



Acute Effect of Resistance Exercises Performed by the Upper and Lower Limbs with Blood Flow Restriction on Hemodynamic Responses

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ABSTRACT

Vilaça-Alves J, Neto GR, Morgado NM, Saavedra F, Lemos, R, Moreira TR, Novaes JS, Rosa C, Reis VM. Acute Effect of Performed Upper and Lower Limbs Resistance Exercises with Blood Flow Restriction on Hemodynamics. **JEPonline** 2016;19(3):100-109. The purpose of this study was to compare the effects of resistance exercises (RE) performed by the upper and lower limbs with and without blood flow restriction (BFR) on systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), and double product (DP). Twelve recreationally trained men randomly performed four experimental protocols: (a) RE at 70% of 1RM for lower limbs (HILL); (b) RE at 70% of 1RM for upper limbs (HIUL); (c) RE at 20% of 1RM with BFR for lower limbs (LI+BFRLL); and (d) RE at 20% of 1RM with BFR for upper limbs (LI+BFRUL). Hemodynamic responses were measured before, immediately after, 15, 30, and 60 min post-exercise. The values of SBP, HR, and DP were higher immediately after exercise when compared with any other measure in every protocol ($P < 0.05$). No significant reductions were found in SBP, DBP, HR, and DP post-exercise ($P > 0.05$) and no significant differences were found between lower and upper body exercises in SBP, HR, and DP

($P > 0.05$). In conclusion, the protocols with and without the BFR performed on the upper and lower limbs increased hemodynamic measures immediately after exercise, but did not decrease the hemodynamic measures after exercise.

Keywords: Strength Training, Vascular Occlusion, Kaatsu, Blood Pressure

INTRODUCTION

The American College of Sports Medicine recommends performing resistance exercise (RE) with intensity equal to or higher than 65% of 1 repetition maximum (1RM) to promote gains in strength and hypertrophy (3). It was believed that any activity below this intensity rarely produced significant strength gains or muscle hypertrophy. However, an alternative RE technique using low loads with blood flow restriction (BFR) has been used to increase strength (12,24,27), muscle mass (12,24), muscular endurance (9,11), and functional capacity (4). This technique consists of using low loads (20 to 50% of 1RM) with BFR applied by the use of a cuff (12) or elastic knee wraps (14) in the upper and lower limbs. Scientific evidence has shown that gains in strength and hypertrophy with BFR are equivalent to those when training at intensities $\geq 80\%$ of 1RM (12).

Some studies have evaluated the acute effect of RE with BFR on the systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), and double product (DP) (7,10,11,19-22,25,29,30), and hypotensive responses (5,16,18,20). However, there is still no consensus in the literature about the impact of this kind of intervention in hemodynamic responses after RE with BFR. In addition, we found no study that compared the hypotensive responses of the upper and lower limbs as a result of RE performed with BFR. However, it is necessary to conduct studies in healthy populations (e.g., youth, adults) with safe procedures and methods appropriate for later use and extrapolated in special populations.

Therefore, the purpose of this study was to compare the effects of RE performed in the upper and lower limbs with and without BFR on the SBP, DBP, HR, and DP of normotensive men. The first hypothesis of this study was that the hypotensive response occurs in RE of low intensity performed with BFR similar to that in high intensity performed without BFR. The second hypothesis was that acute hemodynamic effects promoted by RE exercises of the lower limbs would be greater when compared with the upper limbs.

METHODS

Subjects

Twelve normotensive and recreationally trained men (age, 22.92 ± 1.96 yrs; height, 175.17 ± 4.63 cm; body weight, 72.43 ± 4.60 kg; % body fat, $7.77 \pm 2.58\%$) participated in the study. The sample dimension analysis was performed using G*Power 3.1 software (8). 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 0.36. From these values, an N of 12 subjects was calculated. It was determined that the selected sample size was sufficient to provide a statistical power greater than 80.5%. The sample size was calculated based on procedures suggested by Beck (6). Subjects excluded from the study were: (a) smokers; (b) those who had some type of musculoskeletal medical condition of the upper and/or lower limbs; and (c) those who responded positively to any of the items of the Physical Activity Readiness Questionnaire / PAR-Q (26). The procedures were carried out in accordance with the guidelines of the Declaration of Helsinki on human experimentation, and this research project was

approved by the University Ethics Committee (Protocol no 0476/13). The subjects provided written informed consent after having the risks and benefits explained to them.

