Cardiac Work Remains High after Strength Exercise in Elderly


Abstract

Moderate- to high-intensity strength training is recommended for healthy adults. In young subjects, a single session of strength training decreases blood pressure, while heart rate and cardiac work remain elevated afterwards. However, these effects have not been clearly demonstrated in elderly subjects. To investigate this issue, 16 elderly subjects each underwent a Control and an Exercise (3 sets, 8 RM, 9 exercises) session conducted in random order. Haemodynamic variables and heart rate variability were measured before and after the interventions. Systolic blood pressure did not change after the exercise session but did increase after the control session (+8.1 ± 1.6 mm Hg, P ≤ 0.05). Diastolic blood pressure, as well as systemic vascular resistance increased similarly after both sessions. Cardiac output and stroke volume decreased, while heart rate, rate-pressure product and the low- to high-frequency ratio of heart rate variability increased only after the exercise session (∆0.5 ± 0.1 L/min, ∆−9.3 ± 2.0 ml, ∆3.8 ± 1.6 bpm, ∆+579.3 ± 164.1 mmHg·bpm and ∆+0.71 ± 0.34, P ≤ 0.05). Ambulatory blood pressure was similar after both sessions, while heart rate and rate pressure product remained higher after the exercise session for up to 4.5 h. After a single session of strength training, cardiac sympathetic modulation and heart rate remain elevated in elderly subjects, keeping cardiac work elevated for a long period of time.

Introduction

Aging is associated with reductions in muscle mass and strength [10]. Strength training (ST) is recommended for older adults to reverse or delay these harmful effects [3]. Moderate- to high-intensity ST increases muscle cross-section area by 3.3% [36] and strength by approximately 30% [29].

Aging is also linked to undesirable changes in cardiovascular function, such as increases in heart rate (HR) and blood pressure (BP), which lead to a higher cardiovascular load and risk [6]. Adverse cardiac events are the major cause of death in older adults [9], and physiological conditions that increase cardiac sympathetic activity enhance this risk [25].

In healthy young subjects, a single session of ST decreases BP, thereby reducing the cardiovascular load during the recovery period [24,30,31,35]. In contrast, HR and sympathetic cardiac modulation remain elevated after a ST session [31,35], which also maintains an elevated cardiovascular load. Thus, the effect of a session of ST on the cardiovascular risk depends on the balance between these contrasting post-exercise effects. Information about these responses in elderly subjects who are performing moderate- to high-intensity ST is important for assuring the safety of this kind of exercise in this population. Since aging is associated with structural and functional cardiovascular alterations [27,33] that decrease the physiological capacity to adapt to stressful situations, we hypothesized that, in older adults, after a session of ST, the fall in BP lasts for a short duration, while cardiac sympathetic activation and HR remain elevated for a long duration.

Previous studies that evaluated [16,19,23] cardiovascular responses after a ST session in elderly subjects had several limitations that impaired the complete understanding of what happens after a typical ST session in elderly subjects who exercise regularly. These limitations include the absence of a control session, the inclusion of subjects who were not adapted to training and the measurement of responses for only a short period after the exercise. In addition, most studies have not assessed other variables besides BP, which is
Methods

Participants

16 older adults (60–74 years, 11 women and 5 men) participated in this study after signing an informed consent form approved by the Ethics Committee of the School of Physical Education and Sport, University of São Paulo. This study followed the ethical standards of this journal [15] and was registered in ClinicalTrials.gov system (NCT01113203).

Participants had no previous diagnosis of cardiovascular or musculoskeletal diseases. Subjects who presented high BP levels and/or cardiovascular abnormalities in resting or exercise electrocardiograms (ECG) were excluded. None of the subjects smoked or took medications that could affect cardiovascular responses. All subjects had been participating regularly in a ST program for 10–12 weeks before the experiments. At the time of the experiments, all the subjects were performing, twice a week, 3 sets of 8 RM in 9 resistance exercises, and thus, they were considered as trained subjects. The physical and functional characteristics of the subjects are presented in Table 1.

