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Original Article

Acute cardiovascular responses to resistance training with and without blood flow restriction in healthy individuals

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Abstract
Introduction: Blood flow restriction exercise has proven to be an effective training method to promote neuromuscular adaptations, however, a consensus about the effect on other physiological and safety variables, such as cardiovascular responses, has yet to be reached. **Purpose:** The aim of this study was to compare the acute cardiovascular responses during and after three different resistance training protocols. **Material & methods**: Fifty-two participants (27.3±7 years; 177.6±11 cm; 72.2±13.7 kg) were randomly allocated into three groups: low-intensity exercise without (LI, n=13) and with blood flow restriction (LI-BFR, n=24), and high-intensity exercise (HI, n=15). Participants from LI and LI-BFR groups performed four sets (1x30 + 3x15 reps) at 30% 1RM, while HI group performed four sets (1x30 with 30% 1RM + 3x10 reps with 75% 1RM) of dominant-side plantar flexion exercise. For LI-BFR group, a cuff was placed under popliteal region and inflated at 30% of the individual´s occlusion pressure (47.6 ± 19.8 mmHg). **Results:** Blood pressure (BP), heart rate (HR) and oxygen saturation (SpO_2) were assessed at baseline, after each set and post-exercise. HR increases significantly during exercise across all protocols, with greater increases for HI group after 4^{th} set ($p<0.001$; G=1.072) but without differences between groups. HI and LI-BFR protocols showed higher significant post-exercise hypotension and greater reduction in MAP ($p<0.05$) than LI group. RPP during exercise was different from HI to LI and LI-BFR ($p<0.05$). HI protocol reduced SpO2 during all sets of exercise ($p<0.05$). **Conclusions:** The results of this study indicate that LI-BFR promotes similar hypotensive response to HI, with equal or lower cardiovascular responses during exercise than traditional resistance training.
Key words: **Low-load exercise, occlusion training, hemodynamics responses, blood pressure, hypotension.**

Introduction

High-intensity resistance training (HI-RT) (70-85% 1RM) is widely recommended to achieve increases in muscle mass and strength (Krzysztofik et al., 2019). However, this training method may be inappropriate and even contraindicated for several populations (e.g., elderly, injured). In this sense, the use of low-intensity resistance training associated with blood flow restriction (LI-BFR) is presented as an effective alternative, due to low-loads used (Lixandrão et al., 2018). LI-BFR includes the application of an inflatable cuff to the most proximal portion of a limb, promoting a highly metabolic environment.

Despite the effectiveness of both training methods on muscle adaptations, a consensus about the effect on other physiological and safety variables, such as cardiovascular responses, has yet to be reached. The cardiovascular system responds to different types of training according to the exercise design (load, sets, repetitions, and muscle mass involved) (McCartney, 1999). In this context, it has been demonstrated that both, HI-RT and LI-BFR, increase hemodynamic responses (blood pressure, heart rate and rate-pressure product), amplifying myocardial workload and additional stress on the vasculature (Neto, et al 2016a, Pedon, et al. 2022).

Studies that have investigate the effects of LI-BFR on vascular function have reported that metabolic stress derived by this training method may increase the exercise of pressor reflex to the cardiovascular control center, causing exacerbated increases in sympathetic activity and prompting the need for caution when prescribing LI-BFR training (Cristina-Oliveira et al., 2020; Da Cunha Nascimento et al., 2020; Spranger et al., 2015). Additionally, it has been demonstrated that the magnitude of this cardiovascular responses during and after LI-BFR is directly related to different variables such as: a) the intensity of effort; b) the external levels of restrictive pressure applied; c) the exercise performed or muscle mass involved; d) the type and duration of restriction (continuous vs intermittent) (Brandner et al., 2015). In this sense, Chulvi-Medrano et al. (2023) suggest that methods using 100 mm Hg and the resting brachial systolic blood pressure could represent the safest application prescriptions as they resulted in applied pressures between 60% and 80% LOP. Additionally, a recent meta-analysis (Kesrouani et al., 2022) indicates that the load and intensity of the exercise affect proportionally to the increase in heart rate, a fact that also directly affects the post-exercise recovery behavior. Likewise, the muscle mass involved in the exercise, when comparing the upper and lower limbs, also affect to cardiovascular

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responses, since the larger the muscle group involved in performing the exercise, the more arterioles will be dilated, providing lower values of peripheral vascular resistance and lower blood pressure.

