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Original Research

Cardiovascular Responses to Unilateral, Bilateral, Upper, and Lower Limbs Resistance Exercise

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ABSTRACT

International Journal of Exercise Science 16(2): 1154-1164, 2023. The effects of different resistance exercises on cardiovascular responses remain elusive. Therefore, the present study aimed to investigate acute cardiovascular responses to unilateral and bilateral upper and lower limb resistance exercise. Young healthy males (n = 22; 26.9 ± 5.4 years, 170.0 ± 6.0 cm, 77.0 ± 10.8 kg) participated in the present study. Four experimental sessions were carried out, each consisting of one of the four exercises: unilateral and bilateral knee extension, unilateral and bilateral biceps curl. Cardiovascular responses (heart rate; HR, systolic blood pressure; SBP, and rate-pressure product; RPP) were measured at rest and after each of the three sets in each resistance exercise. All sets were performed until concentric muscle failure with a rest interval of two min. The HR, SBP, and RPP progressively increased during all sessions with uni- and bilateral exercises of the lower and upper limbs. Importantly, bilateral exercises, mainly of the lower limbs, induced greater increases in HR, and RPP than unilateral exercises of the upper and lower limbs. Regarding SBP, bilateral knee extension exercise induced greater increases than unilateral biceps curl. From a practical standpoint, exercise professionals may consider prescribing unilateral upper and lower limb exercises to alleviate cardiovascular stress, because even when performed until concentric muscle failure, this exercise mode seems to induce lower cardiovascular demand during the resistance training session.

KEY WORDS: Strength training, hemodynamic responses, blood pressure, rate-pressure product

INTRODUCTION

It is widely accepted that resistance training improves skeletal muscle mass, strength, power output, and functional capacities (14). Evidence suggests that chronic resistance training also leads to improved cardiovascular health and function evidenced by reductions in systolic blood pressure (SBP) (28), resting heart rate (4), and improved heart rate variability (16). Notably, during resistance exercises, repeated muscle contractions are performed to overcome an external load, which promotes a variety of hemodynamic responses. For example, compression of the vasculature by the contracting muscles increases peripheral resistance to blood flow and acutely increases SBP (20). Additionally, an increased concentration of metabolites within skeletal muscles stimulates chemoreceptors and upregulates heart rate (HR) and cardiac contractility via sympathetic activation (8, 32) resulting greater increase in rate pressuring product (RPP); a proxy of myocardium strain (17).

Previous investigations showed that different resistance training variables influence cardiovascular overload (SBP and HR responses) during resistance exercises such as intensity (13, 20), set (11) and repetition volumes (13, 20), resting intervals (15), contraction velocity (18), muscle mass involved (20, 23), and mode of resistance exercise; unilateral and bilateral in upper and lower limbs (3, 21). It has been proposed that the greater the amount of muscle mass involved during resistance exercise, the greater the cardiovascular responses (29, 30). In fact, there are reports suggesting that multi-joint and bilateral exercises—therefore, the greater amount of muscle mass involved—elicit greater cardiovascular responses (29, 30). However, these findings are not universal. For example, another study observed greater increases in HR and RPP when performing the bilateral biceps curl exercise than the bilateral knee extension; a smaller and greater amount of muscle mass was involved (21).

Given the apparently inconclusive results, further studies comparing resistance exercises for different body segments (upper limbs versus lower limbs) and execution modes (unilateral versus bilateral) are necessary. Therefore, the present study aimed to investigate acute cardiovascular responses to unilateral and bilateral resistance exercises performed with the upper and lower limbs. It was hypothesized that bilateral exercises would have a greater impact on HR, SBP, and RPP than unilateral exercises. Moreover, it was hypothesized that lower limb exercises would result in significantly greater increases on HR, SBP, and RPP compared to upper limb exercises.