<table>
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<tr>
<th>Physical and functional characteristics of the subjects.</th>
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<tr>
<td>N</td>
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<tr>
<td>female/male</td>
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<td>age, yrs</td>
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<td>height, cm</td>
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<td>body mass index, kg/m²</td>
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<td>resting diastolic BP, mmHg</td>
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<td>resting heart rate, bpm</td>
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Values = mean ± SE. BP = blood pressure

Resting auscultatory BP was measured 3 times after 5 min of seated rest in 2 visits, following the recommendations of the European Society of Hypertension [26]. Subjects were excluded if systolic and/or diastolic BP were ≥ 140 and 90 mmHg, respectively [26]. ECGs were performed before and during a maximal exercise test conducted on a treadmill using Balke's modified protocol to exclude subjects with any sign of cardiovascular disease.

Subjects underwent a 1-repetition maximum (1 RM) test in nine exercises (leg press, chest press, right leg curl, left leg curl, lat pull down, right leg kick back, left leg kick back, upright row and leg press rotary raise) following Kraemer and Fry’s protocol [18].

Experimental protocol

All subjects underwent, in a random order, both a control (CS) and an exercise session (ES), with an interval of at least 5 days between them (mean interval 9 ± 1 days). Sessions were performed at least 48 h after a session of their regular training program. Each session began between 12 and 2 pm. Subjects were instructed to take a light meal 2 h before each session, the content of which should be similar on both experimental days, and should not include substances that may influence BP.

Subjects remained seated for 30 min before the intervention in each session. Then they moved to the exercise room where they rested during the CS and exercised during the ES for approximately 90 min each. They did not know which intervention they were going to do until the beginning of the intervention. In the ES, volunteers performed 3 sets of 8 RM in the 9 exercises mentioned above. The workload used in each exercise was the same employed in the subjects’ training program for achieving 8 RM. The resting intervals between sets and exercises lasted 3 and 2 min, respectively. This exercise protocol was adapted from the American College of Sports Medicine (ACSM) Position Stand of Progression Models in Resistance Training for Healthy Adults [2] that recommends for novice and intermediated exercisers 1–3 sets of 8–12 repetitions and rest periods of 2–3 min for core exercises and 1–2 min for assistance exercises. In the CS, subjects were positioned in the exercise machines but did not perform any exercise. After the interventions, they returned to the laboratory and remained seated for 60 min. Afterwards, they had 30 min to take a shower, and then an ambulatory BP device was attached to their non-dominant arm. Subjects were instructed to maintain their usual daily activities and avoid physical exercise, alcohol ingestion and sleep during day while wearing the monitor. They were also asked to report and maintain a similar activity pattern after both experimental sessions.

BP, cardiac output (CO) and HR were measured in triplicate before and after the interventions, and the mean values were calculated. A post-intervention evaluation was performed 60 min after each intervention because the post-exercise hypertensive effect is maximized at this time [31]. ECG, respiratory activity and beat-by-beat BP were collected for autonomic assessment for 10 min in the pre-intervention period and from 35 to 45 min after the intervention. Ambulatory monitoring was performed for 24 h.

Measurements

Auscultatory BP was measured on the dominant arm by the same trained observer in both experimental sessions using a mercury column. 2 researchers performed the measurements, and the intraclass correlation coefficients between them were 0.962 and 0.953 for systolic and diastolic BP, respectively. ECG was continuously monitored (TEB, M–10, São Paulo, Brazil), and HR was recorded immediately after BP measurement.

CO was estimated by the indirect Fick method, employing the CO₂ rebreathing technique [17], and a metabolic cart (Medical Graphics Corporation, CPX/D, Minnesota, USA), as previously reported [35]. Mean BP, systemic vascular resistance (SVR), stroke volume (SV) and rate–pressure product (RPP) were calculated.

For autonomic evaluation, ECG, respiratory activity (UIP, Pneumotrace 2, California, USA) and beat-by-beat BP (Finapres Medical System, Finometer, Amsterdam, Netherlands) were acquired by a data acquisition system (WinDaq DI-720, Akron, Ohio, USA) with a sampling rate of 500Hz/channel. HR variability (HRV) was assessed by autoregressive spectral analysis (Programma di Analisi Lineare, Milan, Italy) [34]. The oscillatory components of the time series were modelled by the Levinson-Durbin recursion and the order of the model chosen according to Akaike's crite-
tion [21, 34]. Low- (LF<sub>R–R</sub>: 0.04–0.15 Hz) and high-frequency (HF<sub>R–R</sub>: 0.15–0.4 Hz) components were expressed both in absolute and normalized units (nu). The LF<sub>R–R</sub> and HF<sub>R–R</sub> components of HRV were accepted as markers of predominant cardiac sympathetic and parasympathetic modulations, respectively [34].