Several studies have evaluated the acute cardiovascular responses during and after resistance training with and without blood flow restriction using different methodological designs (Poton & Polito, 2014b; Poton & Polito, 2015). However, none of them used intermittent and low restrictive pressure (< 100mmHg) and a single exercise for ankle joint. To our knowledge, only three studies (Rossow et al., 2011; Downs et al., 2014; Bunevicius et al., 2016) compared the acute effects on cardiovascular responses after resistance training with and without blood flow restriction, using plantar flexion exercise (added to other exercises for lower body) and restrictive cuff pressures from 100 mmHg to 200 mmHg.

In general, researchers analyzed the effects of one or more lower limb multi-joint exercises (e.g. leg press, leg extension, leg flexion) in order to achieve specificity or functionality, both in healthy patients and within rehabilitation programs (Werasiritat & Yamlamai, 2022). However, this type of exercise has been related to higher cardiovascular responses since it involved larger muscle mass (Assunção et al., 2007; Monteiro et al., 2008). Recently, plantar flexion exercise has been associated to improving the functionality, mainly in elderly, a proportion of population that needs a very close monitoring on acute cardiovascular responses following exercise (Ema et al., 2017). Thus, although several studies analyzed the acute physiological effects of LI-BFR using different exercise design, further investigation is still needed.

The aim of this study was to compare the acute effects on blood pressure (BP), heart rate (HR) and oxygen saturation (SpO_2) during and after three different resistance training protocols performing a single plantar flexion exercise in healthy population. We hypothesized that lower muscle mass involved in plantar flexion exercise may not negatively affect the cardiovascular system regardless of the resistance training protocol applied. Additionally, the lower restrictive pressure used in our study would be an effective and safe stimulus. We assume that healthy subjects do not have any cardiovascular limitation during resistance training, however, the results of this study could elicit future investigations in other populations, such as elderly or hypertensive individuals.

Material & methods

Participants

Fifty-two healthy young individuals (33 males and 19 females) were recruited to participate in this study (as described in Table 1). Prior to commencement of the study, all participants were properly informed in detail of the aim and requirements of the research and were invited to ask any questions related to the nature of the study. Participants were instructed to refrain from physical activity and alcohol consumption, caffeine and/or other performance stimulants ergogenic 48h before trials. The exclusion criteria were the use of any medication that could influence the cardiovascular responses, presence of any diagnosed cardiovascular disease, hypertension, diabetes, or a history of blood clotting (Rossow et al., 2012). Participants completed a medical health history form and signed the informed consent document. All procedures of this study were performed in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of Alicante (Exp. UA-2016-09-18).

Table 1. Characteristics of the participants.

	HI-RT (n=15)	LI-RT (n=13)	LI-BFR (n=24)
Age (yr)	26.9 ± 8.5	27.8 ± 8.7	24.4 ± 3.9
Height (m)	1.80 ± 11.0	1.75 ± 11.0	1.78 ± 11.0
Body mass (Kg)	73.4 ± 12.0	70.5 ± 16.2	72.7 ± 13.0
BMI (Kg·m2)	23.9 ± 3.0	23.8 ± 3.7	22.8 ± 2.7
AOP (mmHg)	-	-	158.8 ± 66.0
30% of AOP (mmHg)	-	-	47.6 ± 19.8
1RM Calf extension (Kg)	166.7 ± 51.1	158.6 ± 35.1	133.2 ± 22.1
30% of 1RM (Kg)	50.0 ± 15.3	47.5 ± 10.5	39.9 ± 6.6
HR (bpm)	70.0 ± 10.0	68.3 ± 11.0	66.1 ± 12.9
SBP (mmHg)	126.1 ± 11.7	119.2 ± 12.0	123.6 ± 15.7
DBP (mmHg).	76.8 ± 9.3	75.8 ± 10.8	74.5 ± 11.2
MAP (mmHg)	93.2 ± 6.9	90.2 ± 9.5	90.88 ± 10.3
RPP (%)	86.0 ± 11.6	81.1 ± 14.0	82.0 ± 20.2
SpO_2 (%)	99.0 ± 1.1	99.2 ± 0.8	98.0 ± 0.8

HI-RT, High-intensity resistance training; LI-RT, Low-intensity resistance training; LI-BFR, Low-intensity associated with blood flow restriction; BMI, body mass index; AOP, arterial occlusion pressure; 1RM, one repetition maximum; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; RPP, rate pressure product; SpO_2, oxygen saturation. Values are presented as Mean ± SD.

