Hypotensive Effects of Resistance Exercises With Blood Flow Restriction

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Abstract

Neto, GR, Sousa, MSC, Costa, PB, Salles, BF, Novaes, GS, and Novaes, JS. Hypotensive effects of resistance exercises with blood flow restriction. *J Strength Cond Res* 29(4): 1064–1070, 2015—The effects of low-intensity resistance exercise (RE) combined with blood flow restriction (BFR) on blood pressure (BP) are an important factor to be considered because of the acute responses imposed by training. The aim of this study was to compare the hypotensive effect of RE performed with and without BFR in normotensive young subjects. After 1 repetition maximum (1RM) tests, 24 men (21.79 ± 3.21 years; 1.72 ± 0.06 m; 69.49 ± 9.80 kg) performed the following 4 experimental protocols in a randomized order: (a) high-intensity RE at 80% of 1RM (HI), (b) low-intensity RE at 20% of 1RM (LI), (c) low-intensity RE at 20% of 1RM combined with partial BFR (LI + BFR), and (d) control. Analysis of systolic blood pressure (SBP) and diastolic blood pressure (DBP) was conducted over a 60-minute period. The 3 RE protocols resulted in hypotensive SBP (HI = −3.8%, LI = −3.3%, LI + BFR = −5.5%) responses during the 60 minutes ($p \le 0.05$). The LI + BFR protocol promoted hypotensive (−11.5%) responses in DBP during the 60 minutes ($p \le 0.05$), and both the HI and LI + BFR protocols resulted in mean blood pressure (MBP) hypotension between 30 (−7.0%, −7.7%) and 60 minutes (−3.6%, −8.8%), respectively. In conclusion, postexercise hypotension may occur after all 3 exercise protocols with greater reductions in SBP after HI and LI + BFR, in DBP after LI + BFR, and in MBP after HI and LI + BFR protocols.

Key Words hypotension, resistance exercise, KAATSU training, vascular occlusion

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Introduction

Resistance exercise (RE) has been used as a strategy to control and maintain normal blood pressure (BP) levels (8,32). The American Heart Association recommends the RE practice for individuals with coronary disorders because it lowers heart rate and causes lower increases in double product than aerobic exercise of moderate-to-high intensities (24). Additionally, this position suggests that the development and maintenance of strength, endurance, power, and muscle hypertrophy in subjects with heart disease is an essential quality of life factor, acting mainly to reduce and maintain BP levels in this population. Resistance exercise results in an important phenomenon called hypotensive response to exercise, which is characterized by postexercise reductions in systolic blood pressure (SBP) or diastolic blood pressure (DBP) to values below those observed at rest or pre-exercise (13,21). A single RE session results in a hypotensive response that can last up to 24 hours (26). Moreover, recent data suggest that RE can produce a greater hypotensive response than aerobic exercise (20). Although RE has traditionally been used to promote postexercise hypotension (4,5,8,23,32), its effect is not clear (19), and further investigation is necessary.

Low-intensity RE (20–50% 1 repetition maximum [RM]) combined with blood flow restriction (BFR) or KAATSU training has been used for both cardiovascular maintenance and rehabilitation (30,37) and also to promote gains in strength and muscle mass (12,17,25). Research has shown that low-intensity RE with BFR is as effective as training at high intensities (≥80% of 1RM) for strength and muscle mass gains (11,16,36). Several studies have evaluated the acute effects of RE with BFR on SBP, DBP, and/or mean blood pressure (MBP) before and immediately after exercise (7,10,29,37,40). However, only 1 study has evaluated the hypotensive effect of combined RE with BFR in normotensive young subjects (30). Rossow et al. (30) compared the hypotensive effect (at 30- and 60-minute postexercise) of RE for lower limbs under 3 conditions: high intensity (70% 1RM, 3 sets of 10 repetitions, 1-minute rest between sets) without BFR; low-intensity (20% of 1RM, 4 sets, 30 repetitions in the first set, 15 repetitions in 2, 3, and 4 sets, 30-second rest between sets) without BFR; and a low-intensity protocol with BFR (200 mm Hg; 5-cm wide cuff). The authors reported that only the high-intensity protocol promoted significant hypotensive responses after exercise. However, Rossow et al. (30) did not show total work (TW), which could explain their results, and did not include a control condition; additionally, only lower-limb exercises were performed.