METHODS

Participants

We estimated the sample size using G*Power (version 3.1.9.6). Previous data on the effects of resistance exercise on cardiovascular parameters were used to estimate the sample size (15). Thus, we estimated the required sample based on an effect size of 0.44, a significance level of 0.05, and a power of 0.90. The analysis indicated that at least 20 participants were needed to achieve adequate statistical power. Twenty-two male volunteers (26.9 ± 5.4 years, 170.0 ± 6.0 cm, 77.0 ± 10.8 kg, 20.0 ± 7.2% of body fat) who were physically active, apparently healthy, did not have any musculoskeletal injuries that could be aggravated by the tests and did not make regular use of medications or any type of drugs that influenced heart rate and blood pressure volunteered to participate in the present study. Hypertension (systolic and diastolic blood pressure > 140 mmHg and > 90 mmHg, respectively), diabetes, smoking, and obesity (BMI > 30 kg/m²) were adopted as inclusion criteria. An anamnesis was performed with each participant to obtain the aforementioned information. Individuals who reported having practiced physical activity for a period longer than 20 minutes per day and with a frequency equal to or greater than three times per week in the 6 months preceding the experiment were considered active (6). Notably, all participants had previous experience with resistance training and were familiar with the exercises performed in the study. This study was approved by the local University Ethics Committee (protocol number: 3.781.675, December 18, 2019) and all participants read and signed an informed consent form. The investigation meets the guidelines set forth by the International Journal of Exercise Science (22). All information about the participants was kept completely confidential.

Protocol

The present study aimed to assess cardiovascular responses to different resistance exercise conditions. To do so, SBP and HR were quantified before and following four situations: bilateral knee extensions, bilateral biceps curls, unilateral knee extensions, and unilateral biceps curls. These exercises were chosen because of their common inclusion in resistance training programs (9, 12). The participants were instructed to refrain from practicing any type of exercise during the experimental period. The experimental period comprised three consecutive weeks. During the first week, participants were informed about the procedures of the present study and performed an anamnesis, anthropometric assessment, and familiarization with the 10-RM tests. During the second week, the 10-repetition maximum (10-RM) load was determined for all exercises on separate days. In the third week of the experiment, participants returned to the laboratory on four consecutive days respecting a 24-h interval between sessions to perform the training sessions. During each session, hemodynamic responses to three sets of four different exercise protocols were assessed. The experimental design is illustrated in Figure 1.

10-RM Load Determination: The 10-RM determination protocol comprised a warm-up consisting of two sets of fifteen repetitions with 30% of individual body weight followed by up to three attempts to perform 10 maximal repetitions with a pre-determined load, as determined by Baechle and Earle (1). Attempts were considered successful when the participants were able to lift the established load 10, but not 11, times. If participants were able to perform more/less than 10 repetitions, the load was decreased/increased by 5-10 kg and another attempt was performed after a three-minute rest interval. 10-RM load assessment sessions were performed with 24-h intervals in between.

