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Original Article

Effects of strength training in Smith press with partial blood flow restriction on jump performance

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Abstract:
Low-intensity strength training with partial blood flow restriction has demonstrated its efficiency in provoking functional adaptations that allow an increase in absolute muscle size and strength, as well as in improving objective measures of physical functionality related to life activities. It has been proposed as a training method equivalent to traditional moderate and high intensity models, with relevant benefits for populations less tolerant or unable to train at high loads. Unfortunately, the information available on its effects on explosive actions, such as jumping ability, is so far less conclusive. This study aimed to evaluate the effects of twelve sessions of Smith press squats, utilizing low-intensity strength training with partial blood flow restriction, and high-intensity strength training on squat jump and countermovement jump performance, as well as the perceived intensity during training sessions. Recreational college athletes were divided into two intervention groups partial blood flow restriction and high-intensity resistance training and engaged in a four-week training regimen. Squat jump and countermovement jump flight times and pre-stretch increases were assessed at the beginning and end of the training protocol. Perceptual intensity was measured during four sessions of both training sessions. Squat jump performance increased at the end of both workouts, although the greatest difference occurred with high-intensity strength training. For the countermovement jump, only partial restriction of blood flow produced an increase in performance. Only high-intensity resistance training produced a change in prestretch augmentation. Perceptual intensity was greater in high-intensity strength training. The results demonstrate that low-intensity training with partial blood flow restriction is a useful alternative to improve squat jump and countermovement jump performance, producing a lower perceptual intensity in recreational athletes.
Key Words: **blood flow restriction training, stretch-shortening exercise, strength training, perceived exertion.**

Introduction

Muscular power, measured by strength and muscle shortening velocity, is considered an important parameter for explosive actions in sports and daily life. Both expressions of strength contribute to the performance of the vertical jump, which commonly used to assess physical fitness in various populations, as it provides a measure of force production or sub-modalities involving low-load, high-velocity force demands (Morris et al., 2022). Vertical jump tests are used to assess complex motor performance and the strength/power of the extensor chain of the lower extremity muscles, and as a functional action, it is considered fundamental to the performance of sports and activities of daily living. (Blosch et al., 2019). Among the most commonly used jumps are the squat jump (SJ), which measures capacity in concentric movements, and the the countermovement jump (CMJ), which measures stretch-shortening cycle (SSC) type actions (Van Hooren & Zolotarjova, 2017). SSC are multi-joint eccentric-concentric muscle actions that in a rapid and coupled transition facilitate optimal power production by storing and reusing elastic energy (Van Roie et al., 2020). One of the indicators analyzed by the SJ and CMJ is the pre-stretch augmentation (PSA), which indicates the percentage difference produced between the two jumps and represents the indirect ability to use muscle pre-stretch during the CMJ to achieve a greater jump height (Suchomel et al., 2016).

To increase vertical jump, evidence indicates that the best options include plyometric or resistance training. The main mechanism explaining the effect of plyometric training is related to the SSC. (Makaruk et al., 2020), traditional plyometric training programs improve jumping ability in athletes who have already reached

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jumping ability (Stojanović et al., 2017) on the other hand, resistance training is associated with neural adaptations and an increase in muscular strength. (Morris et al., 2022), which is attributed a primordial role in the improvement of explosive power (Xiaolin et al., 2023). However, the isolated or combined action of these workouts, either by the action of the SSC or by the % of 1RM used, is considered high intensity. (Pérez-Gómez & Calbet, 2013), which may be an inadequate load for training beginners, untrained or less physically fit people, or older or frail people, as it increases risk (injury) over efficiency (performance), especially in the context of sports. (Chang et al., 2023) or in the presence of musculoskeletal compromise (Grønfeldt et al., 2020).