Study Design

We assessed the anthropometrics, muscle strength (test-retest of 1RM) and the pressure of the tourniquets for the BFR condition during the 1st and 2nd visits to the laboratory. After these visits, the subjects attended the laboratory on four occasions (separated 7 d from each other) to randomly perform four experimental protocols in a crossover model, as follows: (a) RE at 70% of 1RM for lower limbs (HILL); (b) RE at 70% of 1RM for upper limbs (HIUL); (c) RE at 20% of 1RM with BFR for lower limbs (LI+BFRLL); and (d) RE at 20% of 1RM with BFR for upper limbs (LI+BFRUL). All four protocols were performed at the same time of day to control for the circadian variation in blood pressure and heart rate. The measurements of SBP, DBP, HR and DP were performed before (pre), immediately after 15 min (post-15), 30 min (post-30) and 60 min (post-60) post every protocol. The subjects were tested >2 hr post-prandial, and were instructed to avoid ingestion of caffeine, chocolate or medications, and exercise in the preceding days. During all sessions of the RE, the subjects were instructed not to perform the Valsalva maneuver.

Procedures

One Repetition Maximum Testing (1RM)

To obtain reliable 1RM loads, data were assessed during two non-consecutive days following the bilateral exercise sequence: arm curl; arm extension; knee extension; and knee flexion. The test protocol followed the American College of Sports Medicine recommendations (2), using a standardized 10-min recovery time for the different exercises in the test. As a warm-up, each subject performed 2 sets of 5 to 10 repetitions at 40 to 60% of the subject's perceived maximum strength. After a 1-min rest period, a second set was completed consisting of 3 and 5 repetitions at 60 to 80% of the subject's perceived maximum strength. After another rest period (1 min), the strength assessments began, during which up to 5 attempts could be performed, with adjustment of the resistance before each new attempt. The recovery duration between the attempts was standardized at 3 to 5 min. The test was interrupted once the subject could not properly complete the movement from which the maximum load was recorded as the load obtained in the last complete execution. The heaviest load achieved across both days was considered the 1RM.

Determination of Blood Flow Restriction

The pressure used during exercise was 180 mmHg on the upper limbs and 220 mmHg on the lower limbs. A standard blood pressure cuff was used 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 (axillary and inguinal fold region). Prior to the application of pressure training, the subjects underwent an adaptation process to the BFR (1).

Measurement of Hemodynamic Variables

Before and after each session, the measurement of blood pressure was made by the same examiner in every subject with a cuff (RiesterRi-san®, Jungingen, Germany) and a stethoscope (Spain Care KT-118, Valencia, Spain). The cuff was placed on the right arm and wrapped to completely cover at least two thirds of the upper arm. All measurements were performed according to the guidelines of the American Heart Association (23). Heart rate (HR) was continuously monitored before and after the session by an FT80™ monitor (Polar Electro Oy, FIN-90440 KEMPELE, Finland) that transmitted it to a computer through Flow Link™ using the software Web Sync. Double product was obtained by multiplying HR (beats·min⁻¹) x SBP (mmHg).

Experimental Sessions

Four exercises were used: (a) arm curl (Dumbbells Base 1MB2-1MB10, Pannatta Sport, Italy); (b) arm extension (4-Station Multi Gym XP LUX / 1XPL112, Pannatta Sport, Italy); (c) knee extension (Leg Extension XP LUX / 1XPL081, Pannatta Sport, Italy); and (d) knee flexion (Leg Curling XP LUX / 1XPL082, Pannatta Sport, Italy). Four protocols were performed: (a) two exercises at 70% of 1RM for lower limbs (HILL); (b) two exercises at 70% of 1RM for upper limbs (HIUL); (c) two exercises at 20% of 1RM with BFR for lower limbs (LI+BFRLL); and (d) two exercises at 20% of 1RM with BFR for upper limbs (LI+BFRUL). In the protocols at high intensity the subjects completed 3 sets of 10 repetitions with 70% of 1RM with 90 sec rest between sets and 60 sec between exercises. In the protocols at low intensity with BFR, the subjects completed 1 set of 30 repetitions followed by 3 sets of 15 repetitions using 20% of 1RM with 30 sec of rest between sets and 60 sec between exercises. The cuff pressure was maintained throughout the session except for 30 sec of rest between sets and the 60 sec between exercises. The execution speed was 60 beats·min⁻¹ (1 sec concentric and 1 sec eccentric muscle action) controlled by a metronome (Korg MA-30, NY, EUA).