No studies have been found examining the hypotensive effects after RE with BFR as part of training programs involving exercises for both upper and lower limbs in an agonist/antagonist order in the same session. Therefore, the aim of this study was to compare the hypotensive effect of RE performed with and without BFR in normotensive young subjects. The study's hypothesis was that the hypotensive effect would occur in both low-intensity RE performed with BFR and high-intensity RE.

Methods

Experimental Approach to the Problem

During the first and second visits to the laboratory, anthropometrics, blood flow restriction, and muscular strength were assessed. After these visits, participants came to the laboratory on 4 more occasions, separated by at least 48 hours, during which they completed one of the following 4 protocols: (a) a high-intensity 80% 1RM resistance exercise (HI), (b) a low-intensity 20% 1RM resistance exercise (LI), (c) a low-intensity 20% 1RM resistance exercise combined with BFR (LI + BFR), and (d) control (CON). All 4 protocols were performed at the same time of the day to control for diurnal variation in BP and heart rate. Immediately before (pre), immediately after, and approximately 10 minutes (post-10), 20 minutes (post-20), 30 minutes (post-30), 40 minutes (post-40), 50 minutes (post-50), and 60 minutes (post-60) after each protocol, BP flow measurements were performed. This study used a randomized crossover design. During the study, the participants were instructed to refrain from exhaustive exercise, as well as avoid caffeine, chocolate, nutritional supplements, and alcohol ingestion for the 24 hours preceding and after the tests and to sleep for a minimum of 6 hours the night before the exercise session. In addition, participants were instructed to maintain the same dietary habits throughout the study period. During all RE sessions, subjects were asked to not perform a Valsalva maneuver.

Subjects

Twenty-four normotensive and recreationally trained men (21.79 ± 3.21 years, 23.40 ± 3.33 $m^2 \cdot kg^{-1}$) between 18 and 30 years old participated in the study. All volunteers showed aged between 18 and 30 years, and all participants signed an informed consent form. The sample dimension analysis was performed using G*Power 3.1 software (6). Based on a priori analysis, we adopted a power of 0.80, $\alpha = 0.05$, correlation coefficient of 0.5, nonsphericity correction of 1, and an effect size (ES) of 0.25. From these values, an *N* of 24 subjects was calculated. The sample size was calculated based on procedures suggested by Beck (3). This a priori statistical power analysis was conducted to reduce the likelihood of committing a type II error and to determine the minimum number of participants needed for this investigation. It was determined that the selected sample size was sufficient to provide a statistical power greater than 81.6%.

Subjects were excluded if they fell in the following categories: (a) smokers, (b) those who had some type of musculoskeletal injury in the upper or lower limbs, and (c) those who responded positively to any of the items on the *Physical Activity Readiness Questionnaire* (PAR-Q) (31). Written informed consent was obtained from all participants after an explanation was given about the aims, risks, and benefits involved in the study. The study was approved by the local Ethics Committee (protocol No. 0476/13) and performed in accordance with the ethical standards of the Declaration of Helsinki.

Procedures

One Repetition Maximum Test. To obtain reliable and reproducible 1RM loads, data were collected during 2 nonconsecutive days using the following bilateral exercise sequence: biceps, triceps, knee extension, and knee flexion (agonist and antagonist). The test protocol followed American College of Sports Medicine recommendations (1), using a standardized 10-minute recovery time between the different exercises in the test. As a warm-up, each individual performed 2 sets of 5–10 repetitions at 40–60% of the individual's perceived maximum strength. After a 1-minute rest period, a second set was completed that consisted of 3–5 repetitions at 60–80% of perceived maximum strength. After another rest period (1 minute), the strength assessments began, during which up to 5 attempts could be made, adjusting the resistance before each new attempt. Recovery duration between the attempts was standardized at 3–5 minutes. The test was interrupted once the participant could not properly complete the movement, and the maximum load was recorded as the load obtained in the last complete execution. The following strategies were adopted to reduce the margin of error in the data collection procedures: (a) standardized instructions were given before the tests such that participants were aware of the entire routine involved, (b) participants were instructed on proper exercise techniques, (c) all subjects received standardized verbal encouragement throughout the tests, and (d) all tests were conducted at the same time of the day for every session. The heaviest load achieved across both days was considered the 1RM.

