International Journal of EXERCISE SCIENCE

Original Research

The Acute Impacts of Resistance Training Performed with and without Blood Flow Restriction on Lower Body Muscular Power

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ABSTRACT

International Journal of Exercise Science 16(6): 1320-1333, 2023. The American College of Sports Medicine recommends resistance training using at least 70% one repetition maximum to improve muscular strength and hypertrophy; however, these intensities may not be safe for all populations. A training technique that has been reported to elicit increases in strength and muscle size uses low intensity resistance training or low load training in combination with blood flow restriction (BFR) to the working muscle. Although the acute effects of BFR on muscle strength and size are well established, the effects of BFR on muscular power are not definitively known. Resistance trained males (n = 14) completed three experimental sessions in which lower body power output and vertical jump height were measured pre and post exercise protocol. The barbell back squat was performed with either low load and blood flow restriction, high load (90% 1 RM, HL), or control (CON). A significant mean difference between pre (M = 46.35 ± 5.61 cm) and post (M = 43.63 ± 4.59 cm) vertical jump heights following 15 repetitions at 20% 1 RM with BFR was observed (p = 0.034), but not with HL or a CON. A decrement in vertical jump height was experienced after an acute bout of BFR with low load resistance exercise. Low load resistance exercise with BFR or high intensity resistance exercise may not be beneficial as part of a warm-up to acutely enhance vertical jump or power output.

KEY WORDS: Blood flow restriction training, muscle performance, resistance training, warm up, power output

INTRODUCTION

Power output and muscular strength are important characteristics of athletic performance (5). Improvements in both muscular power output and strength, through resistance training, may result in improvements in sport specific athletic movement patterns (5, 6). Acute improvements in power output can occur following a conditioning resistance training exercise. This acute improvement in power output has been termed post activation potentiation (PAP). PAP has been described as an increase in the force exerted by a muscle as a result of a previous contraction (26, 35). PAP can be achieved by contracting a muscle against a near maximal load (80-90% 1RM) and immediately following that with a biomechanically similar power movement, such as a back squat followed by a vertical jump (26). An acute improvement in sprint performance and vertical jump has been reported by some (7, 8, 49) but not by others following maximal muscular contraction of the lower body (14, 20, 41). The PAP phenomenon has the possibility of temporally improving the power output of an athlete. Improvements in power output observed as improvements in vertical jump height have been reported following squats at intensities of 90% 1 RM (26, 35).

Utilizing high-intensity resistance training may not be feasible for all populations or training periods. A unique training technique which uses low intensity resistance training or low load training in combination with blood flow restriction (BFR) to the working muscle (LI-BFRT), often termed BFRT, may be a good alternative to higher intensity resistance training. LI-BFRT has been reported to result in muscular hypertrophy and improvements in strength (1, 2, 12, 16, 24, 27, 28, 40, 48) similarly to traditional high load resistance training (HI-RT). The use of LI-BFRT has also been observed to minimize muscle atrophy during periods of immobilization or post-surgery to improve muscle function (34, 39). BFR to the lower body in combination with walking has been reported to result in muscular hypertrophy and improved strength (3).

LI-BFRT uses the application of tourniquets to restrict blood flow which induces a state of hypoxia, that is believed to trigger the recruitment of additional motor units (32, 40). BFR may result in the recruitment of fast twitch muscle fibers in a similar manner to high intensity resistance exercise even though lighter loads are being utilized (25). If LI-BFRT can mimic HI-RT and elicit similar muscular responses and adaptations then it may be plausible LI-BFRT training could also elicit acute improvements in power output, similarly to what has been observed using HI-RT via PAP.

However, little is known about the effects of LI-BFRT on PAP and muscular power output after acute exposure. It is unclear if an acute improvement in power output, similar to what is observed with HI-RT via PAP, can be experienced using LI-BFRT. Possible improvements in power output with LI-BFRT make this training modality a viable alternative to the use of heavy resistance exercises, reducing the chance for fatigue or injury in athletic, general, and/or clinical populations. Cleary and Cook (9) examined this concept by observing vertical jump height after having subjects complete a complex training session using either LI-BFRT or traditional HI-RT. Both conditions resulted in decrements in post exercise vertical jump heights indicating that neither conditioning exercise initiated a PAP response. The authors state that this decrement in vertical jump performance may be a result of accumulated fatigue and an ineffective complex training protocol (9). It is possible that multiple sets of LI-BFRT, as is used with complex training, may result in too much accumulated fatigue, eliminating the PAP effect and any performance improvements.