Experimental Design

A familiarization session was completed by all participants one week prior to experimental trials. In this phase, one repetition maximum test (1RM), training protocols and arterial occlusion pressure (AOP) measurement were simulated. Afterwards, participants attended the laboratory on three separate days, each one at the same time in the morning. Additionally, the participants were instructed to keep normal hydration and refrain physical activities during the intervention. The first visit consisted in the measurement of anthropometric parameters, AOP and 1RM test of dominant-side plantar flexion exercise. All measurements were performed after 15 min of rest. During the second visit, each participant performed the assigned exercise trial: high-intensity (HI); low-intensity (LI); low-intensity resistance training associated with blood flow restriction (LI-BFR). During this visit, cardiovascular responses were recorded at baseline, during and after exercise, using an automatic heart rate monitor. Finally, 24h after the intervention, participants attended the laboratory for post-exercise assessments.

Exercise trials

Prior to trials, all participants rested quietly for 15 minutes followed by a measurement of cardiovascular responses. Afterwards, participants completed a standardized warm-up that consisted in five minutes on a bicycle at 70W, followed by two sets of 15 repetitions of unilateral plantar flexion exercise in the dominant leg, at ≤20% 1RM. Thereafter, participants from LI-RT and LI-BFR groups performed four sets (1x30 + 3x15 reps) at 30% 1RM, resting 60s between sets, whereas the participants from HI group performed four sets (1x30 at 30% 1RM + 3x10 reps at 75% 1RM) resting 90s between sets. Exercise trials were performed in a leg press exercise machine (TYH Fitness), with the dominant foot placed approximately to the width of the hip, a slight external rotation of the same and avoiding knee valgus. Additionally, participants were instructed to perform the movement in a full range of motion and with the total phase of contraction cycle lasting 3s (1.5s concentric; 1.5s eccentric), being monitored by a digital metronome. For the LI-BFR trial, a blood pressure cuff was positioned on the dominant calf and inflated at 30% of the individual AOP (47.6 ± 19.8 mmHg) during the exercise and released immediately after the end of each set.

One Repetition Maximum Test (1RM)

Maximal dynamic strength of plantar flexion muscles was measured by a one-repetition maximum test (1RM) on a leg press machine. Participants began the test following a neuromuscular warm-up consisting in performing 2 sets of 10 repetitions at 40% of the individual's perceived maximum strength. All subjects were instructed to perform the movement in a full range of motion and to avoid assistance from any other body part (e.g. the thigh). After 3 min, participants performed eight repetitions with a load estimated at 50% 1RM, obtained during the familiarization sessions. In the second test, after other 3 min of rest, the participants performed three to five repetitions at 75% of their estimated 1RM. Thereafter, the loads were adjusted individually, and the participants were instructed to perform repetitions until volitional failure. If more than five repetitions were completed successfully, the load was progressively increased by 5%. If participants were unable to complete the five repetitions, 1RM was estimated by Epley's formula (1RM = load [kg] * [1 + (0.033 * number of repetitions)]) (Martín-Hernández et al., 2013). After each attempt, participants rested for 5 min and then, they had up to new attempts to achieve their 1RM.

Determination of Arterial Occlusion Pressure (AOP)

Prior to the arterial occlusion pressure measurement, participants rested in the supine position for 15 minutes. Then, a vascular Doppler probe (US-B, Logiq-e; General Electric Healthcare, Wauwatosa, WI, USA) was placed over the posterior tibial artery to capture its auscultatory pulse. In order to determine the AOP, a pneumatic cuff (57 cm length x 9 cm width; Riester Komprimeter, Riester, Jungingen, Germany) was placed on the dominant leg under the knee joint and then progressively inflated up to the point in which the auscultatory pulse was interrupted (arterial occlusion pressure) (Gualano et al., 2010).

Cardiovascular measurements

Prior to experimental protocols, participants rested for 15 minutes in order to stabilize the cardiovascular variables. Afterwards, systolic/diastolic blood pressure (SBP/DBP) and HR were assessed using an automatic pneumatic blood pressure machine (Tensoval Duo Control Hartman; OMROM). These measurements were repeated immediately after each set of training (during exercise) and post-exercise (15min, 30min, 45min, 60min and 24h). SpO_2 was also assessed at baseline, during exercise (after each set) and post-exercise (60min and 24h) using a finger pulse oximeter (Contec: CMS50D). For all three conditions, cardiovascular measurements were obtained from the right arm, using the same equipment. The rate pressure product (RPP) was calculated as index of myocardial oxygen consumption using the formula RRP = SBP (mmHg) x HR (bpm) / 100. Mean arterial blood pressure (MAP) was obtained using the formula MAP = 1/3 (SBP-DBP) + DBP.