Resistance training with low loads (20-30% of one repetition maximum-1RM) combined with partial blood flow restriction (PBFR-RT) at the muscle level is a method that has been shown to achieve functional adaptations in increasing muscle size and strength more efficiently than the same exercise without PBFR (Slysz et al., 2016), even in populations that are less tolerant to force development (Vechin et al., 2018). Compared to high-intensity resistance training (>65% of 1RM) (HL-RT), both methods are equally efficient in increasing muscular strength (Grønfeldt et al., 2020) or higher in strength endurance with PBFR (Pucsok et al., 2023). From practical application, it optimizes the dose-response relationship, as it shortens the time and number of repetitions compared to high-volume training without PBFR, or uses a lower volume load (kilograms x number of repetitions) than HL-RT to achieve equivalent adaptations in muscle strength (Bahamondes-Avila et al., 2018; May et al., 2022). This allows PBFR-RT to be positioned as an efficient alternative to increase muscular strength, but more information is needed on associated manifestations such as explosive strength.

A recent review indicated that PBFR-RT provides greater improvements in explosive performance (jump, sprint and power) than traditional strength training, but with a small effect size in jump tests. The authors related these improvements to possible neuromuscular adaptations such as neuromuscular drive (faster and earlier recruitment of muscle fibers), improved oxygen uptake capacity and phosphocreatine utilization in muscle; along with protein synthesis and decreased mRNA gene expression of MURF-1, atrogine and myostatin in muscle. (Xiaolin et al., 2023). Although this information is promising, the low effect sizes observed suggest that the improvement of jumping ability with PBFR-RT is inconclusive (Centner et al., 2020; Horiuchi et al., 2018; Hosseini Kakhak et al., 2022; Madarame et al., 2011; Manimmanakorn et al., 2013; Scott et al., 2017), nor have we observed an analysis on SSC or its relationship to perceptual response. Therefore, this study aimed to evaluate the effects of twelve sessions of Smith Press Squats, with PBFR-RT versus HL-RT, on SJ and CMJ performance. Secondly, to establish the perceptual intensity during the training sessions with both modalities. We hypothesize that PBFR-RT results in similar gains in jump performance as HL-RT without PBFR.

Material & methods

Subjects

This study was approved by the Ethics Committee of the main author's university, in compliance with the Helsinki Declaration. Participants were recruited from within the university population and participated voluntarily. To invite those interested in participating, a meeting was organized to explain the details and objectives of the study, arriving at 33 volunteers. After signing an informed consent, a questionnaire was applied about their medical history and physical activity history using the Physical Activity Questionnaire (IPAQ), as well as a general health evaluation, verifying the inclusion criteria of being a recreational athlete with at least two years of training experience in strength training. The exclusion criteria were: Being a performance athlete, having any type of cardiac, circulatory or metabolic illness, arterial hypertension, infection or inflammatory condition independent of the cause, orthopaedic or musculoskeletal injury, being a smoker or undergoing any type of dieting. Using these criteria, the sample was selected, comprised of 24 males with homogeneous characteristics regarding health, blood pressure, physical activity level and body mass index. These participants were considered able to train according to the characteristics of the protocol. From this sample, 22 participants completed the study. In Table 1, the characteristics of the intervention group are shown.

TABLE 1. Sample characteristics (mean (SD)), according to training group.

	N	Age (years)	BMI (kg/m^2)	SP (mm Hg)	DP (mm Hg)	IPAQ (mets/min/sem)
PBFRT	12	22.62 ±1.37	25.83±1.98	119.67±7.08	78.33±6,43	3081.33±851.77
HIT	10	21.14±1.29	24.77±3.76	118.80±11.97	76.20±5,03	3159.80±1311.13
p	---	0.018	0.407	0.835	0.404	0.867

Abbreviations: PBFR-RT: partial blood flow restriction - resistance training, HL-RT: high load - resistance training, BMI: Body Mass Index, SP: Systolic Pressure, DP: Diastolic Pressure, IPAQ: International Physical Activity Questionnaire

Interventions

A mixed pretest-posttest study design was used, with two training interventions assigned by simple randomization arriving at two groups: PBFR-RT or HL-RT during 12 sessions distributed over 4 weeks (three days per week). The training protocols were carried. These were done with PBFR at 20% 1RM (PBFR-RT) and traditional high-load training without PBFR, at 70% 1RM (HL-RT) (May et al., 2022). All of the training sessions were done between 17:00 and 20:00, according to the availability of each subject. Warm-ups for each group were the same used during the jump tests. Characteristics of the protocols are described in the following section, and are summarized in Figure 1.