Statistical Analyses

To assess the reproducibility of the load between the test and the retest of 1RM, the intraclass correlation coefficient (ICC) was used. For comparisons, a repeated measures analysis of variance (ANOVA) was carried out using a model of 5 times (rest, immediately after, 15 min after, 30 min after, and 60 min after) x 2 training methods (high intensity without BFR and low intensity with BFR) x 2 body segments (lower and upper limbs). Bonferroni *post hoc* test was used to identify differences between moments, training methods, and body segments. All data were tested for assumptions of normality, homogeneity, and sphericity. Statistical significance was set at $P < 0.05$.

RESULTS

The intraclass correlation coefficients of the 1RM test for each exercise were: (a) arm flexion = 0.97; (b) arm extension = 0.91; (c) knee extension = 0.93; and (d) knee flexion = 0.93. No interaction between time x training method, time x body segment and time x training method x body segment was observed in any variable ($P > 0.05$). There was a significant effect time for SBP ($P < 0.0001$; $\mu_p^2 = 0.755$), whereby it had increased immediately post compared with baseline and all other post-exercise time points. The same comportment was observed in both methodologies used (HIRE and LI + BFR) and in the lower and upper limbs when analyzed individually (Table 1).

Table 1. Analysis of SBP between Protocols of Exercise and Body Segments.

SBP (mmHg)	HIRE		LI+BFR	
	Lower Limbs	Upper Limbs	Lower Limbs	Upper Limbs
Rest	110.50 ± 6.27	109.50 ± 9.19	110.83 ± 5.62	109.33 ± 7.05
Immediately after	130.75 ± 12.22*	131.92 ± 13.67*	129.50 ± 12.54*	132.67 ± 7.05*
15 min after	111.33 ± 10.66	111.17 ± 11.83	113.50 ± 11.73	110.33 ± 9.57
30 min after	108.33 ± 8.56	106.75 ± 10.23	108.00 ± 9.53	106.33 ± 9.22
60 min after	109.00 ± 8.20	108.33 ± 9.30	111.00 ± 9.17	110.08 ± 7.19

*Significant differences between the moment immediately after and all moments; BFR = blood flow restriction; SBP = systolic blood pressure (mmHg); HIRE = resistance exercises performed with high intensity load; LI+BFR = resistance exercises performed with low load and blood flow restriction

As to DBP there was a significant time effect ($P < 0.017$; $\mu_p^2 = 0.066$), but with a lower effect size (Table 2). The subjects' immediate post-exercise DBP in the lower limbs was always lower ($P < 0.05$) when compared to the resting and 60 min after measurements. There was also a significant time effect ($P < 0.0001$; $\mu_p^2 = 0.903$) in HR with an increase in the time immediately post compared with baseline and with higher values than all post exercise time points ($P < 0.05$). The same comportment was observed in both methodologies used and body segments when analyzed individually (Table 3).

Table 2. Analysis of DBP between Protocols of Exercise and Body Segments.

DBP (mmHg)	HIRE		LI+BFR	
	Lower Limbs	Upper Limbs	Lower Limbs	Upper Limbs
Rest	60.67 ± 8.94	64.67 ± 9.28	60.67 ± 11.23	63.17 ± 8.76
Immediately after	46.50 ± 15.09*	62.70 ± 19.48	53.00 ± 12.66*	62.50 ± 15.33
15 min after	60.17 ± 5.69	66.50 ± 11.79	62.17 ± 7.71	66.83 ± 8.96
30 min after	62.50 ± 4.91	66.83 ± 10.60	63.67 ± 9.98	65.00 ± 4.94
60 min after	62.17 ± 6.95	66.08 ± 11.54	66.33 ± 8.81	67.17 ± 6.58

*Significant differences between immediately after exercise and rest and 60 min after moments; BFR = blood flow restriction; DBP = diastolic blood pressure (mmHg); HIRE = resistance exercises performed with high intensity load; LI+BFR = resistance exercises performed with low load and blood flow restriction

Table 3. Analysis of HR between Protocols of Exercise and Body Segments.