Statistical Analysis

All data are presented as means ± standard deviation (SD). Prior to analysis, data normality and homogeneity of variance were assessed through the Shapiro-Wilk and Levene tests. Two-way repeated-measures ANOVA (group x time) was applied for dependent variables analysis. Significant interactions between exercise trials were analyzed using DMS post-hoc test. A t-test for paired samples was used across time within each group. Effect size was calculated to determine the magnitude using Hedges' G, and the data obtained were categorized as follows: no effect ($d<0.2$), small effect ($d<0.5$), medium effect ($d<0.8$), or large effect ($d>0.8$). Statistical significance was set at $p<0.05$. All data were analyzed using SPSS version 17.0 software packages.

Results

Heart rate

There was a significant interaction effect of all protocols x time during exercise ($p<0.05$) (as shown in Fig. 1a). This increase of HR was greater for HI protocol after 4th set of exercise ($p<0.001$; G=1.072). The comparative analysis of HR during exercise revealed no significant differences between protocols ($p>0.05$). Post-exercise, intergroup analysis revealed significant differences in post-30min value when comparing HI and LI-BFR protocols ($p<0.05$) (as shown in Fig. 1b).

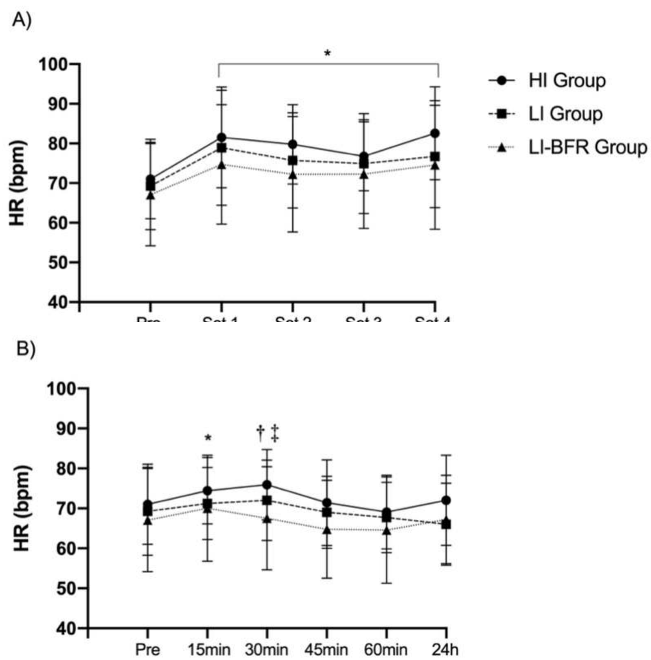

FIG. 1. A) Hearth rate (HR) responses during exercise. * Significant difference to pre (baseline) across all protocols. **B)** HR responses after exercise. * Significant difference to pre for LI-BFR protocol; † Significant difference to pre for HI protocol; ‡ Significant difference from HI to LI-BFR protocols.

Blood pressure, mean arterial pressure and rate pressure product

During exercise, there was no significant interaction effect x time in SBP for either protocol ($p<0.05$) (as shown in Fig. 2a). The comparative analysis of SBP during exercise revealed significant difference in the first set from LI to HI and LI-BFR protocol ($p=0.03$ and $p=0.04$, respectively) and the third and fourth set from HI to LI protocol ($p=0.03$ and $p=0.04$, respectively). Regarding the acute responses of SBP after exercise (as shown in Fig. 2b), significant reduction was observed at 15min, 30min, 45min and 60min post-exercise for all three groups ($p<0.05$).

The greater significant reductions in SBP were observed at 30min and 45min post-exercise for HI protocol ($p=0.001$ for both time points; G=1.06, G=1.18, respectively) and 45min and 60min post-exercise for LI-BFR protocol ($p=0.001$ for both time points; G=0.55, G=0.56, respectively). Intergroup analysis and post-hoc test of SBP at post-exercise revealed no significant differences between protocols ($p>0.05$).