Assessment of Blood Pressure. Before and after each session, subjects were fitted with an automatic BP monitor (model HEM-705CP 705CP; OMROM) (38). The cuff was placed on the right arm and extended completely around the arm, with the bladder width covering at least two-thirds of the upper arm. This equipment was used for all pre- and post-session BP measurements. All measurements were performed according to the American Heart Association guidelines (22). Mean blood pressure was calculated using the equation (SBP + 2DBP) ÷ 3.

Total Work Exercises. The TW of exercise was obtained by multiplying the sets, repetitions, and load of the 4 exercises (sets × repetitions × load) to examine possible differences between the experimental protocols.

Determination of Blood Flow Restriction. The BFR point was determined using a vascular Doppler probe (MedPej® DV-2001; Ribeirão Preto, São Paulo, Brazil) placed over the radial artery (arms) and tibial artery (legs) to determine the BP (mm Hg) required for vascular occlusion. A standard BP cuff (tourniquet pneumatic komprimeter to hemostasis in the extremities–Riester), for the biceps and triceps (width 60 mm; length 470 mm) and the knee extensors and knee flexors (width 100 mm; length 540 mm) attached to the thigh (auxiliary and inguinal fold region), was inflated until the auscultatory pulse of the radial or tibial artery was interrupted. The cuff pressure used during the training protocols was 80% of the pressure needed for complete BFR in resting conditions (14). Blood flow restriction was deflated between sets. The average pressure used throughout the training protocol was 93.75 ± 12.09 mm Hg in the arms and 108.75 ± 11.53 mm Hg in the legs.

Experimental Sessions. Resistance exercise session included bilateral biceps (biceps curl) and triceps (triceps forehead extension), as well as knee extension and knee flexion exercises, using conventional machines and an agonist and antagonist exercise order. Four protocols were performed: a high-intensity RE at 80% 1RM (HI), a low-intensity RE at 20% 1RM (LI), a low-intensity RE at 20% 1RM combined with BFR, and a CON. Participants performing HI exercises completed 4 sets of 8 repetitions using 80% 1RM with 2-minute rest between sets and 1 minute between exercises. Participants performing LI exercises completed 1 set of 30 repetitions followed by 3 sets of 15 repetitions, using 20% 1RM, with 30-second rest between all sets and 1-minute rest between exercises. When performing the BFR RE session, participants performed the same repetitions, sets, and rest as the LI group while wearing specially designed cuffs (tourniquet pneumatic komprimeter to hemostasis in extremities–Riester) attached to the most proximal portion of the arms (width 60 mm; length 470 mm) and legs (width 100 mm; length 540 mm). Cuff pressure was maintained throughout the exercise except for a 30-second deflation performed during the rest period between sets. The purpose of this deflation was to improve participant comfort, and because of its brevity and performance during a rest period, it was not expected to greatly influence stimulus response. The

Table 1. Inferential analysis in systolic blood pressure among the study protocols.*

	Systolic blood pressure (mm Hg)						
Protocols	Rest	10 min	20 min	30 min	40 min	50 min	60 min
HI	120.6 ± 10.0	119.9 ± 10.6	113.5 ± 10.3†	114.4 ± 12.6†	113.9 ± 11.8†	114.2 ± 10.7†	115.9 ± 11.5†
LI	118.81 ± 5.8	119.2 ± 10.9	114.6 ± 9.9	113.5 ± 9.5†	113.0 ± 10.9†	114.0 ± 9.9†	114.2 ± 8.5†
LI + BFR	119.9 ± 8.9	118.0 ± 10.6	116.1 ± 11.6	113.5 ± 12.2†	116.5 ± 8.7	114.0 ± 10.3†	113.3 ± 11.1†
CON	115.1 ± 9.2	116.8 ± 8.9	114.7 ± 9.2	117.3 ± 8.1	118.7 ± 10.3	118.1 ± 7.2	119.1 ± 9.5†

*HI = high-intensity protocol; LI = low-intensity protocol; LI + BFR = low intensity with blood flow restriction protocol; CON = control protocol.
†Significant difference compared with rest.

duration of each repetition cycle was established at 4 seconds (2 seconds for the concentric and 2 seconds for the eccentric muscle action) controlled using a metronome (WMT-30C, Metro-Tuner; Tagima, Tokyo, Japan). In the CON conditions, participants remained seated for 30 minutes, which was the average duration of the experimental protocols.