HR (beats·min ⁻¹)	HIRE		LI+BFR	
	Lower Limbs	Upper Limbs	Lower Limbs	Upper Limbs
Rest	73.17 ± 8.42	70.67 ± 7.73	76.08 ± 8.11	70.58 ± 7.90
Immediately after	136.33 ± 18.90*	140.17 ± 19.70*	132.83 ± 17.87*	133.00 ± 18.46*
15 min after	83.41 ± 9.39	76.83 ± 8.98	83.33 ± 8.76	76.08 ± 11.25
30 min after	75.58 ± 9.81	71.96 ± 9.57	76.25 ± 10.70	72.08 ± 11.07
60 min after	66.33 ± 7.99	63.88 ± 8.00	67.33 ± 8.63	64.00 ± 8.36

*Significant differences between the moment immediately after and all moments; BFR = blood flow restriction; HR = heart rate (beats·min⁻¹); HIRE = resistance exercises performed with high intensity load; LI+BFR = resistance exercises performed with low load and blood flow restriction

A significant time effect was observed for the subjects' DP ($P < 0.0001$; $\mu_p^2 = 0.908$). The DP values were higher immediately after exercise irrespective of the blood restriction or the exercise that was performed ($P < 0.05$). The same comportment was observed in both methodologies used and body segments when analyzed individually (Table 4).

Table 4. Analysis of DP between Protocols of Exercise and Body Segments.

DP	HIRE		LI+BFR	
	Lower Limbs	Upper Limbs	Lower Limbs	Upper Limbs
Rest	8079.67 ± 979.75	7771.50 ± 1338.20	8433.67 ± 987.63	7729.17 ± 1075.01
Immediately after	17924.17 ± 3559.59*	18527.08 ± 3511.35*	17226.17 ± 3669.99*	17662.50 ± 2771.13*
15 min after	9251.83 ± 1278.05	8560.00 ± 803.45	9465.50 ± 1469.69	8396.83 ± 1458.65
30 min after	8165.67 ± 1098.60	7636.00 ± 840.05	8233.33 ± 1334.40	7908.83 ± 1306.35
60 min after	7208.83 ± 820.72	6961.75 ± 918.11	7460.67 ± 1030.64	7044.33 ± 1017.09

*Significant differences between the moment immediately after and all moments; BFR = blood flow restriction; DP = double product; HIRE = resistance exercises performed with high intensity load; LI+BFR = resistance exercises performed with low load and blood flow restriction

DISCUSSION

The present study analyzed the acute effects of RE performed in the upper and lower limbs with and without BFR on the SBP, DBP, HR, and DP of normotensive men. Therefore, the main finding of our study was that the values of SBP, HR, and DP were higher immediately after exercise irrespective of the blood restriction or the exercise that was performed. Also, there were no hypotensive responses after any exercise condition and no differences were observed between the body segments.

The results of the present study corroborate previous observations by Hollander et al. (10), Takano et al. (29), and Vieira et al. (30). Takano et al. (29) assessed HR, SBP, DBP, and MBP after the volunteers performed bilateral knee extension at 20% of 1RM with and without BFR. Each subject performed 4 sets (30 repetitions in the first set and 3 sets to exhaustion with 20 sec of rest between sets). The authors observed a significant increase in HR, SBP, DBP, and MBP in the protocol with the BFR compared without BFR. Vieira et al. (30) also compared RE with and without BFR and its effects on HR, SBP, DBP, and MBP in young and elderly men performing a single set of up to 3 min of unilateral elbow flexion at 30% of 1RM. They also observed a significant increase in HR, SBP, DBP, and MBP in exercise performed with BFR when compared without BFR.

Analyzing the results of the present study in light of the two studies just mentioned, it appears fairly conclusive that even with low intensity the BFR promotes increased hemodynamic responses. Furthermore, it seems that significant differences between the body segments do not exist (upper vs. lower), even when the volume of work was higher for lower limbs. The increase in hemodynamic with BFR can be explained by increased peripheral resistance of blood vessels (15). With the aim of comparing different intensities (low vs. high) on the hemodynamic measures, Hollander et al. (10) studied seven men who underwent two protocols with and without BFR unilateral exercises biceps curls and calf extensions with a speed of 1 rep·sec⁻¹ and 5 min rest between exercises. They used intensities of 30% and 70% of 1RM. In both protocols the subjects performed 3 sets to exhaustion with 60 sec rest between sets. In the low intensity BFR training, a cuff was used (width unknown) with a pressure less than 20 mmHg of SBP at rest for the upper limbs and more than 20 mmHg of SBP at rest for the lower limbs. The authors observed no significant differences between the two exercise protocols.