Spontaneous baroreflex sensitivity was evaluated by the sequence method [28]. Sequences of at least 3 consecutive heart beats that presented concomitant increases (positive sequences) or decreases (negative sequences) in the R-R interval (at least 4 ms) and systolic BP (at least 1 mm Hg) were detected. For each sequence, a linear regression was calculated and considered valid if the correlation coefficient was ≥0.80. Baroreflex sensitivity was determined by the mean of the slopes of all valid sequences.

Ambulatory data were measured every 15 min for 24 h by an oscillometric device (Spacelabs 90207, Spacelabs Inc, Redmond, Washington, USA). Device calibration was checked regularly [4]. Ambulatory data were analysed by the following averages: 24 h (all measurements taken for 24 h), total awake (all measurements taken while the subject was awake), awake until sleep (all measurements taken before the subject reported sleeping), and asleep (all measurements taken while the subject reported sleeping) periods. Moreover, the first 3 h of recordings were also analysed separately.

Statistical analysis
Considering an alpha error of 0.05 and a power of 90%, the minimum sample size necessary to detect a difference of 4 mmHg in BP, considering SD = 3 mm Hg, was calculated to be 10 subjects. Moreover, the sample size necessary to detect a difference of 0.32 L/min in CO with SD = 0.32 L/min was 11 subjects. The values employed for these calculations were based on previous studies [35].

As gender may influence haemodynamic and neural variables, we performed an initial analysis including gender as a main factor, but no consistent difference was observed between men and women. Thus, data from both genders were combined for analysis.

Responses to interventions were compared by a 2-way ANOVA for repeated measures (Statsoft, Statistica for Windows, Oklahoma, USA). The mean values of the ambulatory data were compared between the sessions by paired t-tests. The values of the first 3 h of monitoring were compared by a 2-way ANOVA for repeated measures. A Newman-Keuls post-hoc test was employed. P ≤ 0.05 was defined as significant. Data are presented as mean ± SE.

Results
7 subjects began the experimental protocol with the CS and nine with the ES. The mean workloads employed for each exercise were 93.2 ± 8.1 kg for leg press, 33.8 ± 4.6 kg for chest press, 14.8 ± 1.1 kg for right leg curl, 14.8 ± 1.1 kg for left leg curl, 35.5 ± 2.6 kg for lat pull down, 15.0 ± 1.1 kg for right leg kick back, 15.0 ± 1.1 kg for left leg kick back, 19.1 ± 1.3 kg for upright row, and 101.2 ± 8.7 kg for leg press rotary raise. These workloads corresponded, respectively to 72.7 ± 2.9, 68.4 ± 3.5, 66.1 ± 5.0, 66.1 ± 5.0, 70.7 ± 2.4, 66.4 ± 2.2, 66.4 ± 2.2, 65.4 ± 2.9 and 59.5 ± 4.9% of 1 RM.

Pre-intervention, all the haemodynamic and neural parameters were similar before the sessions, except for CO and SV, which were slightly higher in the ES than in the CS (Fig. 1). The mean workloads employed for each exercise were 93.2 ± 8.1 kg for leg press, 33.8 ± 4.6 kg for chest press, 14.8 ± 1.1 kg for right leg curl, 14.8 ± 1.1 kg for left leg curl, 35.5 ± 2.6 kg for lat pull down, 15.0 ± 1.1 kg for right leg kick back, 15.0 ± 1.1 kg for left leg kick back, 19.1 ± 1.3 kg for upright row, and 101.2 ± 8.7 kg for leg press rotary raise.

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Autonomic responses observed in both sessions are shown in Table 2 (absolute values) and in Fig. 2 (absolute changes). Compared to the pre-intervention values, the total variance of R-R interval variability and HF increased after the CS but did not change after the ES. On the other hand, LF and lnLF/HF increased after the ES but did not change after the CS. Baroreflex sensitivity increased after the CS and did not change after the ES. This response was mainly due to the baroreflex sensitivity of negative sequences that differed significantly between the sessions after the interventions.

Ambulatory measurements are shown in Table 3. Mean systolic, diastolic and mean BP calculated for all the periods (24h, awake, asleep and awake until asleep) did not differ between the sessions. However, both mean HR and mean RPP calculated for the awake until asleep period were greater after the ES than after the CS. In addition, HR and RPP measured in the first 3h of ambulatory monitoring were also greater after the ES than after the CS (Fig. 3).