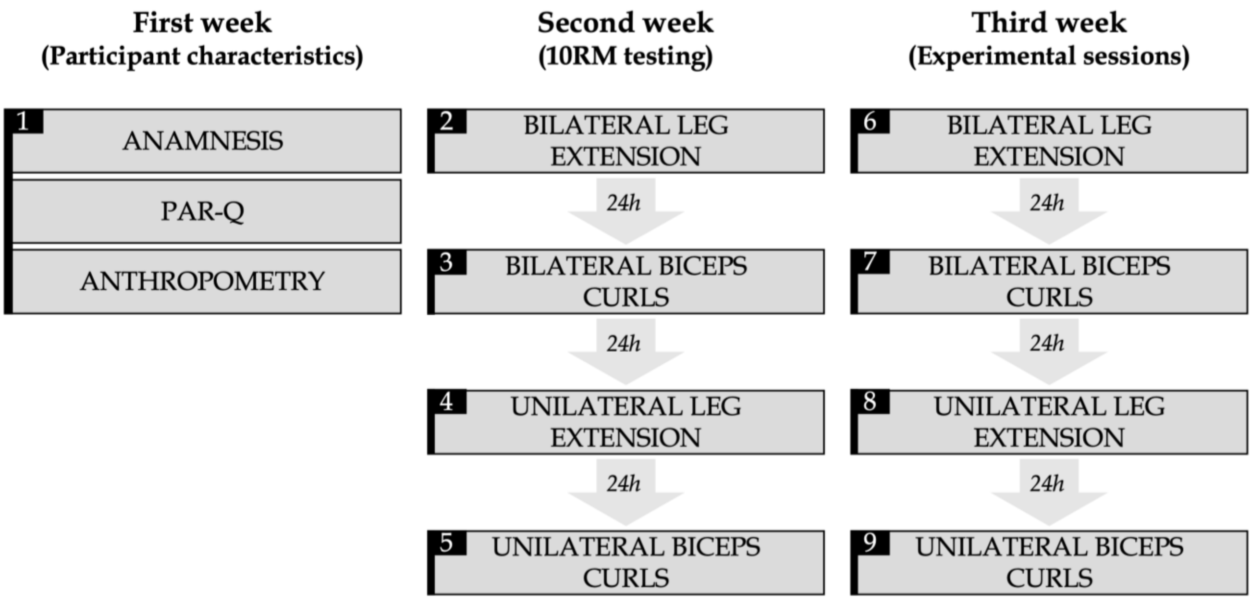

Figure 1. Study design.

Assessment of Cardiovascular Responses: All assessments were performed by the same examiner and at the same time of the day. Blood pressure was assessed based on the recommendations provided by the American Heart Association (24). The inflatable cuff was positioned at approximately 2.5 cm above the antecubital fossa of the left arm and was inflated gradually and deflated at a rate of approximately 2 mmHg until the identification of the 1st and 5th Korotkoff noises, which were recorded as the systolic and diastolic blood pressures values, respectively. Heart rate was assessed continuously using a wrist heart rate monitor (Polar FT1, Polar, Finland). SBP and HR were assessed at rest (following five minutes standing at the position at which the exercise was performed) and one minute following each set for all exercises. The RPP was then calculated for each time point as the product of SBP and HR. Participants were instructed to avoid taking caffeine before laboratory visits to perform the experimental conditions. The coefficients of variation for our dependent variables were ≤ 5%.

Experimental Resistance Training Sessions: Unilateral and bilateral knee extensions were performed sitting on a knee extension chair with the hips flexed at 70° and knees starting each repetition flexed at 90°. Repetitions were completed when the load was lifted until full knee extension. Unilateral and bilateral biceps curls were performed with dumbbells and a free-moving bar, respectively. Unilateral curls were performed in a seated position with the hips and knees flexed at 90° and the back supported by a bench. Bilateral curls were performed in a standing position with the back supported against the wall. In all resistance training sessions, the participants performed three sets, all performed until concentric momentary failure and a tempo of 2:2 seconds was respected for concentric and eccentric contractions. The rest interval between sets was two minutes. Participants were instructed not to perform the Valsalva maneuver and all assessments were conducted by the same examiner.

Statistical Analysis
Data normality was confirmed using Shapiro-Wilk's test. The assumptions of data homogeneity and sphericity were also confirmed using Levene's and Mauchly's tests, respectively. Differences over sets and between exercises were tested by mixed-model analyses of variance (ANOVA) for repeated (sets) and non-repeated (exercises) measurements. Partial eta squared (η_p^2) were calculated for the ANOVA main effects and the magnitudes of η_p^2 were classified as small ≤ 0.06, moderate 0.07-0.14, and large > 0.14 (7). When relevant, pairwise comparisons were conducted using Tukey's post hoc tests. Cohen's d was calculated for significant changes by dividing the difference between the means by the pooled standard deviation of both conditions for the dependent variables. Effect sizes (ES) < 0.2, 0.2-0.5, and > 0.5 were interpreted as trivial, medium, and large, respectively (7). Data are expressed as mean ± standard deviation unless otherwise stated.

RESULTS

Mean, standard deviation, and 95% confidence interval values are presented in the supplementary material. Baseline values for HR, SBP, and RPP were not different between exercise conditions ($p > 0.05$). Changes in HR over sets for all exercises are represented in Figure 2. There was significant ($p < 0.01$) effects of sets (F = 598; $\eta_p^2 = 0.88$), exercise (F = 5.5; $\eta_p^2 = 0.16$) and sets x exercise interaction (F = 7.2; $\eta_p^2 = 0.2$) for HR. Post hoc analyses revealed that HR increased significantly over sets and that HR was greater for bilateral knee extensions and bilateral biceps curls compared to unilateral biceps curls during all sets. HR was greater (51-97%, $p < 0.05$) than resting values following all sets for the four exercises. HR following bilateral knee extensions (5.7%, ES = 0.32) and bilateral biceps curls (4.0%, ES = 0.24) was significantly greater ($P < 0.05$) following the third set compared to the values recorded following the first set. Following the first and second sets, HR was significantly greater ($p < 0.05$) for bilateral knee extensions (1st set: 14.4%, ES = 0.85; 2nd set: 16.4%, ES = 0.23) and bilateral biceps curls (1st set: 16.1%, ES = 1.04; 2nd set: 17.1%, ES = 1.22) compared to unilateral biceps curls. Following the third set, HR was significantly greater ($p < 0.05$) for bilateral knee extensions compared to unilateral knee extensions (12.0%, ES = 0.84) and unilateral biceps curls (16.7%, ES = 1.21), and this was also the case for bilateral biceps curls (vs. unilateral knee extensions: 12.3%, ES = 0.85; vs. unilateral biceps curls: 17.0%, ES = 1.2).