FIGURE 1. Training protocols scheme

Stage	**Pre-Intervention Evaluation**		**Training Program**	**Post-Intervention Evaluation**
Week	1	2	3 – 6	7
Action	Day 1: Friday: Orientation in the jumping tests and parallel squats on a Smith press (1RM test)	Day 2: Tuesday: Measure, SJ – CMJ jumping tests. Day 3: Friday: 1RM press squat	Training days: Mondays, Wednesdays, Fridays 12 sessions in total OMNI-RES: Applied four times, in sessions 1 and 12, and in two random sessions, during the first six and last six sessions, respectively. **Resistance training program details**	7 day later: Measure SJ – CMJ jumps.

Group:	**PBFR-RT**	**HL-RT**
% load	20% 1RM with PBFR	70% 1RM (without PBFR)
Series and repetitions	3 series “with failure” - Up to 30 repetitions	3 series – 12 or 15 repetitions
Pause	30”	1’
Restriction Pressure	160- or 180-mm Hg	-----
Movement Rhythm	2” concentric 2” eccentric	1” concentric 1” eccentric
Progression	Sessions 1 to 6: only 160 mm Hg Sessions 7 to 12: only 180 mm Hg	Sessions 1 to 6: only 12 repetitions Sessions 7 to 12: only 15 repetitions

Abbreviations: 1RM: one repetitions maximum tests; SJ: squat jump; CMJ: counter movement jump; OMNI-RESscale to measure the subjective intensity of effort; PBFR-RT: partial blood flow restriction - resistance training; HL-RT: high load - resistance training; mm Hg: millimeters of mercury.

Resistance Training with Partial Blood Flow Restriction (PBFR-RT)

A resistance training protocol was executed with parallel squats in the Smith press, following the prescription recommendations of PBFR training (Patterson et al., 2019). All participants had a test session and became familiar with the squat and the respective load percentage, and with the use of PBFR-RT performed on light biceps and triceps exercises with dumbbells of 1 kg bilaterally, to make the participants feel the sensations that were expected to occur during the PBFR-RT. This familiarization was not performed on the legs to minimize any influence on future strength performance. The execution followed a rhythm of concentric and eccentric movement that was guided by a pre-recorded audio system during each series of exercises, performing a maximum of 30 repetitions. When it was not possible for the participant to follow the rhythm of execution or did not achieve the required range of movement, the series was stopped, and the corresponding pause began. It was decided to use pressures in the restriction cuff in the lower range of the restriction pressures categorized as fixed, starting at 160 mm Hg in the first six sessions and increasing to 180 mm Hg in the next six sessions, depending on the relationship between the width of the cuffs used and the restriction pressure applied (Jessee et al., 2016).

Partial blood flow restriction was done with a sphygmomanometer and 30 cm pneumatic hoses, which were extendable with inelastic Velcro to 145 cm in length and 5.5 cm width, applied to the proximal end of both lower extremities, 1 cm below the gluteal fold. After warm-up, the hoses were installed without inflation pressure but securely fixed with Velcro to maintain their positioning. Before starting the training, the hoses were progressively insufflated to the corresponding pressures, 160- or 180-mm Hg, respectively, closing the manometer valve to maintain pressure during the entire training session, including rest periods. The hoses were taken off immediately after finishing the session. Before and after the training session, blood pressure was taken. During the training session, % 1RM was not modified, only restriction pressure.

