Title: Acute Hemodynamic Responses to Repetitions to Failure Using Different Resistance Exercises and Protocols in Normotensive Men: A crossover study

Running Head: Hemodynamic Responses to Repetitions to Failure

Abstract

The present crossover design study investigated acute hemodynamic responses to two sets of leg press (LP) and bench press (BeP) at 10 and 20 repetition maximum (RM) in ten normotensive young men. At the end of each set, an increase in systolic blood pressure (SBP), heart rate (HR), and rate pressure product (RPP) was observed ($p<0.01$), with no differences between intensities, but SBP was greater during the LP exercise ($p<0.01$). Lower resting values of diastolic blood pressure (DBP) were observed in the post-BeP exercise period ($p<0.05$), suggesting that DBP post-exercise hypotension may be more evident after upper-limb exercise.

Keywords: Blood pressure, Heart rate, Rate-pressure product, Post-exercise hypotension, Strength training, Repetition maximum.

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INTRODUCTION

Exercise is an effective strategy for promoting strength and body composition benefits, as well as a non-pharmacological intervention for the treatment of hypertension [1,2]. It is known that during resistance exercise an acute increase in systolic (SBP) and diastolic (DBP) blood pressure occurs [3–5]. However, after exercise, blood pressure returns to, or even below, baseline levels. Post-exercise blood pressure below pre-exercise values is a well-reported phenomenon, called post-exercise hypotension [6,7].

Endurance exercise is widely known to bring about post-exercise hypotension, but this phenomenon has also been observed after other types of training, including resistance exercise [8]. In addition, resistance training is known to lead to large blood pressure elevation during exercise performance, which returns towards baseline in the post-exercise period. Acute resistance training variables such as intensity (low-to-moderate vs. moderate-to-high) [9–11] volume (e.g., repetitions by set) [4,9,12,13] and exercise selection (e.g., lower vs. upper-body exercises, muscle mass amount) [4,9,14] may influence the magnitude of acute hemodynamic changes to exercise, including the blood pressure, heart rate (HR), and rate-pressure product (RPP) responses to and post-exercise.

A resistance training routine may be performed based on a percentage of one-repetition maximum or repetitions maximum (RM, i.e., a load leading to skeletal muscle concentric failure within a predetermined range of repetitions) [15]. In recent years, several studies have identified benefits of using RM to improve maximum strength and hypertrophic muscle gains [16–18]. Also, previous studies sought to assess the cardiovascular responses during [4,9,19] and after resistance training sessions employing RM [20–22]. In this regard, investigations have shown significant increases in hemodynamic changes during resistance exercises performed with RM, mainly with high intensity [9,10] and repetitions volume (i.e., total muscle contraction time per set) [3–5,12], as well as greater muscle amount involved in exercise [4,9].

Regarding post-exercise hypotension, some studies have reported this effect with protocols employing RM [14,20–22]. However, the post-hypotensive effects resulting from protocols based on RM with distinct exercises (e.g. upper and lower-body) and training routines (e.g. low vs high number of repetitions) remain underexplored [8,14]. Also, it is important to highlight that most of the mentioned studies involve the effects of single-joint exercises on hemodynamic parameters. It remains unknown how varying the exercise (lower and upper resistance exercise) and RM volume performed influences hemodynamic responses. Traditionally, bench press and leg press exercises are commonly studied in training routines, but their hemodynamic effects both during and after exercise remain poorly explored when these are RM-based.

Considering that cardiovascular outcomes are linked to chronic increases in blood pressure even at the non-hypertensive spectrum [23,24], and that RM is commonplace in resistance training sessions, it becomes relevant to investigate the cardiovascular responses associated with RM protocols even in healthy individuals. Also, acute post-exercise hypotension can be related to chronic blood pressure benefits [25] and understanding the effects of different RM protocols (e.g. upper vs lower body exercise) on post-exercise hemodynamic response may be useful in the development of effective training strategies. As such, the present study aimed to investigate the acute hemodynamic adjustments to multi-joint lower-body (leg press - LP) and upper-body (bench press - BeP) resistance exercises at different RM loads in normotensive healthy individuals.

METHODS

Experimental Approach

This experiment is a randomized cross-over study, in which resistance exercises were performed to investigate hemodynamic responses of normotensive young men. Two resistance exercises (LP and BeP) were performed during separate visits using 10RM and 20RM load (i.e. a total of 4 experimental visits).

