100% AOP. Effect sizes were large for all variables ($\eta p^2 = 0.53$ for HGT and RSI; $\eta p^2 = 0.61$ for POT), with the greatest responses observed in the 100% AOP condition.

Conclusions: The incorporation of complete blood flow restriction (100% AOP) into a high-load PAPE protocol (90% 1RM) may enhance acute neuromuscular performance during explosive tasks such as the countermovement jump in resistance-trained athletes, whereas partial occlusion (80% AOP) did not produce a statistically detectable benefit over no occlusion in this sample.

Keywords: post-activation performance enhancement; blood flow restriction; countermovement jump; reactive strength index; resistance training.

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Purpose

The benefits of resistance training (RT) are widely recognized sport and exercise science.[1] with effects ranging from improvements in aerobic adaptations to reductions in the adverse consequences of obesity, sarcopenia, and osteopenia,[2] RT has also been shown to reduce injury incidence in sports populations.[3] Among common RT exercises, the squat (ST) is widely used due to its strong neuromuscular and physiological demands,[4] and although it primarily targets the lower limbs, it induces systemic adaptations.[5] In recent years, RT has incorporated adjunct methods to enhance adaptations, including flywheel devices,[1] whole-body vibration platforms,[6] blood flow restriction (BFR) training[7] and combinations of these approaches.[6]

BFR training involves the partial or complete restriction of blood flow through pneumatic cuffs applied to the proximal limbs and is typically prescribed relative to arterial occlusion pressure (AOP).[8] When combined with resistance training, BFR promotes strength and hypertrophy adaptations[9] while using low external loads (<40% 1RM) and producing outcomes comparable to those observed with high-load RT (>80% 1RM).[9] This characteristic makes BFR particularly relevant for populations in which high mechanical loads may be contraindicated, such as older adults, individuals with chronic diseases, or those undergoing musculoskeletal rehabilitation[9] Furthermore, BFR may contribute to improvements in sport performance through enhanced motor control and movement efficiency.[10,11]

More recently, RT and BFR strategies have been incorporated into post-activation performance enhancement (PAPE) protocols aimed at acutely improving explosive tasks such as jumps, throws, and sprints.[12] PAPE is thought to result from transient neuromuscular potentiation mechanisms, including increases in muscle temperature that may enhance enzymatic activity and nerve conduction velocity, thereby improving explosive performance.[13] Consistent with these mechanisms, PAPE protocols employ structured preparatory stimuli designed to acutely enhance subsequent performance. These protocols typically begin with a 5–10 min general warm-up (e.g., running, cycling, rowing, or elliptical exercise) performed at a perceived intensity of 4–5 on a 10-point scale.[14]

This is generally followed by joint-mobility exercises.[15] explosive drills performed at 30–50% effort with 30–60 s recovery, and a high-intensity conditioning activity consisting of 1–3 sets of 1–3 repetitions at 80–95% 1RM.[16] Finally, athletes perform an explosive task (e.g., vertical jumps, short sprints, or throws) 1–8 min after the conditioning activity, when potentiation is expected to outweigh fatigue.[14,16] More recently, BFR has been incorporated into PAPE protocols using lower conditioning loads (≈20–50% 1RM),[17] while maintaining similar set–

repetition schemes and recovery intervals to those used in traditional PAPE protocols.[18,19]

One of the most widely used tests of explosive performance is the countermovement jump (CMJ), commonly used to assess lower-body power.[20] The CMJ involves a rapid eccentric–concentric action that exploits the stretch-shortening cycle (SSC), enhancing elastic energy storage and neuromuscular activation.[21,22]

The CMJ provides relevant information on neuromuscular performance when assessed using force platforms or inertial devices.[23] Key variables derived from CMJ testing include jump height (HGT), typically estimated from flight time and widely used as an indicator of lower-body power output (POT),[24] as well as countermovement duration and the Reactive Strength Index (RSI). The RSI, calculated as the ratio between jump height and ground contact time, is commonly used to assess reactive force production and neuromuscular efficiency during stretch-shortening cycle actions.[22,20]

The aim of this study was to examine the acute effects of a PAPE protocol based on resistance training at 90% 1RM combined with blood flow restriction (BFR) at 80% or 100% of arterial occlusion pressure (AOP), or without occlusion (WO), on CMJ performance. Reactive Strength Index (RSI), power output (POT), and jump height (HGT) were assessed using a repeated-measures design.