Notwithstanding these findings and those in the present study, Okuno et al. (22) observed that high intensity RE significantly increased the HR compared with low intensity without BFR and low intensity with BFR. These authors submitted nine men to two protocols without BFR performing unilateral exercise in horizontal leg press (speed unknown) at 40% and at 80% of 1RM. The volunteers were also submitted to a BFR protocol at 40% of 1RM, a 14.0 cm wide cuff and pressure of 100 mmHg were used. The fact that the latter study studied a unilateral movement exercise may help to explain the different results as compared with those in the present study (bilateral movement). In addition, other variables such as the number of joints involved in the movement or the volume of work may have also accounted for the different observations.

The study performed by Rossow et al. (25) was the first to evaluate the post-exercise hypotension with BFR. The results of that study agree in part with our findings. The authors compared the hypotensive effect and HR (30 and 60 min post-exercise) after application of lower limbs RE with three protocols: high intensity (70% of 1RM; 3 sets of 10 repetitions; 60 sec rest between the sets) without BFR; low intensity (20% of 1RM; 4 sets; 30 repetitions in first set; 15 repetitions in 2nd, 3rd, and 4th sets; 30 sec of rest between sets) without BFR; and one protocol of low intensity with application of BFR (200 mmHg; 5 cm wide cuff). The authors observed no significant differences between the exercise conditions in SBP, DBP, and MBP. However the protocol of high intensity promoted significant hypotensive responses after exercise. The explanation of the reduction of BP within 60 min can be due to training volume and muscle area involved, because the study of Rossow et al. (25) used only exercises involving lower limbs. This is in line with the literature that suggests that a high volume of work (17,28) and muscle area involved (13) are essential for the hypotensive effect occurring after RE.

In addition, Brandner et al. (7) investigated the hemodynamics of two common BFR exercise methods and two traditional resistance exercises. Twelve young males completed four unilateral elbow flexion exercise trials in a balanced, randomized crossover design: (a) heavy load [HL; 80% one-repetition maximum (1-RM)]; (b) light load (LL; 20% 1-RM); and two other light-load trials with BFR applied (c) continuously at 80% resting SBP (BFR-C) or (d) intermittently at 130% resting SBP (BFR-I). Hemodynamics were measured at baseline, during exercise, and for 60 min post-exercise. Exercising HR, SBP, and DP were significantly greater for HL and BFR-I compared with LL. The magnitude of hemodynamic stress for BFR-C was between that of HL and LL. These data show reduced hemodynamics for continuous low-pressure BFR exercise compared with intermittent high-pressure BFR in young healthy populations. BFR remains a potentially viable method to improve muscle mass and strength in special/clinical populations.

Different conclusions were drawn by Neto et al. (20) in a study that compared the hypotensive effects post-exercise in RE performed with four protocols: (a) high intensity (80% of 1RM; 4 sets of 8 repetitions; 120 sec rest between sets) without BFR; (b) low intensity (20% of 1RM; 4 sets; 30 repetitions in 1st set; 15 repetitions in 2nd, 3rd, and 4th sets; 30 sec rest between sets) without BFR; (c) low intensity with BFR (arms = 93.75 ± 12.09 mmHg and legs = 108.75 ± 11.53 mmHg; and (d) a control protocol. The authors concluded that the post-exercise hypotension may occur after all 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. Araújo et al. (5) present another report with different results compared to those in the present study. They found post-exercise hypotension in hypertensive subjects after RE performed at 30% of 1RM with continuous BFR (3 sets of 15 repetitions with 45 sec recovery between sets).

Overall the studies seem to indicate that the post-exercise hypotension is more likely to occur with RE for upper and lower limbs combined with BFR, or with hypertensive subjects. Maior et al. (16) and

Moriggi et al. (18) also they found a hypotensive effect. But, Maior et al. (16) utilized a percentage of higher load than the other studies (40% 1RM) in the upper limbs and Mariggi et al. (18) used a training session just for upper limbs. The hypotensive effect may have occurred because both studies used a high training volume. Furthermore, the hypotensive effect seems to occur when using intermittent BFR (18,20).

CONCLUSION

The protocols with and without the BFR performed with the upper and lower limbs increased the subjects' hemodynamic measures immediately after exercise, but did not decrease the hemodynamic measurements after exercise. Therefore, it is important to conduct further experiments that can address both acute and chronic hypotensive responses, particularly involving different BFR pressures and different cuff sizes among normotensive and hypertensive subjects comparing upper and lower limbs.

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We have nothing to declare.

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