High-load resistance training (HL-RT)

This protocol used exercise prescription parameters oriented toward an increase in muscular strength (Garber et al., 2011). The participants also had a session to familiarize them with the technical execution of the squat. About the load, they practised with biceps and triceps exercises and a moderate load (OMNI-RES < 7) to guide the sensations that should be expected during the training. All participants were able to run the familiarization without issue. Movement speed was controlled by a pre-recorded audio system. All training parameters were maintained, except for the number of repetitions, which from the 7th session was increased.

The sessions were supervised by the researchers, permitting correct participant follow-up and control of the protocols. During the intervention periods, participants were instructed and frequently reminded to not do other activities (training or sports) that would interfere with the study variables. Control of the exercise sessions and the pre-and post-intervention measurements were done by different researchers.

Data collection

At the beginning and end of the program, the study variables were measured, using the simple blind method where the evaluators did not know which participants were assigned to which group. All of the participants attended pre- and post-intervention sessions to evaluate the dependent variables. Two weeks before the intervention, the initial phase contemplated three separate evaluations 72 hours apart. The first day was to orient the participants and practice lightly about the tests: SJ, CMJ and parallel squats on a Smith press. During the second day, the SJ and CMJ were measured using a contact platform, recording the flight time (FT) for each jump. Finally, on the third day, an evaluation of 1RM was done on a Smith press to define the individual training load (% 1RM) for each participant. One week after the 12th session, the SJ and CMJ tests were repeated. All of the tests were carried out in the same laboratory. Figure 1 shows a temporal diagram for the evaluation and training periods, as well as the training protocols. Jump tests were measured after general warm-ups, which consisted of 8 minutes of jogging (8-11 km/hr.) and 4 minutes of ballistic stretching for lower extremity extensor muscles (3 sets of 10 repetitions for muscle groups on each extremity). All participants did two attempts at SJ and CMJ, according to the methodology described by Bosco (Van Hooren & Zolotarjova, 2017), obtaining the FT for each jump (SJ-FT and CMJ-FT), selecting the best height reached by the PSA calculation, following the equation ([[CMJ-SJ/SJ]*100]). Between each attempt, participants rested for 3 minutes. The evaluation was done on a contact platform Axonjump® Model C. Intraclass correlation coefficients (ICC) of the FTs were between 0.95 - 0.98 for SJ and 0.96 - 0.99 for CMJ.

The 1RM press squat test followed previous recommendations (Brown & Weir, 2001). The latter was determined by the last load used in the successful lift of the bar, using the sequence of completely extended knees in the biped position, arriving at 90° flexion, and back to full extension. A relevant characteristic of the Smith press squat is that during its kinematics the feet are advanced above the longitudinal axis of the body in the sagittal plane. In addition, to restrict the descent of the body and not exceed 90° of knee flexion, a height-adjustable chair was installed behind the participant, which, by touching the gluteal area, served as feedback to limit the descent and start the ascent. The chair was adjusted to the height of each participant to achieve 90° of flexion. The technical description of the squat was the same as that used during training. The 1RM value was used to prescribe the training load intensity (% 1RM) for each group. The 1RM test was done by evaluators with experience in strength training. The use of a weight-training belt was authorized under the condition that it was also used in the training sessions. Previously, absolute and relative ETMs of 2.74 and 3.39% were established for the 1RM press squat, obtained from a group of 14 males with similar characteristics to the study, using the same protocol on two occasions with one week of separation.

The OMMI-RES scale aims to measure the subjective intensity of effort and seeks to have the participant describe how their body feels during weightlifting exercises and has recently been validated as a method to monitor and regulate intensity during PBFR-RT (Aniceto et al., 2021). This scale was used at the end of each series of exercises in four different sessions, as a follow-up to the perceptual response. They were measured in the first and last session, and in two random sessions of each participant, applied between the second and sixth session (restraint pressure of 160 mm Hg in PBFR-RT and 12 repetitions in HL-RT) and between the seventh and eleventh session (restriction pressure of 180 mm Hg in PBFR-RT and 15 repetitions in HL-RT), respectively. Doing it this way sought to avoid possible influences on personal perception from the response given by a group member.