Changes in SBP over sets for all exercises are represented in Figure 3. There was significant ($P < 0.01$) effects of sets ($F = 241.9$; $\eta_p^2 = 0.74$) and sets x exercise interaction ($F = 3.1$; $\eta_p^2 = 0.1$) for SBP. Post hoc analyses revealed that SBP changed significantly over sets regardless of groups. SBP was greater (16.0–41.0%, $p < 0.05$) than resting values following all sets for the four exercises. SBP was significantly greater (5.0-13.0%, $p < 0.05$) following the second and third sets compared to the values recorded following the first set for all exercises. SBP following the third set of bilateral biceps curls was significantly greater (4.4%, $p < 0.05$) than SBP following the second set of the same exercise. SBP was 9.6% greater ($p < 0.05$, ES = 0.76) for bilateral knee extensions compared to unilateral biceps curls following the second set. SBP was 10.9% greater ($p < 0.05$, ES = 0.78) for bilateral knee extensions compared to unilateral biceps curls following the third set.

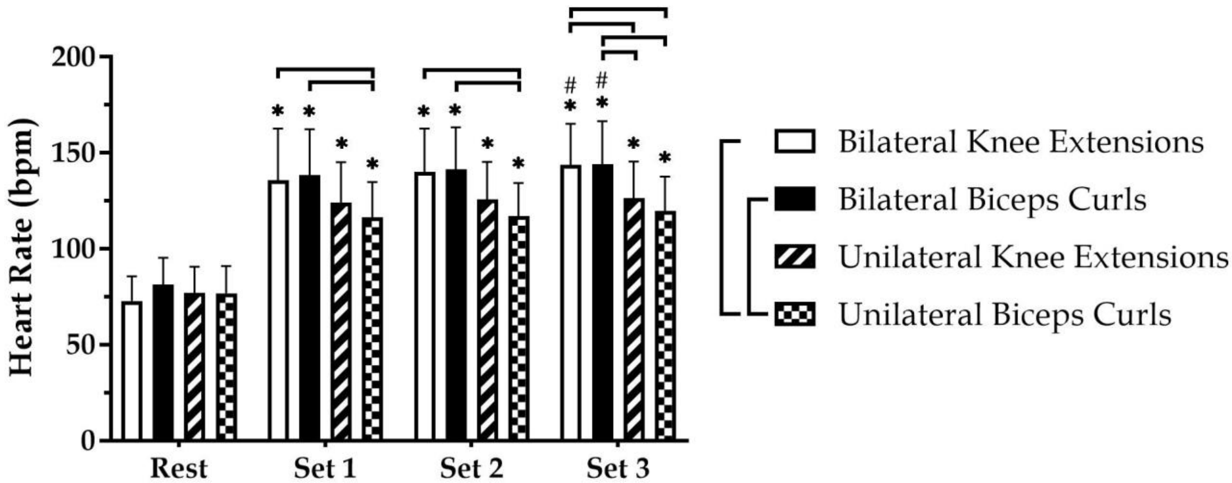

Figure 2. Heart rate (HR) values at rest and following 1-3 sets of bilateral knee extensions, bilateral biceps curls, unilateral knee extensions, and unilateral biceps curls. Brackets represent significant ($p < 0.05$) differences in post hoc/pairwise comparisons. *$p < 0.05$ compared to rest for the same exercise, #$p < 0.05$ compared to set 1 for the same exercise. Values are expressed as mean and standard deviation.

