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1 **Title: Acute Hemodynamic Responses to Repetitions to Failure Using Different Resistance**

2 **Exercises and Protocols in Normotensive Men: A crossover study**

3 **Running Head: Hemodynamic Responses to Repetitions to Failure**

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20 **Abstract**

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

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

30

31 INTRODUCTION

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

38 Endurance exercise is widely known to bring about post-exercise hypotension, but this
39 phenomenon has also been observed after other types of training, including resistance exercise
40 [8]. In addition, resistance training is known to lead to large blood pressure elevation during
41 exercise performance, which returns towards baseline in the post-exercise period. Acute
42 resistance training variables such as intensity (low-to-moderate vs. moderate-to-high) [9–11]
43 volume (e.g., repetitions by set) [4,9,12,13] and exercise selection (e.g., lower vs. upper-body
44 exercises, muscle mass amount) [4,9,14] may influence the magnitude of acute hemodynamic
45 changes to exercise, including the blood pressure, heart rate (HR), and rate-pressure product
46 (RPP) responses to and post-exercise.

47 A resistance training routine may be performed based on a percentage of one-repetition
48 maximum or repetitions maximum (RM, i.e., a load leading to skeletal muscle concentric failure
49 within a predetermined range of repetitions) [15]. In recent years, several studies have identified
50 benefits of using RM to improve maximum strength and hypertrophic muscle gains [16–18].
51 Also, previous studies sought to assess the cardiovascular responses during [4,9,19] and after
52 resistance training sessions employing RM [20–22]. In this regard, investigations have shown
53 significant increases in hemodynamic changes during resistance exercises performed with RM,

54 mainly with high intensity [9,10] and repetitions volume (i.e., total muscle contraction time per
55 set) [3–5,12], as well as greater muscle amount involved in exercise [4,9].

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

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

75

76 **METHODS**

77 **Experimental Approach**

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

82

83 **Participants**

84 The participants were not engaged in regular endurance or resistance training for at least six
85 months prior the experiment, and only normotensive [26] (i.e., resting SBP/DBP <140/90mm
86 Hg) non-obese (body mass index <30kg/m²) male individuals were included. None of the
87 participants were currently taking antihypertensive, cardiovascular, or metabolic medications.
88 All participants were informed of the risks and benefits of the study prior to signing an Informed
89 Consent Form, and all procedures of the study were approved by the Institutional Ethics and
90 Research Board. The sample size required for the present study was determined based on a
91 previous study [27]. Using an α level of 0.05 and a power of 0.90 (PEPI 4.0), ten participants
92 were necessary to test our hypothesis.

93

94 **Procedures**

95 Participants visited the laboratory on six separate occasions, with at least one-week interval
96 between visits. On the first session, anthropometric characteristics were determined, followed by
97 resting SBP, DBP, HR measurements. After that, participants were familiarized with the study
98 procedures and performed the 20RM test for LP and BeP exercises. The 10RM test was
99 conducted on the second visit. During the third, fourth, fifth, and sixth visits, participants

100 completed one of the four exercise protocols in randomized order: LP10RM (LP at 10RM load),
101 LP20RM (LP at 20 RM load), BeP10RM (BeP at 10 RM load), and BeP20RM (BeP at 10 RM
102 load). Participants were allocated to each session in the experimental visits by random allocation
103 to one of all potential combinations. Figure 1 presents the experimental design of the study.

104

105 - Insert Figure 1 here –

106

107 **Repetitions Maximum Tests**

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

120

121 **Experimental Protocols**

122 All participants underwent four experimental sessions in random order: a) 2 sets of 10RM LP, b)
123 2 sets of 20RM LP, c) 2 sets of 10RM BeP and d) 2 sets of 20RM BeP. Each experimental
124 session was performed at the same time of the day (8 a.m. to 12 a.m.), with an interval period of
125 at least one week between experimental sessions. The participant was blinded to exercise
126 intensity before each experimental visit and was instructed to avoid caffeine, medications, and
127 exercises 24h before the visits. After arriving at the laboratory, participants rested for 55 minutes
128 and baseline blood pressure (ABPM-04 recorder with an optical interface, Meditech, Budapest,
129 Hungary), and HR (Polar Electro, Finland) measurements were taken in the supine position.
130 Baseline BP was measured three times with one-minute interval between each. Then, participants
131 performed one of the four experimental exercise protocols with blood pressure and HR recorded
132 in the last repetition of each set. The resistance training protocol was performed without prior
133 warm-up to reduce the influence of confounding factors upon the hemodynamic responses. Two
134 sets of the randomized exercise were performed with a 5-minute passive resting interval between
135 sets, and participants were instructed to avoid breath-holding maneuver throughout the
136 experimental protocols. Participants received constant feedback regarding exercise cadence,
137 range of motion, and technique, and all repetitions in each set were accounted. In the post-
138 exercise period, participants rested in the supine position for 55 minutes, while blood pressure
139 and HR were measured. The SBP, DBP, and HR were recorded prior (Pre), at the end of the first
140 and second set, as well as post-exercise (Post 5, 15, 25, 35, 45 and 55 minutes). Rate-pressure
141 product (RPP) was calculated for each time-point as the product of SBP x HR. Room
142 temperature (about 21 ± 1 °C) and relative humidity ($50\% \pm 5\%$) were relatively constant
143 throughout all visits.

