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MELBOURNE AUSTRALIA

Lunge exercises with blood-flow restriction induces post-activation potentiation and improves vertical jump performance

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Lunge exercises with blood-flow restriction induces post-activation potentiation and improves vertical jump performance

Abstract

Purpose: This study examined the post-activation potentiation effects of body-weight lunge exercises with blood-flow restriction on jump performance. Eighteen anaerobically-trained men took part in this study across three weeks. Methods: During the first week, participants were familiarised with the lunge exercises with blood-flow restriction and the drop-jump protocol. In the second and third week, participants were randomly allocated to complete body-weight lunges (3 sets of 8 repetitions) either with or without blood-flow restriction (occlusion set at 130% of systolic blood pressure) to induce post-activation potentiation. Drop-jump performance was assessed between blood-flow conditions, and prior to, and at the third, sixth, ninth, twelfth and fifteenth minute following each lunge exercise. Relationships between mechanical contributors of jump performance and final jump performance were examined via Pearson correlation coefficients. Results: Lunges with blood-flow restriction significantly improved jump height (~4.5% ± 0.8%), flight time (~3.4% ± 0.3%) and power (~4.1% ± 0.3%) within 6-15 minutes post-exercise ($p<0.05$) with the magnitude of effect between blood-flow conditions, moderate-large (0.54-1.16). No significant changes ($p>0.05$) were found in jump performance measures following lunge exercises without blood-flow restriction. Significant correlations ($p<0.05$) between mechanical contributors of jump performance and jump performance highlighted the potential of blood flow restriction to enhance stretch-shortening cycle mechanics in the current study. Conclusion: Lunge exercises with blood-flow restriction improved subsequent jump performance in anaerobically trained men. The use of blood flow-restriction may be a practical alternative to heavy resistance training equipment during warm-up protocols.

Key words

Resistance training; Muscular power; Occlusion; Lower body; Drop jump

Abbreviations

Analysis of variance	ANOVA
Blood flow restriction	BFR
Blood lactate	LAC
Contact time	CT
Drop-jump	DJ
DJ at baseline	DJ_{Base}
DJ 3-minutes post-exercise	DJ-3
DJ 6-minutes post-exercise	DJ-6
DJ 9-minutes post-exercise	DJ-9
DJ 12-minutes post-exercise	DJ-12
DJ 15-minutes post-exercise	DJ-15
Effect size	ES
Flight time	FT
Heart rate	HR
Least Square Difference	LSD
Mat jump height	MJH
Post-activation potentitation	PAP
Rating of perceived exertion	RPE
Reactive strength index	RSI
Regulatory light chain	RLC
Vertical jump height	VJH

Author contributions

Conceptualization: Kenji Doma, Carl Woods, Daniel Boullosa, Anthony Leicht; Methodology: Kenji Doma, Carl Woods, Anthony Leicht; Formal analysis and investigation: Kenji Doma, Daniel Boullosa; Writing – review and editing: Kenji Doma, Carl Woods, Daniel Boullosa, Anthony Leicht

Introduction

The implementation of a conditioning exercise to increase near-immediate muscular power and improve athlete's performance is referred to as post-activation potentiation (PAP) (Tillin and Bishop 2009). This practice provides acute and temporary enhancement of muscular contractility induced by a prior activity, which typically involves muscular contractions performed at maximal, or near maximal, efforts often via similar biomechanical demands (Hodgson et al. 2005; Doma et al. 2016). The effectiveness by which conditioning contractions optimises the PAP phenomenon depends on the net balance between fatigue and potentiation, and appears to be influenced by the duration between potentiation and performance (Boullosa et al. 2013; Clark et al. 2006), training status (Seitz and Haff 2016) and intensity of conditioning activity (Baker 2003). It has been proposed that the effect of PAP primarily occurs as a result of elevated phosphorylation of myosin regulatory light chain (RLC) due to increased sensitivity to calcium (Boullosa et al. 2018; Metzger et al. 1989), although greater recruitment of higher threshold motor units has also been suggested to enhance muscular power (Sweeney et al. 1993).