Athletes can utilize LI-BFRT during periods of rehabilitation or during training periods of reduced volume, such as in-season, to maintain muscle size and strength and manage fatigue while reducing the potential of injury (47). LI-BFRT may produce improvements in muscle size and strength but one thing that has not been examined in great detail is how power output can be affected by this training modality after a single set. Wilk et al., (45) reported improvements in power output and bar velocity in the barbell bench press when combining BFR with high resistance (70% 1RM). The improvement in power output and bar velocity were only observed during the 2nd of three sets of the bench press with a decrease in bar velocity occurring during the 3rd set of this training protocol. Similarly, an improvement in power output and bar velocity occurred when combining high BFR compression with high resistance during the barbell back squat (13). This evidence supports the idea that BFR can improve bar velocity and power output but when combining BFR with high intensity loads. It is unclear if this same improvement will occur with LI-BFRT. Wilk et al. (46) examined BFR's effect on bar velocity during the barbell back squat at various different loads. BFR did not reduce bar velocity during the barbell back squat when performed at loads between 40%-90 1RM. Although no reductions in bar velocity were noted, acute improvements in power output were not examined nor was any sort of PAP effect investigated, similar to what might be detected during a HI-RT without occlusion.

Therefore, the purpose of this study was to determine the acute effects of a set of LI-BFRT vs. HI-RT on power output of the lower body by observing vertical jump height and power output using a force plate. It was hypothesized that LI-BFRT would display similar acute improvements in lower body power output as HI-RT.

METHODS

Participants

Fifteen college-aged males, with resistance training experience of at least three days a week for the last six months were recruited for this study. Subjects were only admitted into the study after completing a health history questionnaire. Any "yes" response automatically disqualified any subject from participation due to possible contraindications (e.g. high blood pressure or taking blood pressure medications, cardiovascular disease, pulmonary disease, musculoskeletal injuries). The subjects were asked not to engage in any strenuous resistance exercise 36 - 48 hours prior to testing sessions. Subjects were also verbally instructed not to consume alcohol or caffeine 24 hours prior to testing as well as to not use supplements or recreational drugs. Participants were encouraged to maintain a similar diet and sleep regimen while participating in the study. An ad hoc power analysis was performed (G*Power version 3.1) to determine the number of subjects needed for the study to achieve a medium to large effect size with 80% power. The power analysis revealed that a minimum of 15 subjects was needed to achieve a medium to large effect size with 80% power. Prior to participation, the study procedures and any risks associated with the study were explained to subjects, and if agreed, they provided written informed consent. The study was reviewed and approved by the Institutional Review Board at Springfield College, and was conducted in accordance with the ethical standards set forth in the Helsinki Declaration and its most recent revisions. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (33).

Protocol
The study required each subject to participate in four separate sessions (Familiarization and 3 experimental sessions). The experimental protocol was carried out in a randomized order. The sessions were completed in the Strength and Conditioning Laboratory and the Human Performance Laboratory at Springfield College.

Familiarization Session: The familiarization session started with each subject completing a health history questionnaire and reading, understanding, and signing the informed consent form. Participant characteristics data was taken from each subject and includes age, training history, height, weight, and body composition (BOD POD). Height was measured using a stadiometer. The BOD POD (COSMED, Rome, Italy) was used to measure weight and estimate body fat percentage in each subject. Through the use of air displacement plethysmography, fat mass and lean mass was estimated. Previous research has demonstrated the reliability and validity of this instrument for measuring body fat percentage (13).

Each subject was then escorted into the laboratory for 3 repetition maximum (3RM) testing of the barbell back squat. Prior to 3RM testing subjects performed a standardized dynamic warm up (Table 1). A 3RM was performed by the subject with proper form and technique. One complete repetition was judged based on the thighs at or below parallel at the end of the eccentric phase of the squat. Proper form and technique were explained to the subject and assessed prior to the use of any weight. The 3RM was then entered into the Epley formula in order to calculate an estimated 1RM (10,19). Following 3RM testing, 20% 1 repetition max (1RM) for the barbell back squat was calculated and rounded to the nearest 5 lbs. All testing was conducted by a National Strength & Conditioning Association (NSCA) certified personal trainer.