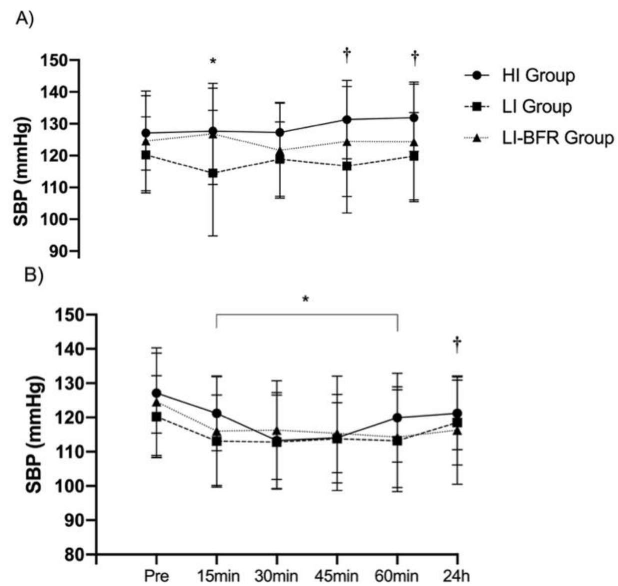

FIG. 2. A) Systolic Blood Pressure (SBP) responses during exercise. * Significant difference from LI to HI and LI-BFR protocol; † Significant difference from HI to LI protocol; **B)** SBP responses after exercise. * Significant difference to pre across all protocols; † Significant difference to pre for LI-BFR protocol.

There was a significant reduction of DBP from pre to third set of training for LI-BFR protocol (p=0.04, G=0.357) (as shown in Fig. 3a). The analysis of interaction revealed no significant differences between protocols (p>0.05). After exercise, DBP decreased significantly for HI protocol at 45min (p=0.035, G=0.487) as well as post-45min and post-24h for LI-BFR group (p=0.04 for both time points, G=0.467 and G=0.474, respectively) (as shown in Fig. 3b). Intergroup analysis and post-hoc test of SBP revealed no significant differences between protocols (p>0.05).

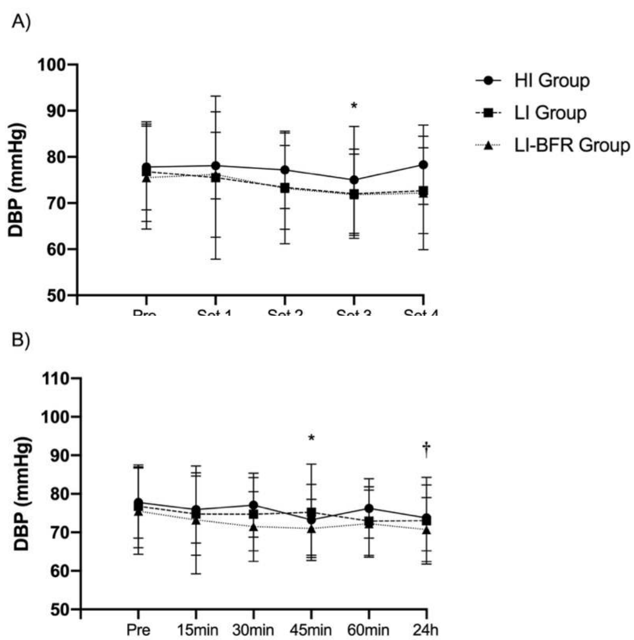

FIG. 3. A) Diastolic Blood Pressure (DBP) responses during exercise. * Significant difference to pre for LI-BFR protocol; **B)** DBP responses after exercise. * Significant difference to pre for HI and LI-BFR protocols; † Significant difference to pre for LI-BFR protocol.

The within protocols analysis and the comparative analysis indicated no significant differences in MAP from pre to four sets of exercise for any group (p>0.05) (as shown in Fig. 4a). After exercise, intragroup analysis showed the greater reductions of MAP at post-30min, post-45min for HI protocol (p=0.008, G=0.66; p=0.000, G=0.96, respectively) and LI-BFR protocol (p=0.003, G=0.54; p=0.004, G=0.62, respectively) (as shown in Fig. 4b). The comparative analysis revealed no significant differences between groups (p>0.05).