Participants

The participants were not engaged in regular endurance or resistance training for at least six months prior the experiment, and only normotensive [26] (i.e., resting SBP/DBP <140/90mm Hg) non-obese (body mass index <30kg/m^2) male individuals were included. None of the participants were currently taking antihypertensive, cardiovascular, or metabolic medications. All participants were informed of the risks and benefits of the study prior to signing an Informed Consent Form, and all procedures of the study were approved by the Institutional Ethics and Research Board. The sample size required for the present study was determined based on a previous study [27]. Using an α level of 0.05 and a power of 0.90 (PEPI 4.0), ten participants were necessary to test our hypothesis.

Procedures

Participants visited the laboratory on six separate occasions, with at least one-week interval between visits. On the first session, anthropometric characteristics were determined, followed by resting SBP, DBP, HR measurements. After that, participants were familiarized with the study procedures and performed the 20RM test for LP and BeP exercises. The 10RM test was conducted on the second visit. During the third, fourth, fifth, and sixth visits, participants completed one of the four exercise protocols in randomized order: LP10RM (LP at 10RM load), LP20RM (LP at 20 RM load), BeP10RM (BeP at 10 RM load), and BeP20RM (BeP at 10 RM load). Participants were allocated to each session in the experimental visits by random allocation to one of all potential combinations. Figure 1 presents the experimental design of the study.

- Insert Figure 1 here –

Repetitions Maximum Tests

The 20RM and 10RM tests were performed during separate visits to determine the participants' resistance exercise load for the BeP and seated LP machine (World- 204 Sculptor, Porto Alegre, Brazil). Before each test, standardized instructions about procedures and exercise techniques were given, and all participants performed a standardized warm-up consisting of 2 sets of 10 repetitions with light resistance. After that, the load was increased until participants could not complete the predetermined number of repetitions (i.e., either 20 or 10 repetitions for the 20RM test and 10RM test, respectively) with the appropriate exercise technique and cadence. The control of exercise cadence (2 s for the concentric phase and 2 s for the eccentric phase of movement) was assisted by an electronic metronome (Korg, New York, USA). The RM of each exercise was determined within four attempts, with a rest interval of 5 minutes between trials, and 10 minutes between the exercises. Total volume load [number of repetitions x external load (kg)] was calculated according to a previous study [28].

Experimental Protocols

All participants underwent four experimental sessions in random order: a) 2 sets of 10RM LP, b) 2 sets of 20RM LP, c) 2 sets of 10RM BeP and d) 2 sets of 20RM BeP. Each experimental session was performed at the same time of the day (8 a.m. to 12 a.m.), with an interval period of at least one week between experimental sessions. The participant was blinded to exercise intensity before each experimental visit and was instructed to avoid caffeine, medications, and exercises 24h before the visits. After arriving at the laboratory, participants rested for 55 minutes and baseline blood pressure (ABPM-04 recorder with an optical interface, Meditech, Budapest, Hungary), and HR (Polar Electro, Finland) measurements were taken in the supine position. Baseline BP was measured three times with one-minute interval between each. Then, participants performed one of the four experimental exercise protocols with blood pressure and HR recorded in the last repetition of each set. The resistance training protocol was performed without prior warm-up to reduce the influence of confounding factors upon the hemodynamic responses. Two sets of the randomized exercise were performed with a 5-minute passive resting interval between sets, and participants were instructed to avoid breath-holding maneuver throughout the experimental protocols. Participants received constant feedback regarding exercise cadence, range of motion, and technique, and all repetitions in each set were accounted. In the post-exercise period, participants rested in the supine position for 55 minutes, while blood pressure and HR were measured. The SBP, DBP, and HR were recorded prior (Pre), at the end of the first and second set, as well as post-exercise (Post 5, 15, 25, 35, 45 and 55 minutes). Rate-pressure product (RPP) was calculated for each time-point as the product of SBP x HR. Room temperature (about 21 ± 1 °C) and relative humidity (50% ± 5%) were relatively constant throughout all visits.