Participants

The study sample consisted of seven male participants (age: 24.5 ± 5.4 years; body mass: 79.6 ± 10.1 kg; height: 178.3 ± 6.1 cm), all of whom had more than 2 years of resistance training experience. At rest, participants exhibited a heart rate of 69.7 ± 16.5 beats·min^{-1}, with systolic and diastolic blood pressures measured at the brachial artery of 138.4 ± 18.6 mmHg and 73.4 ± 7.7 mmHg, respectively.

Regarding strength characteristics, participants demonstrated a one-repetition maximum (1RM) of 91.6 ± 17.4 kg in the back squat exercise (ST). This value corresponded to a relative strength ratio of 123.2 ± 0.1% of body mass. In addition, the mean pressure required to achieve complete femoral arterial occlusion was 165.9 ± 18.5 mmHg across both lower limbs.

Participants were required to have at least 2 years of resistance training experience and to demonstrate adequate technical proficiency in the back squat exercise. All testing sessions were conducted under standardized environmental conditions (20–22°C, 55–65% relative humidity) and at a fixed time (16:00 h, UTC+1) to minimize circadian effects.[25] Given the use of high loads (90% 1RM) and complete blood flow occlusion (100% AOP), exclusion criteria included a history of deep vein thrombosis, uncontrolled hypertension, severe cardiovascular disease, coagulation disorders, severe varicose veins, atrial fibrillation, heart failure, or recent lower-limb musculoskeletal injury that could be exacerbated by femoral occlusion pressure.[26,9] All participants provided written informed consent prior to participation. The study was approved by the Ethics Committee of the University of Alicante (UA/2018-11-15) and conducted in accordance with the Declaration of Helsinki (2013).

Methods

This study used a randomized, repeated-measures crossover design with convenience sampling. As shown in Figure 1, participants attended the laboratory on six occasions separated by at least 48 h. In the first session, they completed a health screening questionnaire and provided written informed consent. Anthropometric measurements included body mass (Avery Ltd Model 3396 ABV) and stature (Holtain Ltd., Dyfed, Wales, UK). Resting blood pressure was then assessed in a seated position using a validated semi-automatic oscillometric device (OMRON 705CP, Matsusaka, Japan).

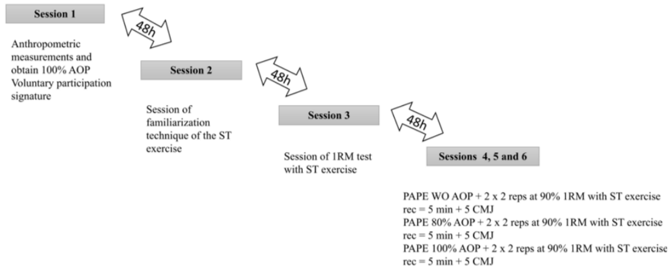

Figure 1 Flowchart of the experimental design of this work.

To determine 100% arterial occlusion pressure (AOP; see Figure 2), participants lay in a prone position for 5 min. Blood flow velocity waveforms were then recorded in each femoral artery using an echo-Doppler ultrasound device (SonoSite Titan, SonoSite Inc., Bothell, WA, USA), with the probe placed at the inguinal crease (Figure 2a). Waveforms were displayed in real time on an electrocardiographic monitor, allowing continuous assessment of the vascular signal while femoral artery auscultation was performed using the Doppler probe (Figure 2b). Once the arterial signal was clearly identified, a pneumatic cuff (Rudolf Riester Standard Pneumatic Komprimeter, Rudolf Riester GmbH, Jungingen, Germany; 96×13 cm) was progressively inflated in 25 mmHg increments every 30 s 8 untilcomplete cessation of the Doppler signal, defined as 100% AOP (Figure 2c).[8] From this value, 80% AOP was subsequently calculated for experimental use. Complete arterial occlusion (100% AOP) was applied only during the conditioning activity.