144

145 **Statistical Analyses**

146 Data normality was assessed using the Shapiro-Wilk test. All values are presented in mean \pm
147 standard deviation. Possible differences between groups for volume load were tested by paired
148 sample t-test. To compare the effect of sets in SBP, DBP, HR, and RPP a two-way repeated
149 measures analysis of variance (ANOVA) was used (2 x 3; intensity [10RM and 20RM] x time
150 point [pre, set 1 and set 2]). For the post-exercise period, a two-way repeated measures ANOVA
151 (2 x 7; intensity [10RM x 20RM] x time point [rest vs. 5 vs. 15 vs. 25 vs. 35 vs. 45 vs. 55
152 minutes]) for SBP, DBP, HR, and RPP was used. For exercise comparisons, a two-way repeated
153 measures ANOVA for SBP and DBP was used (2 x 3; exercises [BeP10RM and 20RM x
154 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.
155 45 vs. 55 minutes]). If significant interaction time x intensity was observed a Bonferroni
156 correction was used to identify time differences. The level of significance (α) was set at 0.05. All
157 statistical procedures were performed using the Statistical Package for Social Science (SPSS)
158 version 20.0 (IBM SPSS Inc., Chicago, IL, USA).

159

160 **RESULTS**

161 **Participants' Characteristics and Exercise Sessions**

162 Participants' characteristics are presented in Table 1. The 10RM protocols were performed with
163 a greater load compared to the 20RM protocols (LP10RM: 224.90 \pm 39.32 vs. LP20RM: 162.80
164 \pm 35.89 kg; $p < 0.05$; BeP10RM: 49.60 \pm 7.63 vs. BeP20RM: 34.20 \pm 7.07 kg; $p < 0.05$). The total
165 volume load, however, was significantly ($p < 0.05$) higher in the 20RM compared to the 10RM
166 protocols in the LP (LP10RM: 2.249.00 \pm 393.18 vs LP20RM: 3.256.00 \pm 717.82 rept x kg,
167 $p < 0.05$) and BeP protocols (BeP10RM: 496.00 \pm 76.33 vs BeP20RM: 684.00 \pm 141.36 rept x kg,

168 p<0.05).

169

170 **Cardiovascular Responses to Exercises**

171 Pre-exercise SBP, DBP, HR, and RPP are shown in Table 1. There was no significant difference
172 in baseline hemodynamic parameters between 10RM and 20RM experimental sessions ($p \geq 0.05$).

173 The absolute values of hemodynamic responses to exercises are shown in Figure 2 (LP, 10RM
174 vs. 20RM), 3 (BeP, 10RM vs. 20RM) and 4 (LP 10RM+20RM vs. BeP 10RM+20RM).

175

176 - Insert Table 1 here -

177

178 **Responses to LP Exercise**

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

186

187 - Insert Figure 2 here -

188

189 **Responses to BeP Exercise**

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

197

198 - Insert Figure 3 here -

199

200 **Responses to LP and BeP Exercises**

201 Since no differences between exercise intensities were observed in each exercise, data from
202 10RM and 20RM were compiled for between exercise comparisons. In the first and second set of
203 exercise a greater SBP increase was observed in the LP compared to the BeP exercise, and
204 participant's SBP remained greater in the first five minutes of post-exercise recovery of the LP
205 protocol (Figure 4a, $p<0.05$). The DBP, however, increased in the second set of exercise only in
206 the LP protocol ($p<0.05$) (Figure 4b). In the post-exercise period, the DBP post-BeP exercise fell
207 below baseline values until 35 min into the recovery period ($p<0.05$) and was consistently lower
208 post-BeP compared to LP exercise ($p<0.05$). No post-exercise hypotension was observed with
209 LP ($p\geq 0.05$).

210

211 - Insert Figure 4 here -

212

213 **DISCUSSION**

214 The present study investigated acute hemodynamic responses to two multi-joint resistance
215 exercises (LP and BeP) performed with different load protocols (10RM and 20RM). The main
216 findings of the present study are that a) hemodynamic parameters responded similarly to the
217 10RM and 20RM protocols; b) only two resistance exercise sets resulted in substantial increase
218 in hemodynamic variables during exercise; c) LP resulted in greater blood pressure values during
219 exercise than BeP, and d) only BeP resulted in post-exercise hypotension (in DBP).