Statistical Analyses

Statistical analysis was initially performed using the Shapiro-Wilk normality test and the homoscedasticity test (Bartlett criterion). To test the reproducibility of the 1RM load between test and retest, we used the intraclass correlation coefficient. The variables showed normal distribution and homoscedasticity ($p > 0.05$). Repeated-measures analysis of variance followed by Bonferroni post hoc tests was used to analyze possible differences in the dependent variables. Effect size was used to determine the change of magnitude (Mag) between study protocol evaluations (28), and percentage variation (Δ%) was used to express possible differences between the significant changes. The level of significance was set at $p \leq 0.05$. All statistical analyses were performed using SPSS statistical software package version 20.0 (SPSS, Inc., Chicago, IL, USA).

Results

The 1RM intraclass correlation coefficient for each exercise was as follows: biceps curl = 0.990, triceps extension = 0.988, knee extension = 0.996, and knee flexion = 0.995. In the comparative analysis of SBP, we observed no significant differences among the protocols ($p > 0.05$). With respect to SBP over time, there were significant reductions in the HI protocol between rest vs. 20 minutes, rest vs. 30 minutes, rest vs. 40 minutes, rest vs. 50 minutes, rest vs. 60 minutes ($p = 0.001$, Δ = −5.8%; ES = 0.71/Mag: small; $p = 0.003$, Δ = −5.1%; ES = 0.62/Mag: small; $p = 0.003$, Δ = −5.5%; ES = 0.67/Mag: small; $p = 0.001$, Δ = −5.3%; ES = 0.64/Mag: small; $p = 0.020$, Δ = −3.8%; ES = 0.47/Mag: small), respectively. For the LI protocol, there were significant reductions between rest vs. 30 minutes, rest vs. 40 minutes, rest vs. 50 minutes, rest vs. 60 minutes ($p = 0.023$, Δ = −3.8%; ES = 0.79/Mag: small; $p = 0.019$, Δ = −4.3%; ES = 0.87/Mag: moderate; $p = 0.034$, Δ = −0.4%; ES = 0.70/Mag: small; $p = 0.048$, Δ = −3.3%; ES = 0.67/Mag: small), respectively. For the LI + BFR protocol, significant differences were found between rest vs. 30 minutes, rest vs. 50 minutes, and rest vs. 60 minutes ($p = 0.002$, Δ = −5.3%; ES = 0.71/Mag: small; $p = 0.003$, Δ = −4.9%; ES = 0.66/Mag: small; $p = 0.001$, Δ = −5.5%, ES = 0.74/Mag: small, respectively). We also observed a significant increase in the CON protocol between rest vs. 60 minutes ($p = 0.048$) (Table 1).

In the comparative analysis of DBP, significant differences were found among HI vs. CON, LI vs. CON, and LI + BFR vs. CON ($p = 0.002$, 0.004, and 0.002, respectively) at both 20 and 40 minutes ($p = 0.034$, 0.009, and 0.012, respectively). There were significant differences between HI vs. CON and LI + BFR vs. CON ($p = 0.041$ and 0.016, respectively) at 50 minutes and between LI + BFR vs. CON ($p = 0.004$) at 60 minutes. During the HI protocol, significant reductions in DBP were observed between rest vs. 20 minutes, rest vs. 30 minutes, rest vs. 40 minutes, and rest vs. 50 minutes ($p = 0.001$, Δ = −12.6%; ES = 1.12/Mag: moderate; $p = 0.003$, Δ = −8.8%; ES = 0.79/Mag: small; $p = 0.007$, Δ = −8.3%; ES = 0.74/Mag: small; $p = 0.006$, Δ = −8.4%; ES = 0.75/Mag: small, respectively). For the LI protocol, there was a significant reduction in DBP between rest vs. 20 minutes ($p = 0.016$, Δ = −6.9%; ES = 0.74/Mag: small). For the LI + BFR protocol, significant differences in DBP were found between rest vs. 10 minutes, rest vs. 20 minutes, rest vs. 30 minutes, rest vs. 40 minutes, rest vs. 50 minutes, and rest vs. 60 minutes ($p = 0.009$, Δ = −9.9%; ES = 0.73/Mag: small; $p = 0.001$, Δ = −14.5%; ES = 1.08/Mag: moderate; $p = 0.001$, Δ = −9.6%, ES = 0.71/Mag: small; $p = 0.001$, Δ = −11.4%; ES = 0.84/Mag: moderate; $p = 0.001$, Δ = −11.4%; ES = 0.84/Mag: moderate; $p = 0.001$, Δ = −11.5%; ES = 0.85/Mag: moderate, respectively), as shown in Table 2.