The application of heavy back squats (>80% of one repetition maximum) is the most common method of causing sufficient PAP-inducing fatigue to improve subsequent performances (e.g., vertical jump or sprint) (Seitz and Haff 2016; Wilson et al. 2013). However, such protocols require relocation of heavy equipment to the field or court that athletes train in, which may be cumbersome (Docherty and Hodgson 2007). Resistance exercises with body weight may be a convenient and simpler alternative, although the level of intensity and stimuli would be insufficient when compared to heavy resistance training. One method of enhancing mechanical stress is the use of blood flow restriction (BFR), by occluding blood flowing to the working muscles during exercise. Incorporating BFR in conjunction with resistance exercises at lighter loads has been shown to elicit similar muscular strength and hypertrophic adaptations to those with heavy resistance training (Centner et al. 2018). Several studies have suggested that BFR exercises induce an earlier onset of fast-twitch fibre recruitment due to inadequate oxygen supply to slow-twitch muscle fibres (Moritani et al. 1992; Takarada et al. 2000). As the recruitment of higher threshold motor units is one proposed mechanism of PAP (Sweeney et al. 1993), BFR exercises with lighter loads, such as body weight, may elicit similar responses to heavy resistance training and generate more sustained, mechanical power improvements.

For instance, a recent study by Miller et al. (2018) examined the effects of whole body vibration exercises and maximal isometric contractions of knee extensors with and without BFR on subsequent vertical jump performance. Their results showed that whole body vibration and maximal isometric contractions with both BFR and non-BFR conditions significantly improved jump height, although the addition of BFR technique did not enhance the PAP response. It is possible that the incorporation of isometric contractions by Miller et al. (2018) may have limited optimum benefits of BFR, given that isometric exercises do not replicate task constraints typically observed during jumping protocols, with the optimal transfer of PAP occurring when the conditioning activity mimics the performance task (Doma et al. 2018; Doma et al. 2016). Incorporating dynamic BFR exercises may further augment the effects of PAP and optimise vertical jump performance measures, although this is yet to be investigated as far as we are aware. Thus, the current study examined the acute effects of dynamic, body weight resistance-exercises between BFR and non-BFR conditions on jump performance. We hypothesised that body weight resistance-exercises performed during the BFR condition would induce greater improvement in jump performance than the non-BFR condition.

Materials and methods

This study was conducted as a cross-over, randomised study across three weeks (Figure 1). The first week consisted of a familiarisation session where participants undertook a standardised warm-up, the PAP protocol and a drop-jump (DJ) performance test. The standardised warm-up consisted of participants performing lower body dynamic stretches (i.e., leg swings, high knees and butt kicks), followed by five DJ exercises at submaximal effort and one at 100% of maximal effort. During the second and third week, participants were randomly assigned to complete the PAP protocol in either a BFR or a non-BFR condition. Both sessions commenced by measuring body mass, followed by an equivalent warm-up method to that of the familiarisation week. After the warm-up, a DJ test was conducted as a baseline measure (DJ_{Base}), then the PAP protocol, and the DJ test was subsequently completed at 3-minutes (DJ-3), 6-minutes (DJ-6), 9-minutes (DJ-9), 12-minutes (DJ-12) and 15-minutes (DJ-15) following the PAP protocol. Heart rate (HR; FS-1, Polar, Finland), rating of perceived exertion (RPE) using Borg's 6-20 visual analogue scale and capillary blood lactate (LAC; Lactate Pro2, Arkray, Japan) sample were also collected just prior to DJ-3, DJ-6 and DJ-9.