Finally, subjects were instructed to perform 3 maximal countermovement vertical jumps (CMJ) on a portable force plate (AMTI AccuPower, AMTI, Watertown, MA) in order to be familiarized with correct jumping technique. Subjects were coached until correct technique was observed. Vertical jump was a motion that begins standing and then flexing at the knees into a squatting position (knees at or below 90º) and then immediately extending the knees, jumping vertically off the ground with arm movement (21). A minimum of 48 hours was observed from completion of the familiarization session to experimental sessions.

Experimental Sessions: The experimental sessions consisted of three separate sessions, which all took place in the Strength and Conditioning Laboratory at Springfield College. Subjects performed a standardized dynamic warm up (Table 1) followed by a progressive warm up of the barbell back squat. The first set of the barbell back squat warm up performed included no added weight for a set of 10 repetitions. Next, 5 repetitions with 40%, 50%, and 60% of the subjects estimated 1 RM was used to warm up with 60 seconds (s) of rest in between each set.

Table 1. Dynamic Warm-up

Exercise	Sets x Reps/Yards
Walking Knee Hug	1 x 5 per leg
Glute Bridge with Twist and Reach	1 x 6 per side
Lateral Lunge	1 x 6 per side
Lunge with Twist and Reach	1 x 8 per side
Kneeling Leg Circles	1 x 10 rotations
Inchworms	1 x 6 reps
Leg Swings (Forward and Backward)	1 x 8 per leg
Power Skip	1 x 6 per leg
Lateral Shuffle	1 x 10 yards
Carioca	1 x 10 yards
Jumps in Place	1 x 5 reps

Subjects then performed three separate CMJs on a portable force plate, sampled at 200 Hz. Each CMJ was separated by a 30 s rest period. The highest vertical jump height (cm) and the largest power output value (Watts/Kg) of the three trials was recorded and used for data analysis. The resistance exercise began upon completion of the standardized dynamic warm up, barbell back squat warm up, and first three CMJs. The time between the resistance exercise and VJ was no longer than 45 s. The three separate conditions subjects completed during the experimental sessions included; the barbell back squat with or without blood flow restriction of the lower body and no exercise (control).

LI-BFRT: With blood restriction, blood pressure cuffs (Prosphyg 760 Series Thigh Cuff, American Diagnostic Corp., Hauppauge, NY) were placed proximally on the upper thigh and inflated to 200 mmHg. This occlusion pressure was selected based on previous research using wide cuffs on the lower body to examine the LI-BFRT's effect on strength and power (3, 46). During blood flow restriction, 20% of 1RM was used while performing the back squat. The resistance exercise was performed following the standardized dynamic warm up, barbell back squat warm up, and the first three CMJs. One set of the back squat was performed using 20% 1RM for 15 repetitions. Immediately following the completion of the barbell back squat the blood pressure cuffs were left on for an additional 60 s before they were removed. The blood pressure cuffs were then removed and the subject stepped onto the force plate to perform three CMJs. Transition time between completion of the resistance exercise and CMJs was no longer than 45 s. Each jump was followed by a 30 s rest period before the next jump was performed. The highest vertical jump value and power output values from the three jumps were recorded and used for data analysis.

HI-RT: The experimental condition of high intensity resistance exercise with no blood flow restriction required subjects to perform the barbell back squat with 90% 1RM for 3 repetitions. The resistance exercise was performed following the standardized dynamic warm up, barbell back squat warm up, and the first three CMJs. After the completion of the barbell back squat exercise, subjects' step onto the force plate to perform three CMJs. Transition time between completion of the resistance exercise and CMJs was no longer than 45 s. Each jump was followed

by a 30 s rest period before the next jump was performed. The highest vertical jump value and power output values from the three jumps were recorded and used for data analysis.
Control condition (Con): The final experimental condition was a control condition in which no resistance exercise or blood flow restriction was performed. Subjects performed the standardized dynamic warm up and barbell back squat warm up. Subjects then perform the initial three CMJ trials on a force plate. Subjects then rested for equivalent time it took to complete the exercise sessions (90 - 120 seconds) and performed the next set of three CMJs on the force plate. Transition time between completion of seated rest and CMJs was no longer than 45 s. Each jump was followed by a 30 s rest period before the next jump was performed. The highest vertical jump value and power output values were from the three jumps was recorded and used for data analysis.