Statistical Analysis

Statistical analysis was carried out using Stata software Version 18.0. For descriptive analysis, mean and standard deviations were used for the different quantitative variables. To verify the normal distribution of the sample, the Shapiro-Wilk test was usedJump measures (SJ and CMJ performance) and OMNI-RES were analyzed using a fixed repeated measures model and fit model via restricted maximum likelihood (REML). SJ and CMJ were analyzed by comparing groups (PBFR-RT and HL-RT), time (start and finish) and the interactions group x time. OMMI-RES responses were analyzed using each session, by examining group interactions (PBFR-RT and HL-RT), time (session 1, session 2, session 3, session 4) and group x time. In each case, a significance level of 0.05 was considered. To estimate the size of the effect (SE) of each intervention, Cohen’s d test was used (= [ending average - starting average]/[initial standard deviation]), classifying its effect as d<0.35: trivial; d≥0.35: small; d≥0.8: moderate; d≥1.5: large (Rhea, 2004).

Results

SJ and CMJ performance

Table 2 presents the results of the jump performance. Significant interactions (p<0.05) were presented in SJ-FT (time), CMJ-FT (time x group) and PSA (time and time x group). Upon finishing the intervention, both training groups increased SJ-FT performance (p<0.05), only CMJ-FT performance increased in PBFR-RT (p=0.001), and PSA decreased in HL-RT (p <0.001). The highest SEs were presented in the SJ-FT from both groups and in PSA from HL-RT.

TABLE 2. SJ and CMJ performance (mean SDs) at the beginning and end of the training protocols

Variable	Training Type	Start	Finish	Group – Time – Time x group p<0,05	Time x training group p<0,05	*SE*
SJ-FT (mseg)	**PBFR-RT**	465.3±21.4	492.00±12.7	0.073 - 0.000* - 0.105	0.007**	1.248††
	HL-RT	485.8±40,0	536.00±28.3		0.000**	1.256††
CMJ-FT (mseg)	**PBFR-RT**	533.3±29.3	553.33±36.0	0.125 – 0.813 - 0.045*	0.001**	0.683†
	HL-RT	556.8±38.0	558.40±40.1		0.813	0.042
PSA (%)	**PBFR-RT**	32.36±18.2	26.92±15.8	0.912 – 0.000*- 0.015*	0.304	-0.299
	HL-RT	33.16±22.2	8.55±7.6		0.000**	-1.109††

*: Significant changes between interactions of group, time and time x group upon finishing training. **: Significant changes between the start and end of each training. SE: between the start and end of trainings †: small; ††: moderate; ‡‡: large.

Abbreviations: PBFR-RT: partial blood flow restriction - resistance training, HL-RT: high load - resistance training, SJ-FT: flight times during SJ, CMJ-FT: flight times during CMJ, PSA: Prestretch Augmentation, SE: size of effect.

OMNI-RES

Table 3 presents the results of the OMMI-RES scale applied in four training sessions. In all sessions OMMI-RES was higher in HL-RT. Significant interactions were observed in group and group x time (p<0.05), especially by the differences produced between sessions 3 and 4 (p<0.05) of both protocols.

TABLE 3. Values of the OMMI-RES scale (mean SDs) applied in four training sessions.

Training Type	Session 1	Session 2	Session 3	Session 4	Group – Time - Group x time
PBFR-RT	2.21±1.70	2.06±1.79	1.90±1.60	1.90±1.61	0.007* - 0.217 - 0.001*
HL-RT	2.90±2.05	2.85±2.03	2.90±2.24	3.45±2.40	
Group x time (specific interaction)	0.092	0.055	0.014**	0.000**	

*: Significant changes between interactions of group, time and group x time. **: Significant changes between each session.
Abbreviations: PBFR-RT: partial blood flow restriction - resistance training; HL-RT: high load - resistance training.