Statistical Analyses

Data normality was assessed using the Shapiro-Wilk test. All values are presented in mean ± standard deviation. Possible differences between groups for volume load were tested by paired sample t-test. To compare the effect of sets in SBP, DBP, HR, and RPP a two-way repeated measures analysis of variance (ANOVA) was used (2 x 3; intensity [10RM and 20RM] x time point [pre, set 1 and set 2]). For the post-exercise period, a two-way repeated measures ANOVA (2 x 7; intensity [10RM x 20RM] x time point [rest vs. 5 vs. 15 vs. 25 vs. 35 vs. 45 vs. 55 minutes]) for SBP, DBP, HR, and RPP was used. For exercise comparisons, a two-way repeated measures ANOVA for SBP and DBP was used (2 x 3; exercises [BeP10RM and 20RM x LP10RM and 20RM] x time point [pre, set 1 and set 2]; 2 x 7 [rest vs. 5 vs. 15 vs. 25 vs. 35 vs. 45 vs. 55 minutes]). If significant interaction time x intensity was observed a Bonferroni correction was used to identify time differences. The level of significance (α) was set at 0.05. All statistical procedures were performed using the Statistical Package for Social Science (SPSS) version 20.0 (IBM SPSS Inc., Chicago, IL, USA).

RESULTS

Participants' Characteristics and Exercise Sessions

Participants' characteristics are presented in Table 1. The 10RM protocols were performed with a greater load compared to the 20RM protocols (LP10RM: 224.90 ± 39.32 vs. LP20RM: 162.80 ± 35.89 kg; $p<0.05$; BeP10RM: 49.60 ± 7.63 vs. BeP20RM: 34.20 ± 7.07 kg; $p<0.05$). The total volume load, however, was significantly ($p<0.05$) higher in the 20RM compared to the 10RM protocols in the LP (LP10RM: 2.249.00 ± 393.18 vs LP20RM: 3.256.00 ± 717.82 rept x kg, $p<0.05$) and BeP protocols (BeP10RM: 496.00 ± 76.33 vs BeP20RM: 684.00 ± 141.36 rept x kg, p<0.05).

Cardiovascular Responses to Exercises

Pre-exercise SBP, DBP, HR, and RPP are shown in Table 1. There was no significant difference in baseline hemodynamic parameters between 10RM and 20RM experimental sessions ($p \geq 0.05$). The absolute values of hemodynamic responses to exercises are shown in Figure 2 (LP, 10RM vs. 20RM), 3 (BeP, 10RM vs. 20RM) and 4 (LP 10RM+20RM vs. BeP 10RM+20RM).

- Insert Table 1 here -

Responses to LP Exercise

Participants' SBP increased in the first and second set of LP exercise ($p<0.01$) (Figure 2a), and an increase in DBP was observed at the second set ($p<0.05$) (Figure 2b), with no differences between exercise intensities ($p \geq 0.05$). In the post-exercise period, SBP remained elevated in the initial five minutes of recovery ($p<0.05$), returning to baseline thereafter ($p \geq 0.05$). The DBP remained unchanged throughout the post-exercise period ($p \geq 0.05$). HR and RPP increased similarly between the 10RM and 20RM protocols during the sets (Figure 2c and 2d) ($p<0.05$), and then returned to baseline within 15 min post LP exercise.

- Insert Figure 2 here –

Responses to BeP Exercise

No differences were observed between 10RM and 20RM BeP protocols ($P>0.05$). Participants' SBP increased during the BeP protocols ($p<0.05$), returning to pre-exercise values within 5 minutes post-BeP ($p\geq0.05$) (Figure 3a). The DBP, however, was unchanged during BeP ($p\geq0.05$) but reached values below baseline after the BeP protocols ($p<0.05$) (Figure 3b). This post-exercise DBP hypotension was evident until 35 min of the recovery period. Participants' HR and RPP increased during the BeP exercise sessions ($p<0.01$) and were elevated within 5 min post-exercise ($p<0.05$) (Figure 3c and 3d).

- Insert Figure 3 here –

Responses to LP and BeP Exercises

Since no differences between exercise intensities were observed in each exercise, data from 10RM and 20RM were compiled for between exercise comparisons. In the first and second set of exercise a greater SBP increase was observed in the LP compared to the BeP exercise, and participant's SBP remained greater in the first five minutes of post-exercise recovery of the LP protocol (Figure 4a, $p<0.05$). The DBP, however, increased in the second set of exercise only in the LP protocol ($p<0.05$) (Figure 4b). In the post-exercise period, the DBP post-BeP exercise fell below baseline values until 35 min into the recovery period ($p<0.05$) and was consistently lower post-BeP compared to LP exercise ($p<0.05$). No post-exercise hypotension was observed with LP ($p\geq0.05$).