Discussion

The most important finding of this study was that HR and RPP remained elevated for up to 4.5h after a session of moderate- to high-intensity ST in elderly subjects.

The aim of this study was to investigate cardiovascular and neural behaviour after a single session of ST in elderly subjects who were regularly performing ST training in order to investigate what occurs in clinical practice when these subjects finish each ST session. Therefore, all the subjects included in the study were participating regularly in a ST program for 10–12 weeks before the acute experimental sessions.
Table 3 Ambulatory blood pressure (BP), heart rate (HR), and rate-pressure product (RPP) measured in the control and the exercise sessions.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Exercise</th>
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<tr>
<td><strong>24-h</strong></td>
<td></td>
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<tr>
<td>systolic BP, mmHg</td>
<td>120 ± 3</td>
<td>119 ± 2</td>
</tr>
<tr>
<td>diastolic BP, mmHg</td>
<td>73 ± 2</td>
<td>73 ± 2</td>
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<tr>
<td>HR, bpm</td>
<td>77 ± 1</td>
<td>77 ± 2</td>
</tr>
<tr>
<td>RPP, mmHg.bpm</td>
<td>9307 ± 298</td>
<td>9236 ± 334</td>
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<tr>
<td><strong>Total Awake</strong></td>
<td></td>
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<tr>
<td>systolic BP, mmHg</td>
<td>126 ± 3</td>
<td>125 ± 2</td>
</tr>
<tr>
<td>diastolic BP, mmHg</td>
<td>79 ± 2</td>
<td>78 ± 2</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>81 ± 1</td>
<td>82 ± 2</td>
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<tr>
<td>RPP, mmHg.bpm</td>
<td>10259 ± 267</td>
<td>10261 ± 372</td>
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<tr>
<td><strong>Awake Until Sleep</strong></td>
<td></td>
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<tr>
<td>systolic BP, mmHg</td>
<td>129 ± 2</td>
<td>127 ± 2</td>
</tr>
<tr>
<td>diastolic BP, mmHg</td>
<td>80 ± 2</td>
<td>80 ± 1</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>81 ± 2</td>
<td>85 ± 3 †</td>
</tr>
<tr>
<td>RPP, mmHg.bpm</td>
<td>10382 ± 335</td>
<td>10853 ± 379 †</td>
</tr>
<tr>
<td><strong>Asleep</strong></td>
<td></td>
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<tr>
<td>systolic BP, mmHg</td>
<td>108 ± 2</td>
<td>109 ± 2</td>
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<tr>
<td>diastolic BP, mmHg</td>
<td>63 ± 2</td>
<td>65 ± 2</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>68 ± 2</td>
<td>68 ± 2</td>
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<tr>
<td>RPP, mmHg.bpm</td>
<td>7374 ± 284</td>
<td>7459 ± 256</td>
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</table>

Values = means ± SE. † Significantly different from the control session (P ≤ 0.05).

Fig. 3 Ambulatory systolic and diastolic blood pressure (SBP and DBP, panel a), heart rate (HR, panel b) and rate-pressure product (RPP, panel c) measurement throughout the 24h of monitoring after the control (dashed line with circle) and the exercise (solid line with squares) sessions. † Significantly different from the control session (P ≤ 0.05).

The exercise protocol employed in the study resulted in an intensity of approximately 60–70% of 1RM. According to the ACSM’s Guidelines [12], this intensity can be considered moderate to hard for novice and intermediate exercisers like the subjects included in this study.

The classical post-exercise hypotension, defined as a reduction in BP after exercise in comparison with the pre-exercise levels, was not observed in the present study. However, previous exercise blunted the systolic BP elevation observed in the CS. An increase in BP after the CS while the subjects were resting in the sitting position might seem odd at first, but this observation has already been reported. Diastolic BP increase has been reported in young subjects [11, 13], and systolic and diastolic BP increases have been observed in elderly subjects [8, 32]. BP elevation has been attributed to the orthostatic stress produced by the sitting position [13], which decreases venous return, thereby deactivating cardiopulmonary reflex and consequently increasing sympathetic activity, SVR and diastolic BP [22]. Given that elderly subjects present a stiffened arterial tree [20, 27], the increase in diastolic BP may lead to a rise in systolic BP.