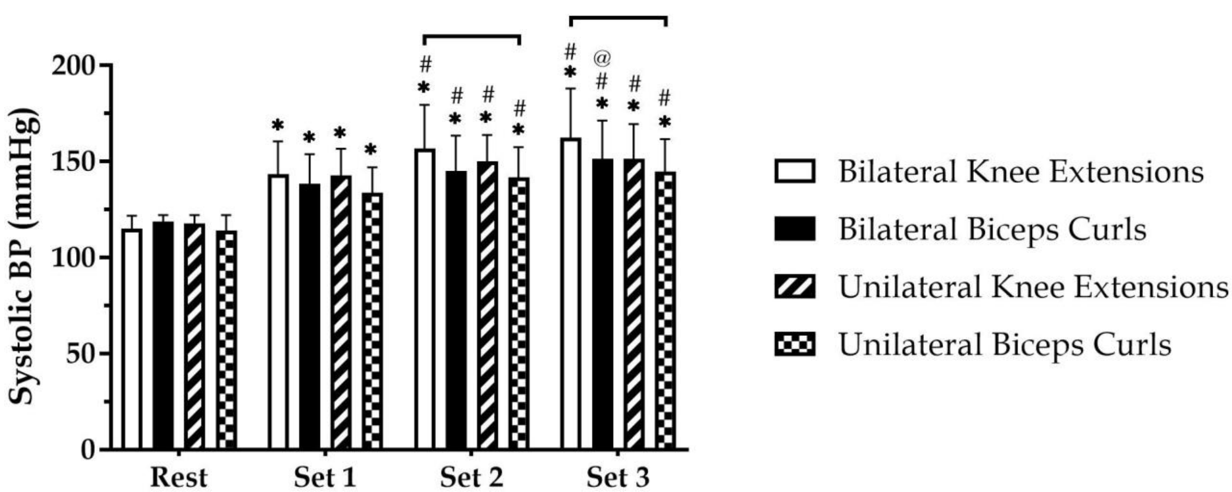

Figure 3. Systolic blood pressure (BP) values at rest and following 1-3 sets of bilateral knee extensions, bilateral biceps curls, unilateral knee extensions, and unilateral biceps curls. Brackets represent significant ($p < 0.05$) differences in post hoc/pairwise comparisons. *$p < 0.05$ compared to Rest for the same exercise, #$p < 0.05$ compared to set 1 for the same exercise, @$p < 0.05$ compared to set 2 for the same exercise. Values are expressed as mean and standard deviation.

Changes in RPP over sets for all exercises are represented in Figure 4. There was significant ($p < 0.01$) effects of sets (F = 510; $\eta_p^2 = 0.86$), exercise (F = 6.5; $\eta_p^2 = 0.19$) and sets x exercise interaction (F = 7.2; $\eta_p^2 = 0.2$) for RPP. Post hoc analyses revealed that RPP changed significantly over sets regardless of groups and that RPP was greater for bilateral knee extensions and bilateral biceps curls compared to unilateral biceps curls during all sets. RPP was greater (77-178%, $p < 0.05$) than resting values following all sets for the four exercises. RPP was significantly greater (6-19%, $p < 0.05$) following the second and third sets compared to the values recorded following the first set for all exercises. RPP following the third set of bilateral biceps curls was significantly greater (6.2%, $p < 0.05$) than SBP following the second set of the same exercise. RPP was significantly greater ($p < 0.05$) for bilateral knee extensions (1st set: 20.7%, ES = 0.99; 2nd set: 24.9%, ES = 1.27) and bilateral biceps curls (1st set: 18.6%, ES = 1.05; 2nd set: 18.7%, ES = 1.07) compared to unilateral biceps curls following the first and second sets. RPP was also 14.7% greater ($p < 0.05$, ES = 0.71) for bilateral knee extensions compared to unilateral knee extensions following the second set. Following the third set, RPP remained greater (17.8%, ES = 0.93) for bilateral knee extensions compared to unilateral knee extensions following the second set. Similarly, RPP was significantly greater ($P < 0.05$) for bilateral knee extensions (25.5%, ES = 1.36) and bilateral biceps curls (19.9%, ES = 1.08) compared to unilateral biceps curls following the third set.