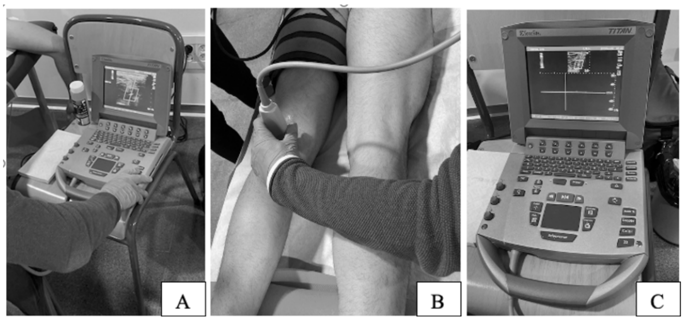

Figure 2 Description of the procedure for obtaining 100% AOP.

Description of the procedure for determining 100% arterial occlusion pressure (AOP).

At the second visit, participants completed a resistance training (RT) familiarization session. The session began with a standardized warm-up consisting of 10 min of treadmill running at 10 km·h^{-1}, followed by 5 min of specific lower-limb mobility exercises designed to prepare participants for the squat exercise.[5] Participants then performed two sets of 8 and 6 repetitions of the back squat exercise using a Smith machine (Multipower Fitness Line, Peroga, Spain), with 3 min of rest and external loads of 20 and 30 kg, respectively.[5] Exercise execution was supervised by two certified strength and conditioning specialists (NSCA-CSCS) to ensure correct technique.

Participants began each repetition from a standing position with hips and knees fully extended, feet shoulder-width apart, and the bar positioned across the upper back at the level of the acromion. They then descended under control until the upper thighs were below parallel [4]. before returning to the starting position. Eccentric velocity was controlled at <0.70 m·s⁻¹, whereas the concentric phase was performed at maximal intended velocity.[27]

A linear position transducer (Chronojump, Bosco System, Barcelona, Spain) operating at 1,000 Hz and connected to a MacBook Pro (Apple Inc., Cupertino, CA, USA) was used to quantify execution velocity (m·s⁻¹). After 10 min of seated rest, participants performed the CMJ under the supervision of the same instructors as in the RT familiarization session. Five CMJ trials were completed, with 30 s of rest between attempts. The first trial was discarded as a familiarization attempt, and the subsequent four trials were retained for analysis. The CMJ started from an upright position with hands on hips and feet shoulder-width apart on the force platform[20] followed by a rapid countermovement to approximately parallel thigh position and an immediate maximal vertical jump.[22] Jump performance was recorded using the Chronojump system with 1 ms temporal resolution and a 1,000 Hz sampling frequency.

In the third session, participants completed an incremental test to determine the individual load corresponding to 90% 1RM in the back squat (ST) using a Smith machine (Multipower Fitness Line, Peroga, Spain). The session began with the standardized warm-up described in session 2.[5] This was followed by sets of 5 repetitions starting at 20 kg, with 10 kg load increments until mean concentric velocity dropped below 0.8 m·s⁻¹. Thereafter, smaller increments (2.5–5 kg) and sets of fewer than 3 repetitions were used to refine the estimation of 1RM at maximal concentric intent.[27] Rest intervals between sets ranged from 3 min when movement velocity remained above 0.68 m·s⁻¹ to 5 min when velocity dropped below this threshold, ensuring sufficient neuromuscular recovery between attempts.[27]

For sessions 4–6, experimental conditions were randomized for each participant: (1) no occlusion (WO), (2) 80% AOP, and (3) 100% AOP. Randomization was performed using Microsoft Excel (v. 11.0; Microsoft Corp., USA) for macOS. All participants completed identical procedures across conditions. Each session began with the standardized warm-up described in session 2, followed by the PAPE protocol consisting of 2 sets of 10 bodyweight repetitions of the back squat (ST), with hands placed under the iliac crest and thumbs and index fingers lightly touching, and 30 s rest between sets.[14]