Figure 1 around here

Eighteen, anaerobically trained, males took part in the study. Each participant was classified as healthy according to medical screening with no reports of illness, injury or medication that would contraindicate any protocols. According to an a priori sample-size calculation (G*Power 3.1.9.2) using data from previous studies examining PAP effects using similar protocols and outcome measures (Garcia-Pinillos et al. 2015; Horan et al. 2015; Miller et al. 2018), 18 participants were sufficient to detect a significant change in variables (≥80% power; $p<0.05$). The participants were considered anaerobically trained if they 1) undertook resistance training, Olympic lifting and/or were taking part in sports that required repeated anaerobic exercises involving both sprinting and jumping tasks (e.g. basketball, volleyball, soccer); and 2) anaerobic training was completed at least twice a week for the last 6 months. All participants were familiar with the lunge protocol utilised in the current study. To control for biological variation, the BFR and non-BFR conditions were separated by seven days, and undertaken at the same time of the week and day to avoid circadian influences on performance. The participants also refrained from anaerobic-based exercises for at least 48 hours prior to all sessions and avoided caffeine and food consumption for at least two hours prior to each testing session. All participants provided written informed consent with all protocols approved by the Institutional Human Research Ethics Committee and in accordance with the Declaration of Helsinki.

The PAP protocol for both the BFR and non-BFR conditions involved performance of lunges by positioning the rear foot on a bench and the leading foot on the floor. This unilateral exercise was selected given that greater load is applied to a single limb as opposed to load being distributed across both limbs during bilateral exercises. Three sets of eight repetitions were completed for both legs, with two minutes of rest in-between each set based on pilot testing. Specifically, the participants completed eight repetitions with the left leg, immediately followed by eight repetitions using the right leg for each set. Prior to the BFR condition, resting blood pressure was initially measured. Following warm-up, a pressure cuff (Sports Rehab Tourniquet, SportsRehab, Australia) was placed on both lower limbs at the most proximal end of the thigh. To ensure standardisation, the cuff pressure was set to 130% of each participant's resting systolic blood pressure. During the non-BFR condition, the same PAP protocol was undertaken without the use of the pressure cuff.

For the DJ protocol, participants dropped off a 30cm box and completed a countermovement jump, which required them to flex at their hips, knees and ankles during the eccentric phase, followed by extending these joints during the concentric phase to jump as fast and as high as possible with full effort (Nagata et al. 2018). The participants were instructed to 'leave the ground as fast as possible, and to jump as high as possible', in order to optimise the stretch-shortening cycle and gain momentum during the concentric phase (Doma et al. 2017). The DJ protocol was used to obtain measures of contact time (CT) and reactive strength index (RSI), which are important determinants of jump height performance (Barker et al. 2018). A jump mat (Speedlight, Swiftperformance, Australia) was used to measure jump height (MJH), contact time (CT), flight time (FT) and power. To confirm the results of the electronic jump height measure, a vertical jump apparatus (Yard Stick, Swift Performance, Queensland, Australia) was also employed to measure vertical jump height (VJH). The reactive strength index (RSI) was also calculated using the formula $RSI = VJH \div CT$, where VJH is jump height in metres and CT is contact time in seconds (Flanagan and Harrison 2007).

The measures of central tendency and dispersion are reported as mean ± standard deviation. All data were analysed using the Statistical Package of Social Sciences (SPSS, version 24) with the majority of the data normally distributed based on the Shapiro-Wilk's test. Reproducibility of the DJ protocol was determined from both DJ_{Base} measures conducted before the PAP conditions via intra-class correlation coefficients (ICC, SPSS 2-way mixed, 95% confidence intervals) and systematic error via paired t-tests. Based on classifications by Menz et al., ICC values of >0.75, $0.40 \leq x \leq 0.75$ and <0.40 were considered having excellent, moderate and poor reliability, respectively. A two-way (condition × time) repeated measures analysis of variance (ANOVA) was conducted to compare DJ measures between the BFR and non-BFR conditions and between each time point. Fisher's Least Square Difference (LSD) test was conducted for post-hoc analyses when interaction, main time or main condition effects were identified. Effect size (ES; Cohen's d) with 95% confidence interval was also calculated to determine the magnitude of differences between the BFR and non-BFR conditions at each post-PAP time point with <0.5, $0.5 \leq x \leq 0.8$ and >0.8 considered small, moderate and large, respectively (Cohen, 1988). To further examine the potential mechanisms of PAP-induced improvement in jump performance for both BFR and non-BFR conditions, Pearson's product moment correlations were calculated between the mechanical (i.e., RSI, CT, FT and power) factors of jump performance and actual vertical jump height. This was accomplished by ascertaining the greatest improvement in VJH measures during the post-PAP time points and calculating the percentage changes from these time points to DJ_{Base}. For example, if a participant exhibited his greatest VJH at DJ-6 during the BFR condition, then the percentage change between DJ_{Base} and DJ-6 were calculated for all DJ parameters. Once these changes were calculated for each participant, correlations between performance measures were determined and reported.