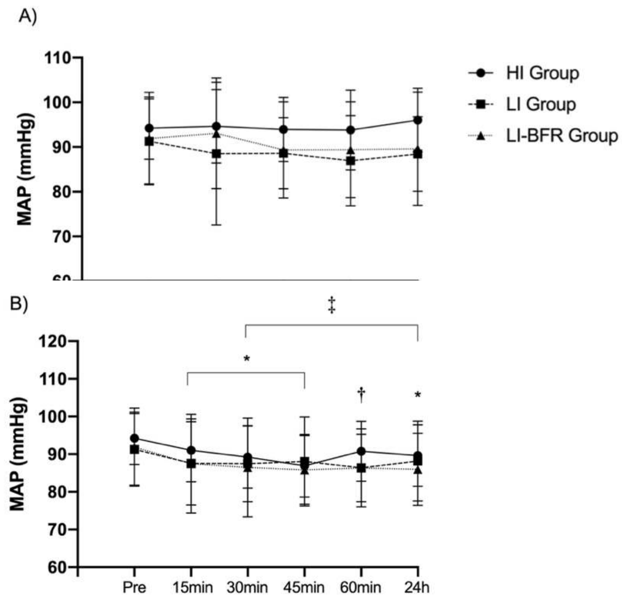

FIG. 4. A) Mean Arterial Pressure (MAP) responses during exercise. No significant effect was observed. **B)** MAP responses after exercise. * Significant difference to pre for HI protocol; † Significant difference to pre for LI protocol; ‡ Significant difference to pre for LI-BFR protocol.

During exercise, there was no significant interaction effect x time in RPP for either protocol (p<0.05) (as shown in Fig. 5a). Significant increases were observed from pre to during exercise for all protocols, with greater differences after first and fourth set of exercise for HI (p=0.002, G=1.11; p=0.000, G=1.45, respectively) and LI-BFR protocols (p=0.003, G=0.51; p=0.013, G=0.40, respectively). Intergroup analysis revealed significant differences for all sets of exercise from HI protocol to LI and LI-BFR (p<0.05). After exercise (as shown in Fig. 5b), significant reduction in RPP was observed at 60min for LI protocol (p=0.029, G=0.47) and post-45min, post-60min and post-24h for LI-BFR group (p=0.006, G=0.49; p=0.005, G=0.49; p=0.037, G=0.27, respectively). Intergroup analysis and post-hoc test revealed no significant differences between protocols (p>0.05).

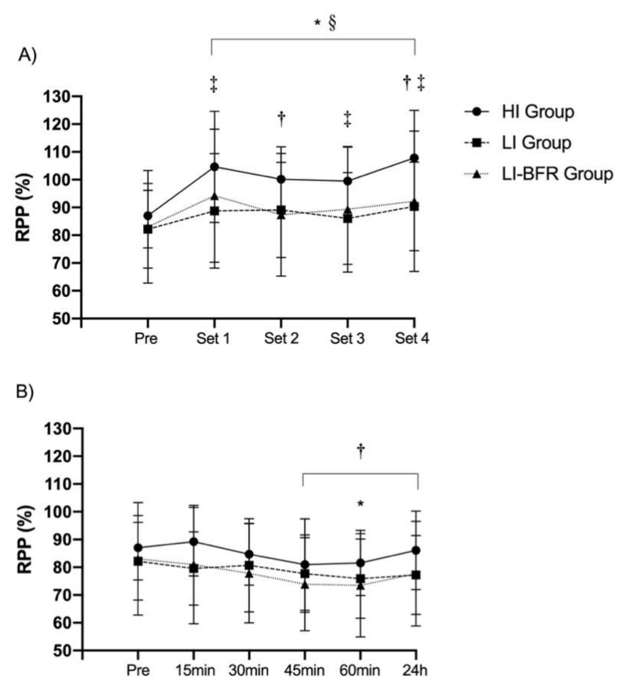

FIG. 5. A) Rate Pressure Product (RPP) responses during exercise. * Significant difference to pre (baseline) for HI protocol; † Significant difference to pre for LI protocol; ‡ Significant difference to pre for LI-BFR protocol; § Significant difference from HI to LI and LI-BFR protocol; **B)** RPP responses after exercise. * Significant difference to pre (baseline) for LI protocol; † Significant difference to pre for LI-BFR protocol.

Oxygen saturation

There was a significant interaction effect x time during exercise for HI group (p=0.01, p=0.004, p=0.002, p=0.02, respectively for each set) (as shown in Fig. 6a). The comparative analysis of SpO_2 during exercise revealed significant difference pre-exercise from LI-BFR to HI and LI groups ($p<0.05$) and from LI to HI and LI-BFR after first (p=0.02, p=0.009) and fourth set (p=0.03, p=0.008). After exercise, the interaction between effect and time revealed significant reduction of SpO_2 post-60min for HI group (p=0.03, G=0.505) (as shown in Fig. 6b). Intergroup analysis revealed significant differences in post-60min across all groups ($p<0.001$) and in post-24h value when comparing LI and LI-BFR protocols (p=0.02).