Dicussion

This study demonstrated that SJ-FT increased in both training groups, although the largest difference was presented in HL-RT. The CMJ-FT only showed significant differences in PBFR-RT, and the PSA showed significant changes only in HL-RT. Furthermore, the perception in OMMI-RES was lower in all sessions of PBFR-RT compared to HL-RT and tended to decrease as the training progressed. PBFR-RT has been demonstrated to be equally effective in producing maximum force gains compared to HL-RT in adults over a wide age range (Grønfeldt et al., 2020) and improvements in performance explosive force (Nielsen et al., 2017), or the rate of strength development (Behringer et al., 2017), but information is less known on modifications to the Bosco test. In our study, performance improvements were observed for FT in both jumps (SJ and CMJ). It is probable that the greater improvements in BFR may be related to neuromuscular adaptation induced by blood flow restriction (Xiaoling et al., 2023). Previous studies have shown that in designs based on training programs, power (Cook, 2014) or height or CMJ increased with PBFR-RT, but without finding notable differences with the baseline or with other training modalities (Centner et al., 2020; Hosseini Kakhak et al., 2022; Madarame et al., 2011; Manimmanakorn et al., 2013; Yang et al., 2022), similarly, other authors have not observed improvements with the application of PBFR-RT (Gil et al., 2017; Horiuchi et al., 2018; Scott et al., 2017). In the present study, we did find differences in the CMJ at the end of the training with the initial measurement and with HL-RT. The causes that can sustain these results could lie in the methods of intervention, which are different and non-comparable, especially by including different ways of measuring the results and the ways of applying the training. Other differences include the variables from PBFR-RT (type, modality, pressure or duration of the restriction), study population, %1RM, type of exercise, distribution in sets and repetitions, resting times, frequency of weekly training, intervention duration and other specific variables of each intervention protocol (Centner et al., 2020; Cook et al., 2014; Gil et al., 2017; Horiuchi et al., 2018; Hosseini Kakhak et al., 2022; Madarame et al., 2011; Manimmanakorn et al., 2013; Scott et al., 2017; Yang et al., 2022; Wang et al., 2022). Only two studies analyzed both jumps. Horiuchi et al. (2018) reported that PBFR training does not affect SJ and CMJ jump performance, but used vertical jump with and without PBFR as an intervention, while Yang et al (2022) found an improvement in SJ and CMJ performance in preadolescents, using as an intervention a contrast training (sequence of strength exercises with low load and PBFR (back and front squat with 25 - 35% 3RM), followed by slow (power) and fast SSC (plyometric) exercises with body weight).

This modality is closer to our study since it shares the movement pattern and the application of PBFR only during training in the Smith press. In the specific prescription of BFR-RT, the relationship between the width of the compression cuffs and the applied restriction pressure is a relevant factor, since wide cuffs restrict blood flow to a lower restriction pressure than narrower ones (Weatherholt, 2019). Our study used two fixed restriction pressures in all participants (160-180 mm Hg), which coincides with previous studies in the range of restriction pressures and cuff width used (Hosseini, 2020; Manimmanakorn et al., 2013) and was lower when wider devices were used (Centner, 2020, Gil, 2017). It has been described that fixed or standardized restriction pressures could be less efficient in the dose-response relationship than individualized pressures (50-80% of limb occlusion pressure (LOP)), in positive muscle responses and adaptations and mitigation of risks (Wilk et al., 2018). Unfortunately, the two previous studies that used a % LOP and measured CMJ performance had conflicting results (Centner, 2020, Gil, 2017). We decided to use restraint pressures that were in the range of 150-180 mm Hg, since the thigh circumference of the participants was between 52.3-58.9 cm (Loenneke et al., 2012) We also considered that the width of the cuff was in the lower range of known dimensions for lower limb devices, so greater restraining pressure was applied without exceeding the recommended LOP percentages (<80%) (Rossow et al., 2012).