In the comparative analysis of MBP, significant differences were found among HI vs. CON, LI vs. CON, and LI + BFR

Table 2. Inferential analysis of diastolic blood pressure between the study protocols.

	Diastolic blood pressure (mm Hg)						
Protocols	Rest	10 min	20 min	30 min	40 min	50 min	60 min
HI	72.1 ± 8.1	66.8 ± 13.4	63.0 ± 7.3*†	65.7 ± 8.3†	66.1 ± 8.3*†	66.0 ± 7.2*†	69.5 ± 7.0
LI	68.1 ± 6.3	64.1 ± 15.3	63.4 ± 7.4*†	66.3 ± 8.8	64.7 ± 8.3*	67.0 ± 10.8	67.5 ± 11.1
LI + BFR	73.4 ± 9.9	66.1 ± 11.0†	62.7 ± 10.6*†	66.3 ± 13.2†	65.0 ± 11.8*†	65.0 ± 9.2*†	64.9 ± 9.2*†
CON	69.9 ± 7.8	69.8 ± 7.4	70.3 ± 6.3	71.0 ± 8.1	72.0 ± 9.0	71.4 ± 8.1	72.4 ± 7.7

*HI vs. CON, LI vs. CON, LI + BFR vs. CON; HI = high-intensity protocol; LI = low-intensity protocol; LI + BFR = low intensity with blood flow restriction protocol; CON = control protocol.
†Significant difference compared with rest.

Table 3. Inferential analysis of mean blood pressure between the study protocols.

	Mean blood pressure (mm Hg)			
Protocols	Rest	Post	30 min	60 min
HI	88.2 ± 7.7	92.6 ± 9.0*†	82.0 ± 8†	85.0 ± 8.1†
LI	84.8 ± 5.4	90.9 ± 8.3*†	82.0 ± 7.8	83.0 ± 9.5*
LI + BFR	88.9 ± 8.7	91.7 ± 11.7*	82.0 ± 11.8†	81.0 ± 8.2*†
CON	85.0 ± 7.4	84.0 ± 6.3	86.4 ± 7.2	88.0 ± 7.4

*HI vs. CON, LI vs. CON, LI + BFR vs. CON; Post = postexercise; HI = high-intensity protocol; LI = low-intensity protocol; LI + BFR = low intensity with blood flow restriction protocol; CON = control protocol.

†Significant difference compared with rest.

vs. CON ($p = 0.001$, 0.010, and 0.004, respectively) postexercise and between LI vs. CON and LI + BFR vs. CON ($p =$ 0.045 and 0.005, respectively) at 60 minutes. During the HI exercise protocol, a significant increase in MBP was observed between rest vs. postexercise ($p = 0.039$, $\Delta =$ 4.9%; ES = 0.57/Mag: small), and a significant reduction was observed between rest vs. 30 minutes and rest vs. 60 minutes ($p = 0.001$, $\Delta = -7.0\%$; ES = 0.80/Mag: moderate; $p =$ 0.040, $\Delta = -3.6\%$; ES = 0.41/Mag: small, respectively). For the LI protocol, a significant increase in MBP was observed between rest vs. postexercise ($p = 0.004$, $\Delta = 7.1\%$; ES = 1.12/Mag: moderate). For the LI + BFR protocol, there were significant reductions in MBP between rest vs. 30 minutes and rest vs. 60 minutes ($p = 0.001$, $\Delta = -7.7\%$; ES = 0.79/Mag: small; $p = 0.001$, $\Delta = -8.8\%$; ES = 0.90/Mag: moderate, respectively), as shown in Table 3.

Figure 1 shows comparative analysis of TW; we observed a significant difference between HI vs. LI and HI vs. LI + BFR ($p = 0.001$).