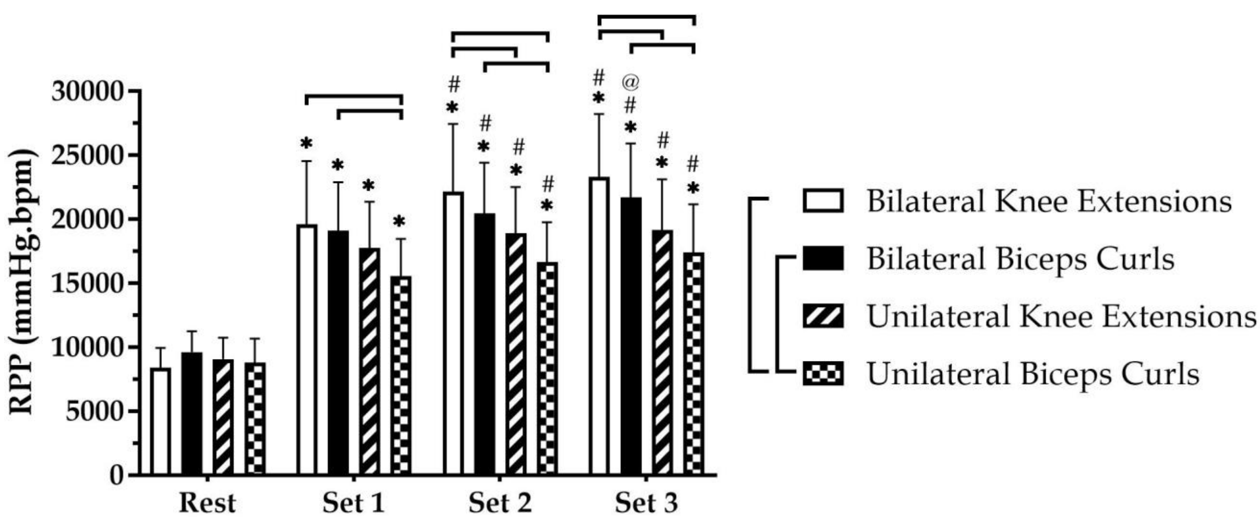

Figure 4. Rate-pressure product (RPP) values at rest and following 1-3 sets of bilateral knee extensions, bilateral biceps curls, unilateral knee extensions, and unilateral biceps curls. Brackets represent significant ($p < 0.05$) differences in post hoc/pairwise comparisons. *$p < 0.05$ compared to Rest for the same exercise, #$p < 0.05$ compared to set 1 for the same exercise, @$p < 0.05$ compared to set 2 for the same exercise. Values are expressed as mean and standard deviation.

DISCUSSION

The present study aimed to investigate the cardiovascular responses to different variations of upper and lower limb exercises. Our main findings were a) HR increased after all four exercises, however, HR increases were greater for bilateral knee extensions and bilateral biceps curls compared to unilateral biceps curls during all sets and following the third set; b) SBP increased after all four exercises, however, SBP was higher in response to bilateral knee extension than unilateral biceps curl; and c) RPP increased in all conditions, however, bilateral knee extension was higher than unilateral knee extension and unilateral biceps curl after all sets, as well as bilateral biceps curl induced higher increases in RPP than unilateral biceps curl after all sets.

In the present study, we observed greater increases in HR following bilateral exercise than unilateral exercise. Interestingly, increases in HR were not different between upper and lower limb exercises at any point. Our findings partially corroborate the results from a previous study on the topic by Moreira et al. (21), who observed a greater increase in HR with exercises performed bilaterally than unilaterally. On the other hand, Moreira et al. (21) observed greater increases in HR after bilateral biceps curl than bilateral knee extension. Such divergences can be explained, at least in part, by the differences in the level of effort. In the present study, the sets were performed to concentric muscle failure (therefore, maximum effort), whereas in the study by Moreira et al. (21) the exercises were performed at 80% of 10RM load, therefore likely not performed to failure. In this sense, the maximum effort experienced by participants in the present study may have contributed to a similar increase in HR by mechanisms related to the autonomic nervous system, e.g., suppression of parasympathetic activity—known to regulate HR (15, 16). In fact, resistance exercise performed to failure elicited greater reductions in parasympathetic activity indices than stopping the sets before failure (15). This conceivably helps to explain similar increases in HR observed in the present study when comparing upper and lower limbs.