Although it may be contradictory, given that wider compression cuffs have managed to increase the power and speed performance of the bench press (Wilk et al., 2020), or the efficiency of the SSC in a drop jump (DJ) (Doma et al., 2020), in this study we opted for narrow cuffs, as they are recognized as more practical to use (Scott et al., 2015) and would avoid the drawbacks of wider devices such as greater compression on the underlying tissues (Loenneke et al., 2012), a greater degree of discomfort and perception of effort, and a greater cardiovascular response (Rossow et al., 2012). Another relevant factor in exercise prescription is the number of repetitions, speed of movement or time under tension, since there seems to be an optimal zone of repetition duration with a relatively significant number of them (Patterson et al., 2019), which would favor an adequate accumulation of metabolites in the muscle and neuromuscular and metabolic benefits related to PBFR-RT (Alberti et al., 2013). Finally, the adaptations produced in rapid strength linked to PBFR-RT also seem to have a time-dependent relationship, since it has been shown that these gains in rapid strength were manifested 12 days after the last exercise session, and before that, no modifications or negative effects were observed (Nielsen et al., 2017). In our study, jump tests were measured 7 days after finishing the interventions. The methodological variability of studies with PBFR is still high, however, guidelines for efficiency in exercise prescription are beginning to appear (Xiaolin et al., 2023). This meta-analysis analyzed the variables that induce greater improvements in the explosive strength of the lower limbs, which fortunately includes essential elements of the methodology of our study. Modifications to PSA are related to changes produced in the SSC, performance differences in SJ and CMJ, and could be mainly related to better absorption of the muscle slack and the accumulation of high stimulation produced during the countermovement produced during the CMJ (Van Hooren & Zolotarjova, 2017). We have found only one study that has addressed the relationship between SJ and CMJ linked to PBFR-RT using the eccentric utilization ratio (EUR), it was found that performance increased in SJ and CMJ and decreased EUR, regardless of using HL-RT or PBFR-RT (Yang et al., 2022), data were of greater magnitude, but coincide in trend with our findings, especially in SJ performance.

Our results indicate a significant increase of SJ-FT in both groups (moderate SE), with a larger difference in the HL-RT group (5.8% in PBFR-RT vs. 10.3% in HL-RT). Conversely, in the CMJ-FT, a significant increase was only produced in PBFR-RT (3.8%). These differences generated lower PSA at the end of the intervention, especially in HL-RT (PBFR-RT: -16.8% versus HL-RT: -74.2%). In this regard, it appears that a larger difference between SJ and CMJ is not necessarily better, given that it reflects a deficient capacity to reduce the degree of muscle slack and quick increase of stimulation in the SJ (Van Hooren & Zolotarjova, 2017). Accordingly, the SJ could be crucial for high-intensity sports performance, where training recommendations are oriented at minimizing the difference between these jumps, seeing as that there is not generally sufficient time to perform a large countermovement during sporting activities (Van Hooren & Bosch, 2017).

Data registered on PSA suggested great muscular compliance at the beginning of both protocols, a situation that was reversed at the end of both training sessions, especially in HL-RT. The proportional increase of FT from both jumps in PBFR-RT (5.7% in SJ and 3.8% in CMJ), together with the greater increase in SJ (10.3%) and the null modification of the CMJ (0.3 %) would denote a positive reduction in muscle slack in HL-RT; probably not due to lack of elastic contribution during the eccentric phase of the SSC, but due to improvement in the SJ (Yang et al., 2022). Even though methodological differences exist with our study, Kubo et al. (2006), noted a difference in the muscle force relationship – tendon stiffness upon comparing two protocols, PBFR-RT (20% 1RM) and HL-RT (80% 1RM) using a unilateral dynamic exercise with eccentric predominance in the lower limb open kinetic chain, observing an increase in muscle size and strength in both groups. However, only specific tension and stiffness of the tendon-aponeurosis complex were observed in the HL-RT group. In these exercises, the mechanical stress of the HL-RT exercise contributes to the adaptation to tendon stiffness, not so, the greater metabolic stress of PBFR associated with muscle hypertrophy. Thus, the behaviour of muscular structures appears to respond differently to characteristics of both types of training, especially to the load or mechanical tension applied (% 1RM). According to our results, even when both trainings increased SJ-FT, the lesser load of PBFR-RT would not achieve modification of the muscle slack, and approximate performance of SJ and CMJ, contrary to what was observed for HL-RT. However, improvements in the performance of each jump would facilitate the inclusion of PBFR-RT in training programs that are based on SSC-type actions and could be considered together with other training modalities (Yang et al., 2022, Sarfabadi et al., 2023).