- Insert Figure 4 here –

DISCUSSION

The present study investigated acute hemodynamic responses to two multi-joint resistance exercises (LP and BeP) performed with different load protocols (10RM and 20RM). The main findings of the present study are that a) hemodynamic parameters responded similarly to the 10RM and 20RM protocols; b) only two resistance exercise sets resulted in substantial increase in hemodynamic variables during exercise; c) LP resulted in greater blood pressure values during exercise than BeP, and d) only BeP resulted in post-exercise hypotension (in DBP).

Major hemodynamic adjustments during exercise have been observed with resistance training sessions with repetitions to failure [3,4,12,19]. In the present study, substantial increments of SBP, HR, and RPP were observed with just two exercise sets, regardless of the RM protocol employed. These results contrast to previous studies, in which higher hemodynamics responses were found with higher volume RM protocols [3,12,19,29]. The distinct findings may be related to the different protocols between the current (10RM vs. 20RM) and previous studies (<10RM vs. <20RM) [3,12,19]. Even so, it should be noted that participants reached muscle failure in a shorter time (≅40 s) during moderate volume and intensity (10RM) compared to high volume-light load protocol (20RM) (≅80s). Thus, although a similar hemodynamic response between 10RM and 20RM exercises were observed, it is important to highlight that the 10RM protocol may have resulted in a faster dynamic of cardiovascular adjustments than the 20RM sessions.

Relative to hemodynamic responses during exercise, LP led to greater SBP and DBP than the BeP, which is likely to relate to larger muscle mass engaged in the LP exercise, resulting in greater mechanical vascular compression and total peripheral resistance during exercise [4].

The current protocols did not result in SBP post-exercise hypotension, which is a contrast to previous studies using RM reporting SBP hypotension [14,21,22,30]. This difference may be linked to the smaller total exercise volume in the present study, as participants performed only 2 sets of one exercise per protocol, while in prior studies a greater number of sets or exercises were used, resulting in a higher total resistance training volume [14,21,22,30]. It has been reported that the magnitude of post-exercise hypotension relates to the number of sets performed in hypertensive individuals [13,20,31]. In agreement, Polito et al. [14] observed post-exercise hypotension in young normotensive men after 10 exercise sets, while no hypotensive effect was observed with 6 sets. In the previous meta-analysis, Casonatto et al. [8] found superior post-exercise SBP hypotension in hypertensive compared to normotensive individuals, as well as after greater resistance training volume than the present study [8]. Furthermore, it might be possible that a higher number of sets, and hence greater resistance training volume than employed in the present study would be necessary to elicit SBP post-exercise hypotension in normotensive individuals.

A DBP hypotension after exercise was observed in the present study, but only after the BeP protocol. Although different findings have been reported [14], the DBP hypotension post-upper-body exercise in the present study is in accordance to Drouet et al. [32] stud, which reported DBP post-exercise hypotension in prehypertensive (but not in normotensive) men after upper-body exercise, with no DBP hypotension post lower-body exercise [32]. Differences in the resistance exercise protocols (e.g., intensity and volume) may have contributed to the divergent findings between Drouet et al. [32] and the present study. In another study, Almeida et al. [33] reported a decrease in DBP at rest after arm-crank exercise, with no effect of cycling exercise in non-hypertensive individuals. However, the cycling-like nature of their protocols limits the comparison to the current resistance exercise protocol. Since DBP is highly dependent on vasodilatory mechanisms, these findings suggest that exercise engaging a large muscle mass of the upper-body may result in enough vasodilatory stimulation, leading to a sustained reduction in DBP.

Post-exercise hypotension has been related to various adjustments leading to a reduction in peripheral vascular resistance and, to a lesser extent, cardiac output (i.e. the determinants of blood pressure) [23]. The mechanisms related to the greater DBP hypotensive effect of BeP compared to LP exercise observed in this study are unknown, but lower-limb exercise is related to greater metabolic stress compared to upper-limb exercise [34], which may influence autonomic control. For example, Okuno et al. [35] reported a faster recovery of heart rate variability parameters after low intensity resistance exercise compared to the same exercise performed with vascular occlusion, suggesting a delayed recovery of cardiac autonomic function in the condition with greater metabolic stress. Alternatively, and because a greater sympathoadrenergic response occurs in exercise engaging larger muscle mass [36], it is possible that the concentration of blood catecholamines may have been greater after the LP protocol and resulted in increased vasoconstrictor tonus, potentially explaining the difference between LP and BeP in the present study. Nevertheless, more studies are necessary to elucidate the mechanisms driving this differential response post upper vs lower-body exercise.