Statistical Analysis
Data were analyzed using commercially available software (SPSS, Windows v. 24.0, IBM, Chicago, IL). Data screening procedures were completed to assess for normality, missing data points, and outliers. Outliers were quantified as a value of ± 3.3 standard deviations of a normally distributed variable. Basic assumptions of the data analysis being performed were assessed. Mauchly's test was used to verify sphericity of data variance. A two factor 3 (treatment: CON, HIRT, LIBFRT) x 2 (time: pre vs. post) repeated measures analysis of variance (ANOVA) was used for statistical analyses of the dependent variables (vertical jump height and lower body power output). A Bonferonni *post hoc* test was applied to data during analysis when a main effect or interaction occurred. Estimates of effect size are provided to complement *p* values, specifically partial eta2 (η_p^2). The alpha level was set at 0.05. Data are presented as mean ± standard deviation.

RESULTS

Subject characteristics are presented in Table 2. During preliminary data screening, no outliers or missing data was identified for the dependent variables (power output and vertical jump height). One subject was excluded from the study due to a contraindication identified during the health screening. The overall assumption of normality was met for each dependent variable. Normality was evaluated through examination of skewness, kurtosis, and histograms. Mauchly's Test of Sphericity indicated homogeneity of variance was met for both dependent variables (both, $p > 0.05$).

Table 2. Participant Characteristics ($n = 14$)

Variable	Mean ± *SD*
Age (yr)	20.79 ± 2.36
Height (cm)	181.88 ± 6.36
Body Fat %	11.87 ± 4.67
3RM (lbs)	291.79 ± 50.79
1RM (lbs)	322.50 ± 50.70

There was no significant interaction between time and condition on power output: F (2, 26) = .730, p = .492. There was no significant main effect for condition: F (2, 26) = 1.27, p = .298. A significant main effect for time was discovered: F (1, 26) = 5.62, p = .034, η_p^2 = .302. Power output decreased from pre (M = 62.18 ± 1.15 W/Kg) to post (M = 60.87 ± .71 W/Kg) exercise (Figure 1; Table 3).

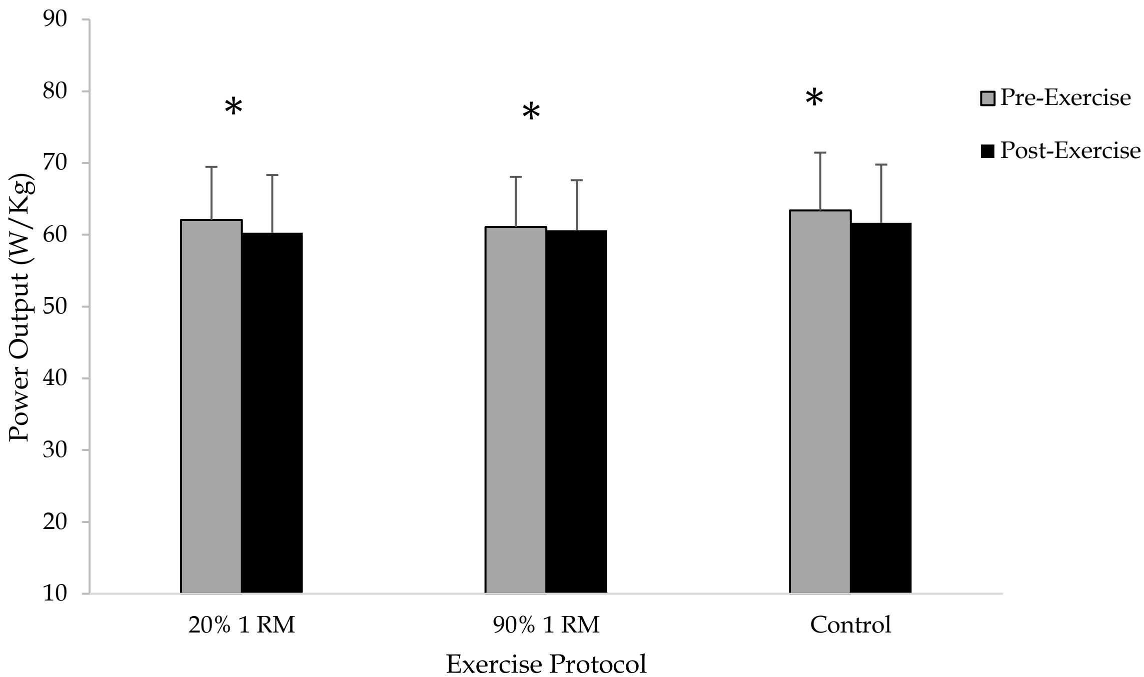

Figure 1. Effects of Training Protocol on Power Output. *represents a significant different from pre-condition values (n = 14).