Within traditional training methods, evidence suggests that the best way to improve the vertical jump is through a combination of plyometric training and weight training (Perez-Gomez & Calbet, 2013 Sabillah et al., 2022). Executed with high-speed or mechanical loading. In contrast, our results suggest that PBFR-RT can be used as an alternative to improve vertical jumps in active or individuals who are recreational. This increases training options when traditional methods are not an efficient loading alternative that facilitates muscle adaptation, like in individuals with weakness who need to rapidly enhance muscle performance. Another application could be during periodization when it is necessary to lower the intensity of the load and maintain the explosive levels necessary for optimal sports performance. Doma et al. (2020) propose that PBFR-RT with light loads can elicit similar responses to intense resistance training and lead to more sustained mechanical power improvements.

We used the OMMI-RES scale to measure the perception of effort intensity. Our results indicate a greater response in HL-RT throughout the intervention, especially in sessions 3 and 4. When comparing these results with PBFR-RT vs. HL-RT protocols, it was observed that perceptual responses can be higher in either of the two training modalities (Kim et al., 2014; Neto et al., 2016). The greater HL-RT perceptual response observed in our study would be related to the greater load applied, and in particular, in sessions 3 and 4, by increasing the number of repetitions with the same intensity (70% 1RM), that would require greater muscular effort, and activate more motor units, especially those with a high threshold (type II fibers), which would induce a greater perception of effort (Eston & Evans, 2009; Rolnick et al., 2021). The methodological variability of the studies that compared PBFR with another training modality facilitates discrepancies in the results, however, it is possible to infer a greater adaptive response in the perception of effort (<OMNI-RES) as the PBFR-RT sessions progress (Brandner et al., 2018). The lower PBFR perceptual responses visualized in our work are likely attributed to the characteristics of the intervention used, such as a period of familiarization with the training, the use of narrower cuffs and carrying out a large part of the sessions without reaching muscle failure (Rolnick et al., 2021). We highlight that lower scores in OMNI-RES did not hinder the improvements in SJ and CMJ performance observed in PBFR-RT.

The present study has some limitations. Where, our sample size is small, determined by convenience and with rigorous selection criteria, subtracting possible participants. Consequently, a larger sample would give greater validity to the results. Although the use of fixed restriction pressures could limit the effect of PBFR, it should not be forgotten that its application must be closely related to the width of the restriction cuff, so in future research, it would be pertinent to use individualized restriction pressures with different % of the LOP and with the application of different widths of cuffs to observe their results. Also, the scientific literature guides us regarding the prescription of training volume, however, it is not accurately counted in our study, limiting the interpretation of the results. Finally, even when the results are of interest, these are not transferable to other populations, although it allows for hypothesizing coherent effects and variants of strength training.

Conclusions

In conclusion, the study demonstrated that in four weeks, the two types of training produced a significant increase in SJ-FT and CMJ-FT in PBFR-RT, along with a decrease in PSA only in HL-RT. In addition, the perception of intensity relative to effort was lower in PBFR-RT throughout the training period. Based on these results, PBFR-RT may be a useful alternative for improving vertical jumps in active or recreational individuals and increases training options when traditional methods fail to be efficient in rapidly increasing explosive muscle performance, such as in individuals with less experience in intense strength training or with muscle weakness. Another operational advantage for practical application with individuals is the reduced sensation of perceived exertion during training sessions.

Conflicts of interest: The authors have no conflict of interest to declare.

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