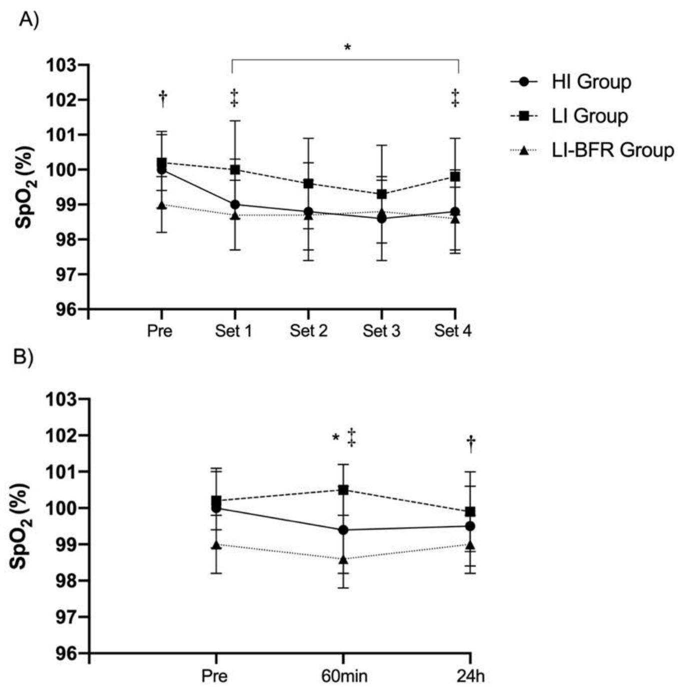

FIG. 6. A) Oxygen saturation (SpO_2) responses during exercise. * Significant difference to pre (baseline) for HI protocol; † Significant difference from LI-BFR to HI and LI protocol; ‡ Significant difference from LI to HI and LI-BFR protocol. **B)** SpO_2 responses after exercise. * Significant difference to rest for HI protocol; † Significant difference from LI-BFR to LI protocol; ‡ Significant differences across all protocols.

Discussion

The present study compared the acute cardiovascular responses during and after different resistance training protocols in healthy individuals. To our knowledge, this is the first study that evaluated the acute effect of LI-BFR on cardiovascular responses using a single exercise of ankle joint and very low restrictive pressure. The main findings of this study indicate that, (1) all three protocols promoted increases in HR during exercise, with greater effect for HI protocol, (2) HI and LI-BFR groups resulted in similar post-exercise hypotension effect, (3) MAP post-exercise was reduced significantly for HI and LI-BFR protocols, (4) RPP increased during exercise for HI protocol, with significantly differences to other two protocols, (5) HI exercise promoted a significant reduction in SpO_2 during training. It has been suggested that HI-RT promotes acute physiological alterations due to the increases of the supply of oxygenation to active muscles and, in turn, the exercise design affects the magnitude of these responses (McCartney, 1999). In the present study, HR increased significantly during all protocols without differences between them. These results are in line with previous studies in healthy young individuals (Figueroa & Vicil, 2011; Downs et al., 2014; Neto et al., 2016b) but not others. For instance, several studies found greater increases on HR for HI-RT compared with LI-RT protocols with and without blood flow restriction (Poton & Polito, 2014b; Brandner et al., 2015; Poton & Polito, 2015), while others revealed more significant increases during LI-BFR compared with HI and/or LI (Vieira et al., 2013; Poton & Polito, 2014a; Takano et al., 2015; Bunevicius et al., 2016). These contrasting findings could be attributed to the different manipulation of exercise variables between research. In our study, the use of a single exercise may not affect the total training volume between protocols. Additionally, it is likely that the intermittent low restrictive pressure applied in plantar flexion exercise does not confer great cardiovascular workload for LI-BFR compared to other two protocols.

Despite LI-BFR being presented as an effective and safe training method for a variety of population, Spranger et al. (2015) and Da Cunha Nascimento et al. (2020) reported that the reduction of blood flow may promote an increase of exercise pressor reflex, causing sympathetic hyperreactivity with consequent BP increase. However, in the present study, we found no significant increase in blood pressure and MAP during exercise for any protocol. These results are in line with those obtained by Bunevicius et al. (2016) and could be explained by the magnitude of the training load since both studies used a single exercise for a relatively small muscle (calf muscle). In contrast, for instance, Poton & Polito (2014b) and Takano et al. (2015) used a leg extension exercise and high restrictive pressure (close to 160-180 mmHg) which triggered exacerbated increases on cardiovascular parameters (SBP, DBP, HR, RPP and cardiac output). Additionally, it has been demonstrated that healthy individuals present more efficient autonomic regulation through adaptation to the regular practice of training (Fu and Levine, 2003), which also could explain the lower increase of BP during our protocols. Nevertheless, higher SBP values were observed in the 1st, 3rd and 4th set for HI-RT group compared with LI-RT, as well as in RPP during exercise when compared HI-RT with LI-RT and LI-BFR training. These findings are consistent with other studies (Poton & Polito, 2014b; Brandner et al., 2015) and may have occurred because the training volume was higher for HI exercise compared with LI-RT protocols.