Results

The physical characteristics of the participants for age, height and body mass were 22.9±5.0 years, 1.80±0.06 m and 79.4±9.9 kg, respectively. With respect to the systematic error of the performance parameters, no significant differences were found between BFR and non-BFR at DJ_{Base} for VJH, CT, FT, MJH, Power and RSI ($p > 0.05$). In addition, ICC measures demonstrated excellent test-retest reliability, for all variables with values ranging from 0.85 to 0.96 (Table 1).

When comparing performance measures between time points (i.e., DJ_{Base} to DJ-15) and between BFR and non-BFR conditions, a significant interaction effect was found for FT ($p = 0.02$), MJH ($p = 0.05$) and power ($p = 0.005$) while there were no interaction effects for VJH, CT and RSI ($p > 0.05$). Specifically, the BFR condition exhibited significantly greater values for FT, MJH and power at DJ-15 compared to the non-BFR condition ($p \leq 0.05$; Figure 2). During the BFR condition, FT and and DJ-15 compared to DJ_{Base} ($p \leq 0.05$) whilst power was significantly greater at DJ-6, DJ-9 and DJ-15 compared to DJ_{Base} ($p \leq 0.05$). There were no significant differences across time points for these measures within the non-BFR condition ($p > 0.05$). The BFR condition exhibited greater ES for VJH ($0.55 \leq x \leq 0.82$), FT ($0.60 \leq x \leq 1.08$), MJH ($0.54 \leq x \leq 1.06$) and power ($0.64 \leq x \leq 1.16$) with moderate to large ES at DJ-6, DJ-9 and DJ-15, when compared to DJ-3 and DJ-12 with small ES ($-0.20 \leq x \leq 0.35$) (Table 2).

Figure 2 around here

Table 2 around here

When comparing the percentage change between DJ_{Base} and best DJ performance, significant correlations were identified between several performance parameters in each condition (Table 3). Specifically, significant correlations were identified between VJH and CT, FT and RSI ($p \leq 0.05$), whilst the correlation between VJH and power was not significant for both BFR and non-BFR conditions ($p > 0.05$).

Table 3 around here

With respect to the psycho-physiological measures, there were no significant interaction effects for RPE, LAC and HR measures ($p > 0.05$). However, non-significant, but moderately greater values were observed for RPE (~8.9 vs. 8.6, ES = $-0.11 \leq x \leq 0.55$) and LAC (~4.0 $mmol \cdot L^{-1}$ vs. 5.1 $mmol \cdot L^{-1}$, ES = $0.50 \leq x \leq 0.78$), with small changes for HR (~97.6 bpm vs. 97.4 bpm, ES = $-0.15 \leq x \leq 0.13$) during the BFR compared to non-BFR condition (Table 2).