After 1 min, participants performed 2 sets of 5 jumps with reduced knee flexion (~45° from full extension), with 30 s rest between sets. This was followed by progressive CMJ activation at 80–90% of perceived maximal effort (2 sets, 45 s rest). Five minutes later, participants performed 2 sets of 2 repetitions of the back squat at 90% 1RM with 5 min recovery between sets.[15] During all squat sets, the concentric phase was performed at maximal intended velocity, while eccentric velocity was controlled at <0.70 m·s⁻¹.[5]

This procedure was identical in the without occlusion (WO) condition. In the 80% and 100% AOP conditions, BFR was applied during exercise sets (Figure 3a), with cuff pressure released to 0 mmHg during recovery intervals to allow reperfusion and facilitate metabolite clearance.[7] Cuff pressure was continuously monitored to ensure the prescribed occlusion level during each set (Figure 3c). Five minutes after the final back squat repetition, participants performed five consecutive CMJs (Figure 3b). The first jump was discarded, and the subsequent four were retained for analysis.[20] All CMJ assessments were conducted using the same contact platform described in session 2.

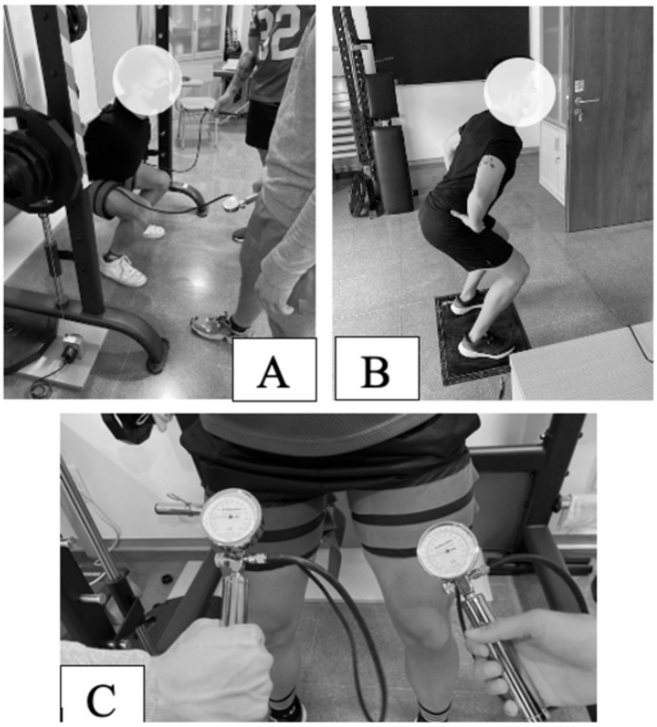

Figure 3 Description of the experimental points in the intervention procedure.

Data analysis

All dependent variables, including jump height (HGT), Reactive Strength Index (RSI), and power output (POT), are presented as mean ± standard deviation (SD). Data normality was assessed using the Shapiro–Wilk test. To examine the effects of arterial occlusion pressure (AOP) on countermovement jump (CMJ) performance, a one-way repeated-measures analysis of variance (ANOVA) was conducted with three within-subject conditions: without occlusion (WO), 80% AOP, and 100% AOP. For each participant and condition, the four retained CMJ trials were averaged prior to analysis, yielding one value per participant per condition (n = 7). When the assumption of sphericity was violated, degrees of freedom were adjusted using the Greenhouse–Geisser correction. When significant main effects were detected, pairwise post hoc comparisons with Bonferroni adjustment were performed to identify differences between conditions. Effect sizes were quantified using partial eta squared (ηp^2) and interpreted as small (0.01–0.059), moderate (0.06–0.137), or large (>0.137) according to Cohen (1988).[28] Statistical significance was set at $p < 0.05$. All analyses were performed using IBM SPSS Statistics (version 25.0; IBM Corp., Armonk, NY, USA) on a macOS operating system.

Results

Significant differences were observed for Reactive Strength Index (RSI) across experimental conditions (Figure 4a), with a large effect size ($F(2,12) = 6.83$, $p = 0.011$, $\eta p^2 = 0.53$). Post hoc analyses revealed that RSI values were significantly greater in the 100% AOP condition (M = 1.57, SD = 0.20; p = 0.042, 95% CI [0.01, 0.54]) compared with the WO condition (M = 1.30, SD = 0.17). No significant difference was found between the 80% AOP condition (M = 1.48, SD = 0.20) and WO (p = 0.325), nor between the 80% AOP and 100% AOP conditions (p = 0.152).