There was a significant interaction between exercise condition and time on vertical jump height F (2, 26) = 3.47, p = .046, n_p^2= .211. For post hoc comparisons, a simple effects test was run. Simple effects test revealed significant mean differences between pre (M = 46.35 ± 5.61 cm) and post (M = 43.63 ± 4.59 cm) vertical jump heights following 15 repetitions at 20% 1 RM with BFR (p = .033) (Table 4). Vertical jump height did not change following the use of 90% 1 RM for three repetitions and a control session with no exercise performed (p > .05; Figure 2; Table 4).

Table 3. Effects of Training Protocols on Power Output

Condition	Mean ± *SD*
Pre LI-BFRT	62.07 ± 7.39 W/kg
Post LI-BFRT	60.30 ± 8.02 W/kg
Pre HI-RT	61.08 ± 6.98 W/kg
Post HI-RT	60.65 ± 6.96 W/kg
Pre-Control	63.38 ± 8.06 W/kg
Post-Control	61.66 ± 8.12 W/kg

*LI-BFRT represents 20% 1RM with Blood Flow Restriction; HI-RT represents 90% 1RM without Blood Flow Restriction; Control represents no exercise performed.

Table 4. Effects of Training Protocols on Vertical Jump Height

Condition	Mean ± *SD*
Pre LI-BFRT	46.35 ± 5.61 cm
Post LI-BFRT	43.63 ± 4.59 cm#
Pre HI-RT	45.40 ± 4.72 cm
Post HI-RT	46.21 ± 4.94 cm
Pre-Control	47.58 ± 5.89 cm
Post-Control	45.61 ± 5.71 cm

*LI-BFRT represents 20% 1RM with Blood Flow Restriction; HI-RT represents 90% 1RM without Blood Flow Restriction; Control represents no exercise performed; # represents a significant different from pre-condition values.

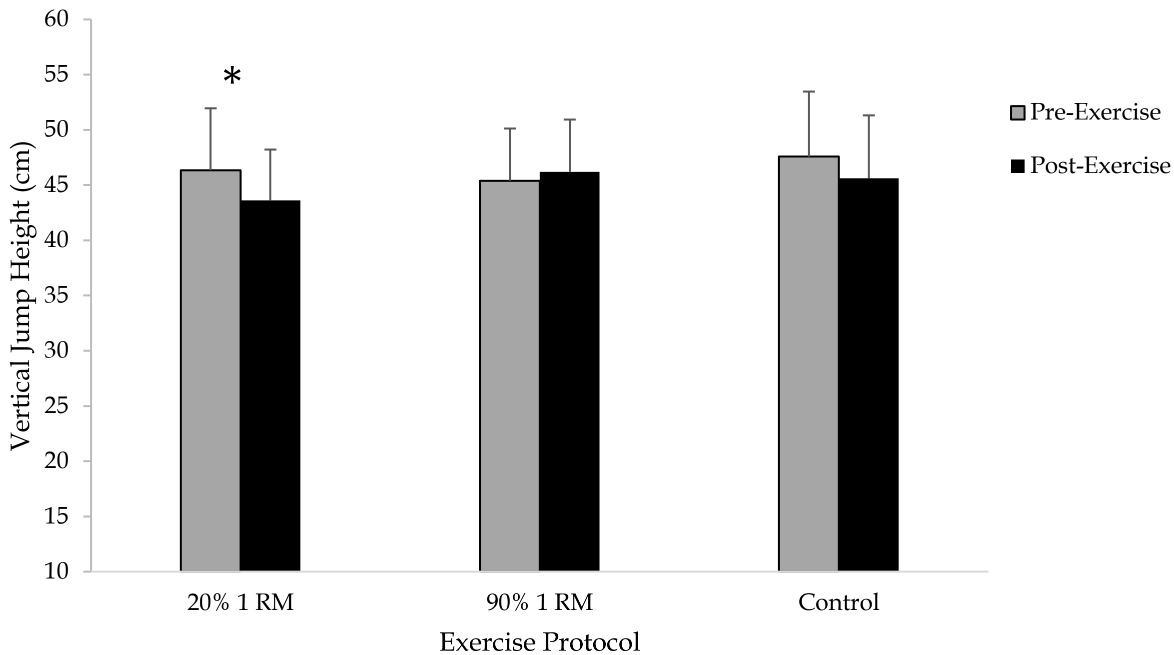

Figure 2. Effects of Training Protocols on Vertical Jump Height. * represents a significant different from pre-condition values in the LI-BFRT Condition