Discussion

The current study compared the PAP effects of lunge exercises between those performed in a BFR and non-BFR condition. The improvement in DJ measures during the BFR condition suggests that the occlusion of the lower limbs above brachial systolic blood pressure induces a substantial PAP stimulus compared to the non-BFR condition despite equated workload between conditions. Whilst still not fully understood, intra-muscular hypoxic conditions caused by occluded exercises may accelerate the fatigue response of slow-twitch muscle fibres, thereby eliciting an earlier onset of fast-twitch muscle fibre recruitment (Moritani et al. 1992; Takarada et al. 2000). Given that the recruitment of higher threshold motor units has been reported as one of the underpinning mechanisms of PAP (Tillin and Bishop 2009), it is likely that the lunge exercises during the BFR condition in the current study was sufficient to elicit PAP. In addition, the greater LAC values (moderate ES) provided further confirmation of the increased recruitment of type II muscle fibres as a result of greater anaerobic metabolism during the occluded condition (Luscher et al. 1983). Interestingly, previous studies (Garcia-Pinillos et al. 2015; Boullosa and Tuimil 2009) also reported greater LAC measures as a result of PAP in aerobically trained, young males. However, it is important to note that differences in LAC measures reported by previous studies (Boullosa and Tuimil 2009; Garcia-Pinillos et al. 2015) were statistically significant, whilst the PAP protocol in the current study augmented LAC measures at a non-significant level and moderate ES. The distinct findings between the current study, and those by others (Boullosa and Tuimil 2009; Garcia-Pinillos et al. 2015), may be due to differences in the type of PAP protocol, participant's physical characteristics, recovery periods and timing of when LAC measures were obtained. Nonetheless, the improvement in jump performance reported in the current study demonstrates that body-weight lunge exercises with occlusion may be a practical, and more readily accessible method of acutely preparing anaerobically-trained athletes for conditioning sessions or matches in sport.

The current findings are in line with those of Moore et al. (2004), who examined twitch torque characteristics of the biceps brachii muscles immediately following a 10-second maximal isometric contraction in an occluded condition (100 mmHg). In their study, the PAP effect was assessed after participants completed an 8-week, resistance training program consisting of occluded, low intensity (50% of 1 repetition maximum) elbow flexion exercises. Their chronic, occluded training resulted in significantly greater improvement in twitch torque following an occluded, maximal voluntary, acute contraction, when compared to a similar non-occluded, maximal acute contraction. Interestingly, Miller et al. (2018) recently reported comparable levels of improvement in vertical jump performance between BFR and non-BFR conditions of isometric squat exercises on a vibration machine, although greater improvement in isometric contraction force was observed in the BFR condition (2.9 vs 0.8%). The discrepancy in findings between the current study, and that of Miller et al. (2018) may be due to the mode of conditioning exercises and subsequent performance protocol. For example, the current study incorporated dynamic, conditioning contractions to improve a subsequent dynamic performance measure (i.e., vertical jump performance), as opposed to isometric exercises utilised by Miller et al. (2018), who only showed greater improvement in isometric contraction force. It has been suggested that a better transfer of PAP occurs when the kinematic characteristics of conditioning contractions are similar to that of the subsequent performance measure (Doma et al. 2018; Doma et al. 2016). Therefore, dynamic conditioning contractions may need to be considered when optimising the PAP effects via BFR methods for subsequent performance measures that are dynamic in nature. Further research is warranted to compare various modes of conditioning exercises on subsequent dynamic performance measures during BFR and non-BFR conditions.

Within the BFR condition in the current study, significant improvements in MJH, FT and power were observed across several time points after the lunge exercises when compared to baseline measures, although no differences were identified between time points within the non-BFR condition. These findings suggest that, whilst lunge exercises with BFR exhibited benefits for vertical jump performance, the metabolic stimuli induced by three sets of eight repetitions during the non-BFR condition was insufficient to evoke any PAP effects. In fact, Horan et al. (2015) reported significant improvement in vertical jump performance after one set of 20 repetitions of body-weight lunge exercises, which was greater than twice the mechanical work compared to that of the current study for one set (i.e., eight repetitions). However, it is important to note that Horan et al. (2015) assessed vertical jump performance for only 30 seconds after the conditioning activity, and it is unclear whether PAP would have been sustained beyond this period. Thus, according to the current findings, it appears that body-weight lunge exercises requires BFR to facilitate PAP-induced improvement in jump performance for longer periods.