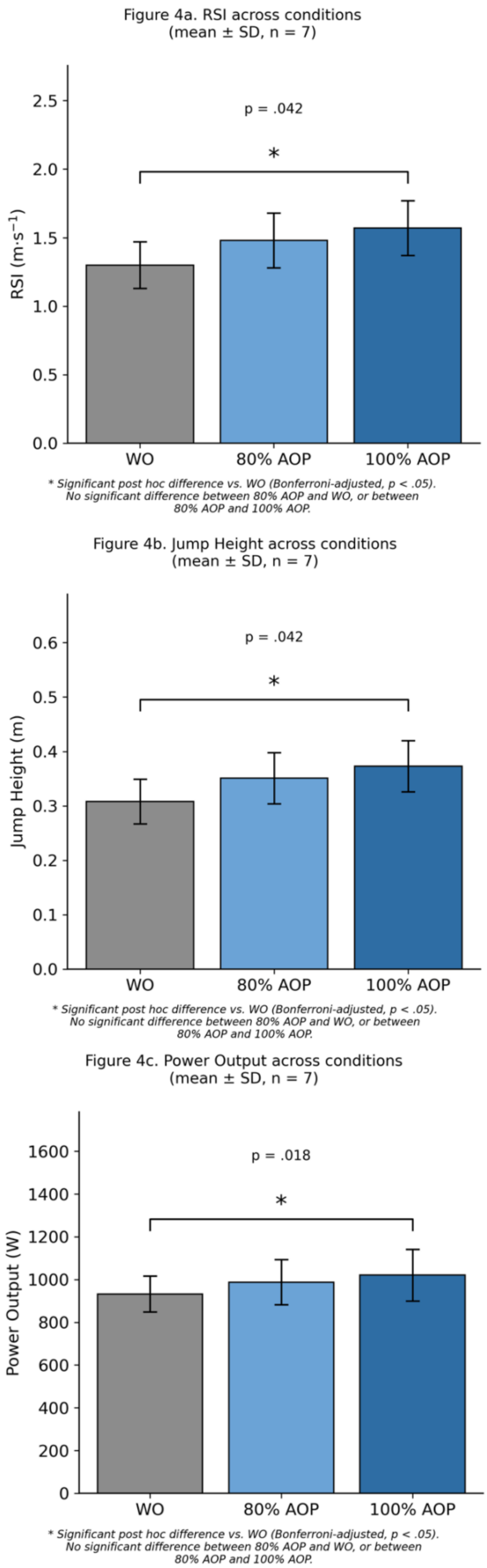

Figure 4 Graphic description of the values obtained for the variables RSI(a), HGT(b) and POT(c) during the intervention

Mean ± SD values for Reactive Strength Index (RSI; panel A), jump height (HGT; panel B), and power output (POT; panel C) across the experimental conditions (WO, 80% AOP, and 100% AOP).

Similarly, jump height (HGT) (Figure 4b) differed significantly between conditions, with a large effect size ($F(2,12) = 6.83$, $p = 0.011$, $\eta p^2 = 0.53$). Higher HGT values were observed in the 100% AOP condition (M = 0.373 m, SD = 0.047; p = 0.042, 95% CI [0.003, 0.127]) compared with the WO condition (M = 0.308 m, SD = 0.041). No significant difference was found between the 80% AOP condition (M = 0.351 m, SD = 0.047) and WO (p = 0.325), nor between the 80% AOP and 100% AOP conditions (p = 0.152).

For power output (POT) (Figure 4c), significant differences were also identified across conditions ($F(2,12) = 9.24$, $p = 0.004$, $\eta p^2 = 0.61$), indicating a large effect size. Post hoc analyses showed significantly higher POT values in the 100% AOP condition (M = 1020.42 W, SD = 121.56; p = 0.018, 95% CI [18.07, 157.86]) compared with the WO condition (M = 932.45 W, SD = 84.44). No significant difference was found between the 80% AOP condition (M = 988.03 W, SD = 105.18) and WO (p = 0.206), nor between the 80% AOP and 100% AOP conditions (p = 0.190).