DISCUSSION

The purpose of the study was to determine if an acute bout of LI-BFRT influenced power output of the lower body and vertical jump height compared to a HI-RT protocol without occlusion (90% 1RM for 3 repetitions) and a control condition (seated rest). The main finding of this study was a decrement in vertical jump height following the LI-BFRT exercise protocol. Vertical jump height was unchanged in the HI-RT and control conditions. Another interesting finding was a decrease in power output from pre to post testing, independent of exercise protocol. Using LI-BFRT may reduce power and vertical jump height, possibly due to accumulated fatigue, and therefore may not be a viable training method to acutely enhance power output and force development. The accumulated fatigue and subsequent decline in performance may have been a result of one or more of the following mechanisms; PCr depletion, accumulation of inorganic phosphate, elevated hydrogen ion concentrations, and/or discomfort from the restrictive devices placed on the legs. Consistent training with high intensity loads may be a better option if one is looking to enhance power and force development.

A decrement in vertical jump height with LI-BFRT was observed in this study. Wernbom et al. (44), reported a decrement in maximal voluntary isometric contractions (MVC), a measure of muscular strength, following LI-BFRT. Similarly, Loenneke et al. (23) also reported a decrement in MVC of the knee extensors with 40%, 50%, and 60% of arterial blood flow occlusion. It is speculated that the decrement in contractile ability of the muscle may have been due to fatigue, the accumulation of inorganic phosphate ions (P_i), diminished creatine phosphate (PCr) levels, and/or low plasma pH levels, not muscular damage (23, 44). Fatigue will inhibit muscular strength and ultimately muscular power. Eight days of BFR has been reported to improve sprint performance but not jumping performance of male track and field athletes (2). Abe et al. (2) highlights the improvement in power after a training period with LI-BFRT but acute improvements remain unclear.

During the exercise portion of this study ATP and PCr levels may have been depleted following the exercise protocols and needed to be replenished to perform a near maximal contraction. Depletion of PCr and altered activation of muscle fibers has been reported with complete occlusion of the thigh and submaximal knee extension exercise (18). Partial occlusion with exercise can delay the recovery of PCr levels when compared to exercise with no occlusion (30). It is possible that the application of occlusion resulted in a large depletion of PCr and altered muscle activation, coupled with an insufficient recovery time, resulting in a decrease in power output and vertical jump height. Longer recovery times following exercise may have been required to allow near complete PCr replenishment in the LI-BFRT condition, before a post-exercise vertical jump is to be performed.

PCr breakdown results in an increase in P_i levels within the muscle. Increased levels of P_i are associated with muscular fatigue and may result in a decrease in contractile force generated by the muscle displayed by a decrease in vertical jump height in this study (4). Sugaya et al. (36), reported a significantly higher P_i concentration in muscles exposed to BFR after one set of exercise compared to no occlusion. The increase in P_i concentration appears to occur only when high levels of occlusion are present (~230 mmHg or ~43% restricted flow), comparable to pressures used in the present study (36). Elevated P_i levels may result in a decreases in myofibril force production from a reduction in calcium sensitivity in the muscle, a disruption in calcium release from the sarcoplasmic reticulum, and inhibition of cross-bridge cycling resulting in fatigue (4). All of which may have led to a decrease in force production, power output and in turn vertical jump height.

Elevations in hydrogen ion concentration in skeletal muscle due to LI-BFRT have been reported, which will lower plasma pH levels (11, 38). A lower skeletal muscle pH level appears to have some inhibitory effects on the central nervous system, which may lead to a decrement in nervous stimulation of skeletal muscle and a subsequent decrease in force generated (17). Lower pH may also reduce the contractile proteins sensitivity to calcium due to hydrogen ions competing with calcium to bind to troponin C (4). This study did not measure lactate levels or plasma pH so it cannot be stated with certainty that elevations in lactate and a lower pH occurred in the LI-BFRT condition. However, it is possible that metabolic byproduct accumulation and an altered intramuscular environment may have been present and may have altered the contractile properties of the muscle, thus impairing vertical jump.