The significant improvement in vertical jump and power from the 6th to the 9th minute after the BFR lunge exercise in the current study is similar to results of previous studies, where optimal potentiation for subsequent power output occurs between 5-10 minutes following dynamic conditioning contractions (Wilson et al. 2013; Doma et al. 2018; Doma et al. 2016). Interestingly, the current study also identified significantly better vertical jump performance measures at the 15th minute following the lung exercise. Previous studies have also noted that PAP effects were sustained for up to 16-20 minutes following conditioning contractions (Jo et al. 2010; Kilduff et al. 2007). The magnitude and duration of PAP is highly dependent on the balance between fatigue and potentiation, with more strenuous conditioning activities requiring greater recovery for potentiation to offset fatigue (Seitz and Haff 2016). Whilst participants in the current study were anaerobically trained, it is possible that a longer period of recovery was required for optimal PAP as they were not undertaking long-term BFR training.

The significant correlations between both jump height measures (i.e., VJH and MJH) and RSI and CT during the best jump, demonstrates that the period of foot contact with the ground was an important determinant for vertical jump height in both conditions. Previous studies have reported increased RSI values following several weeks of explosive training, with a concomitant reduction in CT and increased vertical drop jump height (Dello Iacono et al. 2017; Lockie et al. 2012). It has been suggested that greater RSI values are indicative of enhanced stretch-shortening cycle mechanics, by increasing vertical ground reaction force in a shorter period of time (i.e., rate of force development), with elevated leg spring stiffness (Barker et al. 2018; Douglas et al. 2018). Given that rate of force development is affected by phosphorylation of myosin RLC (Greenberg et al. 2009), a primary mechanism of PAP (Sweeney et al. 1993), we speculate that the conditioning contractions optimised stretch-shortening cycle mechanics via myosin RLC phosphorylation in the current study. Interestingly, whilst no PAP-effects were found in the non-BFR condition, the correlations suggested that those participants, who acutely improved jump performance, also exhibited changes in mechanical contributors (i.e., CT, RSI and power). However, it should be noted that assessment of kinetic measures was beyond the scope of this study, and future research could examine the effects of occluded PAP protocols on ground-reaction force characteristics.

Whilst the current study demonstrated the benefits of occluded lunge exercises on subsequent vertical jump performance measures, some limitations should be considered. Firstly, we were unable to report on whether occluded, body weight exercises were equally effective in inducing PAP effects as heavy resistance exercises, as this was beyond the scope of this study. Nonetheless, we were able to identify that occluded, body weight exercises were sufficient to acutely improve vertical jump performance, and may be a convenient alternative to a common heavy resistance training protocol based on similar levels of improvement in jump performance between the current study and that of a meta-analysis with heavy resistance exercise (Seitz and Haff 2016). Secondly, the effects of occluded lunge exercises were examined on vertical jump performance only, which may not be replicated to other sport-specific performance measures, including sprint and change-of-direction speed. Thus, further research is warranted to determine whether the PAP protocol in the current study is also beneficial to other performance tasks considered essential in sports. Finally, our cohort was limited to younger, anaerobically trained males, and thus our data may not be extrapolated to the general population, warranting further research to confirm our findings with other age groups.

In conclusion, the current study showed that body weight lunge exercise with BFR improved subsequent vertical jump performance measures for several minutes, post-exercise. Therefore, occluded, body weight lunge exercise during a warm-up routine may be a practical and effective protocol for optimising anaerobic power.

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Figure legends

Figure 1. The mean ± standard deviation at baseline (DJ_{Base}), 3 minutes (DJ-3), 6 minutes (DJ-6), 9 minutes (DJ-9), 12 minutes (DJ-12) and 15 minutes (DJ-15) after lunge exercises for A) vertical jump height; B) contact time; C) flight time; D) power; E) mat jump height; and F) reactive strength index during the blood flow restriction (BFR) and non-BFR conditions

* Significant differences between the two conditions ($p < 0.05$)

† Significantly greater than DJ_{Base} during the BFR condition ($p < 0.05$)