Discussion

The main purpose of this study was to examine the effects of different levels of arterial occlusion pressure (AOP) (80% and 100%) combined with a high-intensity resistance load (90% 1RM) on vertical jump performance. The findings partially support the initial hypothesis, indicating that the application of blood flow restriction (BFR) at 100% AOP elicited greater acute performance enhancements compared with the without occlusion (WO) condition. However, no statistically significant difference was found between the 100% AOP and 80% AOP conditions, suggesting that the acute benefit may depend on a threshold level of occlusion rather than increasing linearly with occlusion pressure. However, no statistically significant difference was found between the 100% AOP and 80% AOP conditions, suggesting that the acute benefit may depend on a threshold level of occlusion rather than increasing linearly with occlusion pressure.

These improvements were evident in power output (POT), jump height (HGT), and Reactive Strength Index (RSI), suggesting that complete arterial occlusion (100% AOP), but not partial occlusion (80% AOP), may enhance acute neuromuscular responsiveness under high-load conditioning stimuli.

This increase in reactivity is reflected in the improvement observed in the Reactive Strength Index (RSI), which is commonly interpreted as an indicator of enhanced stretch–shortening cycle (SSC) function.[22] From a mechanistic perspective, these changes may be partly explained by increases in muscle-tendon stiffness and acute alterations in contractile properties, including myosin light chain phosphorylation, which could facilitate a more rapid transition between the eccentric and concentric phases of the jump.[22] These findings are consistent with the theoretical framework proposed by Rappelt et al. (2024).[14] who suggested that high-intensity PAPE may enhance elastic energy utilization and neuromuscular efficiency. However, the present study extends this evidence by suggesting that the addition of complete arterial occlusion (100% AOP), rather than partial occlusion (80% AOP), may further amplify these acute mechanical responses, leading to greater improvements compared with traditional PAPE protocols[29] or lower occlusion pressures.[30]

Regarding jump height (HGT), the present results suggest that total occlusion (100% AOP) may be an effective strategy to enhance vertical displacement in acute performance contexts. These findings are in line with those reported by Wei et al. (2025)[19] who also observed increases in HGT following BFR-based PAPE protocols. However, a key difference between studies is the loading magnitude used during the conditioning stimulus, which was substantially lower in their study (30% vs. 90% 1RM in the present investigation). In addition, methodological differences in the prescription of occlusion pressure should be considered. Whereas previous research has often applied a generalized cuff pressure (e.g., 200 mmHg), the present study used an individualized approach based on arterial occlusion pressure (165.9 ± 18.5 mmHg), which may provide a more accurate and subject-specific stimulus.

In contrast, the present findings differ from those reported by Zheng et al. (2025).[31] who observed reductions in countermovement jump (CMJ) height following a low-load conditioning stimulus (30% 1RM). Similarly, Silva et al. (2025).[32] reported that low-load resistance exercise combined with blood flow restriction (BFR) did not enhance neuromuscular transmission sufficiently to improve jump height (HGT). Methodological differences between these studies and the present investigation may help explain the discrepancies, particularly regarding the level of arterial occlusion pressure applied. Whereas the present study employed complete arterial occlusion (100% AOP), previous studies used lower pressures (75% and 50% AOP, respectively), which may have been insufficient to elicit comparable acute neuromuscular responses.

Likewise, the present results also differ from those reported by Gabrys et al. (2025)[33] who found no improvements in HGT following a BFR-based protocol in ice hockey players. These differences may be attributed to the greater complexity and prolonged peripheral fatigue associated with sport-specific skating activities compared with traditional resistance exercises such as the back squat, which may alter the balance between fatigue and potentiation.