Regarding SBP, there were increases in response to all exercise conditions. Moreover, SBP values at the second and third sets were also greater than those recorded at the final of the first set in all exercise conditions and bilateral biceps curls resulted in greater SBP values at the third set compared to the second set. Our findings are in line with previous reports showing that SBP increases abruptly at the onset of resistance exercise (10, 19, 20). The mechanisms underpinning increases in SBP observed from the third to the second set of bilateral biceps curl are not clear, but the accumulative activation of trunk muscles as a stabilizer might have increased peripheral vascular resistance signaling for an exacerbated inotropic response (25). Notably, increases in SBP were greater for bilateral knee extensions compared to unilateral biceps curls in the present study but no significant differences were found between any other conditions. These findings indicate that muscle mass involved in the bilateral lower limb exercise appears to influence the magnitude of inotropic response through increased peripheral vascular resistance only when the muscle mass involved is remarkably different (i.e., knee extensors from both limbs vs. elbow flexors of only one limb) (2, 20).

Regarding RPP, we have found significant increases from the first to the third set compared to resting values for all exercise conditions. Increases in the RPP compared to the resting condition were expected for all conditions since resistance exercise promotes sympathetic activation, resulting in increased HR and SBP (26). Similar responses were reported by Camilo et al. (5) during sets of leg press exercise that showed an association between exercise volume and increases in RPP. In fact, a progressive increase in RPP was observed according to the exercise volume in the present study. Physiologically, the observed changes in RPP as exercise set progressed can be explained by the peripheral vascular resistance promoted by the contracting muscles (2) as well as metabolite accumulation (31) by activation of chemical receptors that promote chronotropic and inotropic effects. Metabolite accumulation as a mechanism underpinning increases in RPP in response to exercise is corroborated by previous data (31) as well as the time under tension (due to higher training volume) are keys factors determining increases in RPP in response to resistance exercise, and SBP being the most affected factor (18).

Interestingly, RPP after the third set was significantly greater than RPP after the second set for bilateral biceps curls only. As previously discussed, the activation of stabilizing trunk muscles during orthostatic bilateral biceps curls associated with bilaterality might have resulted in greater RPP response due to increased peripheral vascular resistance and metabolite accumulation. It is also possible that the orthostatic exercise might have diminished venous return, which is known to signal HR increase (27). This is an important finding of the present study, since bilateral elbow flexors exercise was performed in an orthostatic—and therefore more cardiovascular-demanding—position compared to unilateral elbow flexors exercise, which was performed at a seated position. This result suggests that the bilateral exercise in the orthostatic position by itself can significantly increase cardiovascular strain during exercise as evidenced by the bilateral biceps curl being the only exercise during which the RPP increased in the third set compared to the second set.

The results of this study provide indicatives that there are differential effects of resistance exercise performed using different modes of execution (unilaterally, bilaterally with lower and upper limbs) on cardiovascular responses. However, our study is not free from limitations. We measured cardiovascular responses during sessions with a single exercise. Therefore, it is recommended that further studies of similar designs should be carried out with sessions that include more exercises. A second consideration concerns the population investigated in this study, apparently healthy young men. In this regard, further studies in different populations, such as hypertensive and older adults, are needed to assess the safety of prescribing different resistance exercise protocols, as responses may be different for these populations. Importantly, all modes of resistance exercise for the different body segments were safe for apparently healthy adults.

Conclusion: From our results, the HR, SBP, and RPP progressively increase during resistance training sessions with unilateral and bilateral exercises of the lower and upper limbs with sets performed until concentric muscle failure. Importantly, bilateral exercises, mainly of lower limbs, performed until concentric momentary muscle failure induces greater increases in HR and RPP than unilateral exercises of upper and lower limbs. Regarding SBP, bilateral knee extension exercise seems to induce greater increases than unilateral biceps curl, but it was not different from unilateral knee extension and bilateral biceps curl. In practical terms, when the objective of the resistance training session is to alleviate and control cardiovascular stress, exercise professionals may consider using unilateral upper and lower limb exercises; because even when performed until concentric muscle failure, they seem to induce relatively lower cardiovascular demand (i.e., RPP) than bilateral resistance exercise.

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