Discomfort and subjects perceived effort may have also affected vertical jump height in the LI-BFRT condition. Greater pain scores following low load resistance exercise with BFR compared to without BFR have been reported (43). Although others have reported no difference in rating of perceived exertion with BFR compared to without BFR (37). A possibility is that the unfamiliarity with LI-BFRT and the perceived effort of the subjects may have led to a decrement in vertical jump height. Each subject was instructed and coached on proper jumping technique, however the unfamiliar feeling of BFR may have altered subject perception of jumping performance/mechanics.

Both the HI-RT and the control condition resulted in maintenance of vertical jump height. PAP did not appear to have an impact on the contractile properties of the muscle in the HI-RT condition. Jensen and Ebben (15) reported no improvement in countermovement jump performance at various time points following a 5 RM back squat. A decrease in performance appeared to occur immediately following a PAP stimulating exercise and no significant improvements in jump performance were observed between one to four minutes post exercise when compare to pre exercise performance (15). Observing PAP requires one to finely balance accumulated fatigue and recovery time without losing the potentiation effects. If recovery is insufficient, muscular fatigue may blunt the enhancement PAP elicits resulting in little, if any, performance improvements (35). Different methods and alteration in training variables have been utilized to produce a PAP response with the best method for producing a PAP response still remaining unknown (41).

The use of LI-BFRT or a HI-RT protocol may not be beneficial to use as part of a warm up or immediately before an explosive activity or event to acutely enhance vertical jump or power output. Athletes looking to optimize vertical jump or power output prior to an event may be better served by performing a dynamic warm up. The use of LI-BFRT or a HI-RT over a period of weeks to months may improve vertical jump and power output, however acute improvements are unclear. Moore et al. (31), demonstrated the effect occlusion training has on neuromuscular function. Strength, motor unit activation, and PAP all improved following eight weeks of occlusion training in the elbow flexors (31). Therefore, a longer training period may have been necessary to elicit neuromuscular adaptations, such as improvements in power output. Acutely, LI-BFRT appeared to provide no benefit on power output.

A potential limitation of this study was subject compliance with exercise restrictions prior to experimental sessions. Subjects were instructed to reframe from any strenuous lower body physical activity or exercise 36 to 48 hours prior to visiting the lab. Any exercise immediately prior to testing may have negatively impacted power output and vertical jump performance. Additionally, subjects were instructed to maintain a normal diet and consume similar meals on testing days though dietary fluctuations may have impacted testing performance, resulting in day-to-day variations, however given randomization this would be distributed across conditions. Also, partial arterial occlusion of the lower body has been reported with pressures near 200 mmHg. Partial occlusion was not directly confirmed in this study through use of ultrasonography. A one size fits all pressure may not be the best choice to ensure partial occlusion due to variation in subject body types, limb circumferences, and occlusion cuff widths (22, 29, 42), but may provide insight into ecological validity of approaches used by lay population. Wider cuffs were also utilized in this study and research has reported wider cuffs require lower pressure to partially occlude arterial flow compared to narrow cuffs (22, 42). To ensure a closer representation of weight room conditions, we opted for the utilization of blood pressure cuffs over automated machines like KAATSU or Delphi units. This decision aligns with practicality and relevance, as the devices typically used to restrict blood flow in a laboratory setting may not accurately simulate real weightlifting scenarios. Future research should ensure complete venous occlusion and partial arterial occlusion via vascular ultrasonography and should also note limb circumference as this will have an impact on occlusion pressures used. Various restriction pressures should be examined in future studies to determine their effects on vertical jump height and power output. Finally, only male subjects were used in this study, which is a limitation. It is important for future studies to examine the effect of LI-BFRT on PAP in females subjects to determine if males and females respond differently to this training modality.

In conclusion, a decrement in vertical jump height was experienced after an acute bout of LI-BFRT. Vertical jump height was unchanged following a HI-RT and control condition. Finally, a decrease in lower body power output was observed from pre to post exercise independent of exercising conditions. The use of LI-BFRT did not result in an acute improvement in vertical jump height. Future research should focus on a training period where LI-BFRT is utilized to examine effects on power and jump performance. Various factors need to be considered with examining PAP. This study utilized a shorter rest period which may not have allowed improvements in vertical jump height due to fatigue accumulation. Future research should continue to alter rest periods and restriction pressures to determine optimal recommendations to allow PAP and BFR to be fully exploited.

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