In contrast, in the study by Gabrys et al. (2025)[33] the dynamic nature of the conditioning stimulus may have attenuated the expression of potentiation effects. In the present investigation, the protocol may have allowed a more effective dissipation of metabolic fatigue, potentially facilitating the expression of post-activation responses, particularly following the release of 100% AOP. This may have contributed to the observed improvements in power output (POT) under complete blood flow restriction (100% AOP). These findings are consistent with those reported by Zhou et al. (2024)[34] who also observed improvements in POT following a BFR-based intervention. However, methodological differences should be acknowledged, including the use of higher occlusion pressures (200–220 vs. 165.9 ± 18.5 mmHg in the present study), longer intervention periods (8 weeks vs. an acute design), and differences in training loads across experimental conditions (20–30% vs. 75–80% 1RM).

However, the similarities in the improvements in power output (POT) observed across studies may be explained by the suggestion that blood flow restriction (BFR) at high occlusion levels could facilitate the expression of explosive force[7] potentially enhancing the acute effects of traditional post-activation performance enhancement (PAPE) protocols on power production. Beyond mechanical considerations, the observed increases in jump height (HGT) and power output (POT) under the 100% AOP condition may also be partially mediated by greater motor unit recruitment and enhanced neural drive during explosive actions.

Along these lines, Wei et al. (2025)[19] reported significant increases in the electromyographic (EMG) activity of the rectus femoris and vastus muscles during exercise performed with blood flow restriction (BFR). This observation may suggest that arterial occlusion, through a reduction in local oxygen availability, could accelerate the recruitment of higher-threshold motor units, including fast-twitch (type II) fibers, potentially as a compensatory response to the fatigue of lower-threshold (type I) fibers. In the present study, the use of a high external load (90% 1RM) would already be expected to elicit substantial motor unit recruitment. However, the addition of BFR at 100% AOP may further increase neuromuscular demand, potentially elevating neural excitability beyond that achieved with high-load resistance exercise alone, in line with previous findings reported by Wilk et al. (2020)[35] in upper-body power exercises.

Despite these preliminary findings, several limitations should be acknowledged. First, the relatively small and homogeneous sample may limit the external validity of the results, particularly with respect to elite athletes or untrained populations. Second, the study examined only acute responses, and therefore the duration of the post-activation performance enhancement (PAPE) window following blood flow restriction (BFR) remains unknown.

Finally, although the 100% AOP condition appeared to be the most effective, the potential influence of perceptual factors such as discomfort or perceived exertion associated with complete occlusion should be considered, as these may affect athlete readiness and psychological responses in real performance contexts. Notably, no systematic monitoring of adverse events, discomfort, or tolerance (e.g., pain scores, numbness) was performed during the 100% AOP condition in the present study. Given the use of complete arterial occlusion combined with high mechanical loads, future research should incorporate structured safety monitoring alongside physiological markers of metabolic stress and muscle damage (e.g., lactate, ammonia, urea, and creatine kinase) to further elucidate both the underlying mechanisms and the risk–benefit profile of this protocol.[10]

Conclusions

This study provides preliminary evidence that a post-activation performance enhancement (PAPE) protocol combined with complete blood flow restriction (100% AOP), applied during a conditioning stimulus consisting of back squat exercise at 90% 1RM, may acutely enhance countermovement jump (CMJ) performance, as reflected in improvements in Reactive Strength Index (RSI), jump height (HGT), and power output (POT). Partial occlusion (80% AOP) did not produce a statistically detectable benefit over the non-occluded condition in this sample.

Practical applications

These findings may be of practical interest for strength and conditioning practitioners seeking to integrate BFR-based strategies within velocity-oriented resistance training approaches to acutely enhance neuromuscular performance. In addition, they may inform coaches aiming to optimize athlete activation prior to explosive performance tasks. However, given that the greatest benefits were observed specifically under complete arterial occlusion (100% AOP) combined with a high mechanical load (90% 1RM), and that no systematic safety or tolerance monitoring was performed in the present study, the practical application of this protocol should be restricted to supervised settings with trained personnel experienced in BFR administration, individualized occlusion pressure assessment, and athlete screening for contraindications. Partial occlusion (80% AOP) did not provide a statistically distinguishable benefit over the non-occluded condition in this sample and therefore cannot currently be recommended as an effective alternative based on these findings.

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