In the present study, the volume (moderate vs high) and load (high vs light) pattern (i.e., 10RM vs. 20RM) did not influence post-exercise responses, which in contrasts to earlier investigations reporting larger magnitudes or duration of post-exercise hypotension according to exercise volume [4,5,8,13,14] and intensity [5,8,11,12,20]. The differences between the present and previous results may be due to the various resistance training protocols employed (i.e., the volume of exercises and sets, exercises selection, intensities, and RM presence or not), as well as differences in the populations investigated [8,11,37]. In addition, greater acute blood pressure reductions after exercise have been reported in individuals with higher blood pressure levels [37,38], and the participants in the present study were young, healthy, and normotensive, which may have influenced the current findings.

The present study has some limitations, including the method used to investigate cardiovascular responses (i.e., oscillometric and not intra-arterial or beat by beat methods), as well as the lack of investigation of possible mechanisms related to changes in hemodynamic response after exercise (such as sympathetic activity, changes in cardiac output, and vasodilator agents). Also, the level of physical activity of the participants was not assessed, and the current protocols do not enable us to tease out the isolated effects of exercise intensity or volume on the hemodynamic responses observed. Finally, our results should not be extrapolated to populations with BP and training status.

PRACTICAL APPLICATIONS

Repetitions to failure are commonly employed in resistance training programs and understanding the cardiovascular responses to protocols with different load and engaging upper and lower-limb strength exercises is important to predict physiological adjustments to sessions using distinct resistance training variables. The two-set protocols of the present study resulted in a substantial hemodynamic response during exercises, as evidenced by acute increases in SBP, HR and RPP of the participants, with DBP post-exercise hypotension observed after BeP exercise, irrespective of exercise load protocol employed to failure. In a practical perspective, the current findings suggest that, in young normotensive men, irrespective of exercise load (10RM or 20RM), even a low volume (i.e. two sets of a single exercise) resistance training session to failure can bring about a DBP hypotensive response in the post-exercise period, which may serve as a clinical lifestyle approach to help blood pressure control. This post-exercise response to a low volume resistance training session, however, might be limited to upper-body routines.

CONCLUSIONS

The results of the present study suggest that both the BeP and the LP exercise performed as part of a high volume-light load or a moderate volume and load protocol may bring about a similar increase in HR, SBP and RPP during exercise with both the 10RM and 20RM loads in young healthy men, although a greater BP rise may be expected with LP exercise. Conversely, upper-body exercise may result in a greater decrease in DBP for up to 35 min after resistance exercise employing repetitions to failure, which may have positive implications for blood pressure control and maintenance in normotensive individuals.

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Figures and Tables

Figure 1. Experimental design. BP: blood pressure; 10RM: 10 repetition maximum; 20RM: 20 repetition maximum.

Figure 2. Systolic (SBP), diastolic blood pressure (DBP), heart rate (HR) and rate-pressure product (RPP) for bench press (BeP) exercise at pre, after first set (S1) and second set (S2), and in the post-exercise period (5, 15, 25, 35, 45 and 55 minutes) with 10RM (closed square) and 20RM (open square). RM: repetitions maximum. *significant difference from pre-exercise ($p \leq 0.05$).

Figure 3. Systolic (SBP), diastolic blood pressure (DBP), heart rate (HR) and rate-pressure product (RPP) for bench press (BeP) exercise at pre, after first set (S1) and second set (S2), and in the post-exercise period (5, 15, 25, 35, 45 and 55 minutes) with 10RM (closed circle) and 20RM (open circle). RM: repetitions maximum. *significant difference from pre-exercise ($p \leq 0.05$).

Figure 4. Systolic (SBP) and diastolic blood pressure (DBP) for bench press (BeP; circle) and leg press (LP; square) exercises at pre, after the first set (S1) and second set (S2), and in the post-exercise period (5, 15, 25, 35, 45 and 55 minutes). *significant difference from pre-exercise ($p \leq 0.05$). #significant difference between bench and leg press ($p \leq 0.05$).

Table 1. Baseline hemodynamic characteristics in each experimental visit (n=10).

Legend: Values are means ± SD; LP: leg press exercise; BeP: bench press exercise; RM: repetitions maximum.