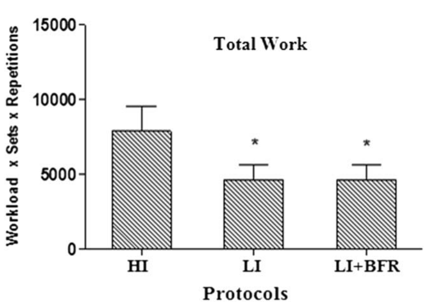

Figure 1. Inferential analysis of the total work for the exercises between the study protocols. HI = high-intensity protocol; LI = low-intensity protocol; LI + BFR = low intensity with blood flow restriction protocol. *Significant difference in total work between the protocols.

Discussion

This study analyzed the hypotensive effects of RE performed with and without BFR in normotensive men. To the authors' knowledge, this is the first work presenting postexercise BP response with and without BFR in an exercise session working both upper and lower limbs (agonist/antagonist). The major finding of this study was that all exercise programs resulted in a significant hypotensive effect with respect to SBP, though there were no significant differences between the various programs. The high-intensity protocol produced a faster hypotensive response, which occurred between 20 and 60 minutes after exercise. This can be explained by the TW being significantly higher during HI exercise compared with other protocols. This result is consistent with literature suggesting that increased TW training is essential to induce a hypotensive effect after RE (18,32).

Several studies have observed the hypotensive response to traditional RE training (4,5,8,23,32), although results have been conflicting (19). The hypotensive response seems to occur in exercises with higher intensities (33); however, even at low intensity (20% of 1RM), this study revealed a significant reduction in SBP both with and without BFR. This may have occurred because of an increase in nitric oxide synthase, which is an enzyme responsible for the conversion of L-arginine into nitric oxide and a small electrically neutral molecule that is able to move easily through the tissue and promote positive changes in the endothelium (2,39). As in this study, Rossow et al. (30) showed similar results at high intensities. The authors compared the hypotensive effect of RE with and without lower-limb BFR and concluded that only high-intensity exercise promoted significant hypotensive responses in SBP after 60 minutes. However, Rossow et al. (30) did not control the TW, which may explain the SBP reduction reported while RE was limited only to the lower limbs. It seems that performing exercises working the upper and lower limbs in the same session can promote greater hypotensive effects than those observed when performing exercises in only 1 segment, and this effect may be associated with the amount of muscle mass involved (4,15). In addition, Rossow et al. (30) speculated that the LI + BFR protocol did not result in a hypotensive response because the stimulus was insufficient (20% of 1RM) and suggested that the accumulation of metabolites occurs only at intensities above 30% of 1RM (34). However, other studies have reported that intensities as low as 20% of 1RM are enough to elevate metabolite levels (9,35).

Another important finding of this study was that the low-intensity BFR protocol promoted a faster and longer-lasting hypotensive DBP response. Protocols for HI and LI + BFR showed significant reductions in MBP at 30 and 60 minutes. However, the LI + BFR protocol did not result in increased MBP after exercise, which is an important finding because a hypotensive response has been previously observed. In contrast, Renzi et al. (27) analyzed the effects of BFR while walking on cardiovascular function in healthy individuals, and observed large magnitude increases in SBP, DBP, and MBP compared with controls. Additionally, Kacin and Strazer (10) analyzed the effects of knee extension RE with and without BFR on cardiovascular response and found that both conditions (with and without BFR) increased SBP, DBP, and MBP. Based on these studies, it seems the type of exercise (walking vs. knee extension) and level of exertion (submaximal exertion vs. repetition to failure) can determine the BP increase when performed with BFR. The results of this study provide important information on hemodynamic responses, unlike others previously presented, because our findings suggest positive effects on SBP, DBP, and MBP after RE with BFR. The venous return decrease promoted by RE performed with BFR reduces cardiac preload during exercise, which may be an excellent strategy for treating people affected by vascular diseases (37). Thus, postexercise hypotensive response seems to occur after the completion of the 3 protocols (HI, LI, LI + BFR) with a larger effect on SBP after high-intensity exercise, and the hypotensive effect on DBP and MBP seems to occur only in response to HI and LI protocols combined with BFR.

Practical Applications

In conclusion, both HI and the LI + BFR exercise can be used to maximize the hypotensive effect associated with RE. Additionally, the LI + BFR protocol can be used to improve DBP and MBP. It is recommended that physical education professionals use the protocols HI and LI + BFR as a non-drug intervention for controlling BP in novice, older people hypertensive, and sedentary subjects. Future studies are required to analyze the acute and chronic hypotensive effects of exercise with BFR, particularly those including different subjects and different exercise protocols with BFR at different intensities.

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