It has been demonstrated that a single session of HI-RT results in a hypotensive response that can maintain until 24 hours (Figueiredo et al., 2014). However, the effect of LI-BFR on this phenomenon remains unclear (Neto et al., 2016a). To the authors knowledge, this is the first study that revealed a hypotension effect using a single exercise for lower body, with greater post-exercise reduction for HI and LI-BFR conditions. Several studies revealed hypotensive responses in normotensive population after resistance exercise with and without blood flow restriction (Moriggi et al., 2015; Neto et al., 2015) although unlike the present study, this research applied four exercises for upper body and full body, respectively. Similar to our study, Maior et al. (2015) shown that HI-RT and LI-BFR protocols can promote a post-exercise hypotensive effect when used a single exercise for upper body. These findings suggest that low load (20-30% of 1RM) and a low restrictive pressure (close to 50-100 mmHg) may be enough stimulus to promote an accumulation of metabolites, peripheral vasodilatation and the consequent reduction of BP (Rezk et al., 2006). Nevertheless, it is necessary to remark that, unlike to Maior et al. (2015), if analyzed our results in terms of ES, it was observed that HI condition elicited a greater hypotensive response, that could be explained by the resistance exercise intensity. In this sense, Rossow et al., (2011), after performing three exercises for lower body, revealed post-exercise hypotensive effect only for HI-RT when compared to LI-RT with and without blood flow restriction. Therefore, new research is necessary to examine the acute effect of LI-BFR on hypotensive response when used different training design, including single or multi-joint exercises for a small and/or larges muscles.

Related to SpO_2, several studies have found that resistance exercise can promote a reduction in supply of intramuscular oxygen, providing an increase in oxidative stress and an anabolic environment (Tanimoto et al., 2005; Loenneke et al. 2010), although few studies have verified these acute responses after LI-BFR and the findings are controversial. In this sense, our results differ from the studies conducted by Tanimoto et al. (2005) and Neto et al. (2016b) that found greater reductions on SpO_2 after LI-BFR compared with HI-RT and/or LI-RT. However, Downs et al. (2014) shown that SpO_2 decreased during exercise for all protocols analyzed (HI-RT, LI-RT, LI-BFR) with the recovery to baseline levels during rest period for LI-RT and HI-RT. These controversial results between research may be justified by the different exercise design of each study (particularly, the restrictive pressure, muscle mass involved and total training volume of each session). Thereby, in our study, it is likely that plantar flexion exercise is not capable of promoting great blood mobilization and, consequently, of avoiding the reduction of muscle oxygenation compared to LI exercises. The findings of this study are limited by several aspects. First, the material used for cardiovascular responses measurement, since the use of photophethysmographic device would have provided greater reliability to our findings. Additionally, this technique would have allowed us the assessment of other important variables such as stroke volume, cardiac output and total peripheral vascular resistance, that could have explained the possible mechanisms behind our results. Second, the different sample size from each group may have decreased statistical power. Lastly, the authors evaluated cardiovascular responses in healthy individuals so these results should not be extended to other populations, such as elderly or hypertensive patients. Therefore, new research is necessary to analyze the acute and chronic cardiovascular responses of exercise with and without blood flow restriction, particularly comparing different populations and study designs.

Conclusions

The main conclusions of the present study were: a) HI-RT promoted greater increases in HR and RPP during exercise compared with LI-RT and LI-BFR protocols; b) similar post-exercise hypotension effect and reduction of MAP were observed after HI-RT and LI-BFR; c) oxygen saturation was reduced during training only after HI-RT. The findings of the present study shown that LI-BFR training may be considered a safe and effective strategy for healthy population in terms of cardiovascular parameters although the evidence is still heterogeneous. Therefore, to maximize the positive effects of this training method and apply it safely, it is suggested to attend the particularities of each study design, considering specially the muscle mass involved in the exercise performed, the duration of protocol and the restrictive pressure applied. For clinicians/researchers planning future studies of LI-BFR, consideration should be given to the standardize protocols and so facilitate comparison of findings.

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Declaration of interest statement The authors have no conflict of interest.

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