220 Major hemodynamic adjustments during exercise have been observed with resistance training
221 sessions with repetitions to failure [3,4,12,19]. In the present study, substantial increments of
222 SBP, HR, and RPP were observed with just two exercise sets, regardless of the RM protocol
223 employed. These results contrast to previous studies, in which higher hemodynamics responses
224 were found with higher volume RM protocols [3,12,19,29]. The distinct findings may be related
225 to the different protocols between the current (10RM vs. 20RM) and previous studies (<10RM
226 vs. <20RM) [3,12,19]. Even so, it should be noted that participants reached muscle failure in a
227 shorter time ($\cong 40$ s) during moderate volume and intensity (10RM) compared to high volume-
228 light load protocol (20RM) ($\cong 80$ s). Thus, although a similar hemodynamic response between
229 10RM and 20RM exercises were observed, it is important to highlight that the 10RM protocol
230 may have resulted in a faster dynamic of cardiovascular adjustments than the 20RM sessions.

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

234 The current protocols did not result in SBP post-exercise hypotension, which is a contrast to
235 previous studies using RM reporting SBP hypotension [14,21,22,30]. This difference may be

236 linked to the smaller total exercise volume in the present study, as participants performed only 2
237 sets of one exercise per protocol, while in prior studies a greater number of sets or exercises were
238 used, resulting in a higher total resistance training volume [14,21,22,30]. It has been reported
239 that the magnitude of post-exercise hypotension relates to the number of sets performed in
240 hypertensive individuals [13,20,31]. In agreement, Polito et al. [14] observed post-exercise
241 hypotension in young normotensive men after 10 exercise sets, while no hypotensive effect was
242 observed with 6 sets. In the previous meta-analysis, Casonatto et al. [8] found superior post-
243 exercise SBP hypotension in hypertensive compared to normotensive individuals, as well as after
244 greater resistance training volume than the present study [8]. Furthermore, it might be possible
245 that a higher number of sets, and hence greater resistance training volume than employed in the
246 present study would be necessary to elicit SBP post-exercise hypotension in normotensive
247 individuals.

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

259 the upper-body may result in enough vasodilatory stimulation, leading to a sustained reduction in
260 DBP.

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

275 In the present study, the volume (moderate vs high) and load (high vs light) pattern (i.e., 10RM
276 vs. 20RM) did not influence post-exercise responses, which in contrasts to earlier investigations
277 reporting larger magnitudes or duration of post-exercise hypotension according to exercise
278 volume [4,5,8,13,14] and intensity [5,8,11,12,20]. The differences between the present and
279 previous results may be due to the various resistance training protocols employed (i.e., the
280 volume of exercises and sets, exercises selection, intensities, and RM presence or not), as well as
281 differences in the populations investigated [8,11,37]. In addition, greater acute blood pressure

282 reductions after exercise have been reported in individuals with higher blood pressure levels
283 [37,38], and the participants in the present study were young, healthy, and normotensive, which
284 may have influenced the current findings.

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

293

294 **PRACTICAL APPLICATIONS**

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

305 lifestyle approach to help blood pressure control. This post-exercise response to a low volume
306 resistance training session, however, might be limited to upper-body routines.

307

308 **CONCLUSIONS**

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

316

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322

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426 **Figures and Tables**

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

429 **Figure 2.** Systolic (SBP), diastolic blood pressure (DBP), heart rate (HR) and rate-pressure
430 product (RPP) for bench press (BeP) exercise at pre, after first set (S1) and second set (S2), and
431 in the post-exercise period (5, 15, 25, 35, 45 and 55 minutes) with 10RM (closed square) and
432 20RM (open square). RM: repetitions maximum. *significant difference from pre-exercise ($p \leq$
433 0.05).

434 **Figure 3.** Systolic (SBP), diastolic blood pressure (DBP), heart rate (HR) and rate-pressure
435 product (RPP) for bench press (BeP) exercise at pre, after first set (S1) and second set (S2), and
436 in the post-exercise period (5, 15, 25, 35, 45 and 55 minutes) with 10RM (closed circle) and
437 20RM (open circle). RM: repetitions maximum. *significant difference from pre-exercise ($p \leq$
438 0.05).

439 **Figure 4.** Systolic (SBP) and diastolic blood pressure (DBP) for bench press (BeP; circle) and
440 leg press (LP; square) exercises at pre, after the first set (S1) and second set (S2), and in the post-
441 exercise period (5, 15, 25, 35, 45 and 55 minutes). *significant difference from pre-exercise ($p \leq$
442 0.05). #significant difference between bench and leg press ($p \leq 0.05$).

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

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

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