As systolic BP increased after the CS but not in the ES, exercise produced a net blunting effect of $-6.4 ± 1.9\text{mmHg}$ in systolic BP rise, which is only slightly lower than the classical post-exercise hypotension reported by previous studies [8, 23, 31, 32, 35]. This hypotensive effect was mainly due to a decrease in CO produced by a decrease in SV. The mechanisms responsible for the SV decrease were not evaluated in the present study. However, a reduction in preload is the most probable mechanism, since decreases in plasma volume and venous return have been reported after a session of ST [7]. It is interesting to observe, however, that SVR increased similarly after both experimental sessions, regardless of the larger decrease in venous return observed after the ES. Nevertheless, in response to greater cardiopulmonary deactivation, a higher increase in SVR should have occurred after the ES [22]. The absence of this response suggests that exercise also decreased vascular reactivity to constrictive stimulus. However, this hypothesis needs to be tested by future research.

In contrast to BP response, HR decreased in the CS and increased in the ES, demonstrating that after exercise HR remains elevated. The reduction in HR in the CS was due to an increase in cardiac vagal modulation, as observed by the increase in the HF$_{RRI}$ component of HRV [34], and this response may reflect the baroreflex response to the increase in systolic BP [1] that was observed in this session. On the other hand, HR response after the ES was accompanied by an increase in LF$_{RRI}$ and LF/HF of HRV, showing that cardiac sympathetic modulation remained elevated during the post-exercise period [34]. The increase in HR without a decrease in BP observed after the ES could reflect the reduction in the baroreflex sensitivity reported in this session, especially for the negative sequences. In addition, the increase in HR after the exercise resulted in an increase in RPP, which lasted for up to 4.5 h (90 min inside the laboratory and 3 h during the ambulatory period) maintaining cardiac load elevated after exercise while the subjects were awake.

The results of the present study highlight several possible clinical implications of a session of ST in elderly subjects. The hypotensive effect of previous exercise blunting BP elevation while the subjects were sitting might decrease the cardiovascular load in elderly subjects who stay seated for long periods during the day [5]. However, this effect was not sustained during daily activities, showing that the hypotensive effect was only transient and may not have an important clinical implication. In
addition, HR remained elevated after the ES for many hours, primarily by the maintenance of an elevated sympathetic modulation to the heart, which resulted in increased cardiac work. However, it is important to note that the mean increases in HR were approximately 4bpm in the laboratory and varied from 5 to 7bpm in the first 3h of monitoring, which implies that although cardiovascular load increased after exercise, this load might not have any clinical implication for healthy subjects. However, they raise some concerns if they were replicable in elderly subjects who already have an elevated cardiovascular risk, such as cardiac patients. If cardiac sympathetic modulation and work also remain elevated for a long period of time after resistance exercise in these patients, this response may represent a risk for acute cardiovascular events during exercise recovery. However, these subjects are usually on medications that may influence cardiovascular responses after exercise. In addition, these concerns are related to the kind of exercise protocol employed in the present study (moderate to hard intensity and conducted to concentric fatigue) which is not recommended to subjects with cardiovascular problems.

This study has some limitations. We did not evaluate the acute effects of a ST session in sedentary subjects, who might respond differently. However, the analysis in subjects who were already participating in a ST program increases the practical applicability of the results, enhancing the knowledge about what happens when elderly subjects who are training regularly at moderate to high intensities undergo a session of exercise. Besides randomizing session order, pre-intervention CO and SV were slightly different between the sessions. To minimize any possible influence of these differences and since the objective of the study was to compare the post-exercise responses, data were also analysed based on the difference between pre- and post-intervention data. Monitoring HR by an ambulatory BP device might bring some concern about the results precision. However, Groppelli et al. [14] compared ambulatory HR measured by SpaceLabs monitor and intra-arterial monitoring and concluded that both methods revealed similar HR values.

In conclusion, in elderly subjects who regularly perform a session of moderate-to-high intensity ST, heart rate and cardiac work remain elevated for up to 4.5h after the exercise session.

Acknowledgements

The authors want to acknowledge the volunteers who contributed to this study. We also thank students of Neuromuscular Adaptation Laboratory for providing strength training for the volunteers, and Octávio Barbosa Neto for support in cardiovascular autonomic evaluation. This study was financially supported by FAPESP (07/56653-1:07/00788-6), CNPQ (471600/2008-3), CAPES (PROEX and Demanda Social) and Head of the Psychopharmacology Incentive Fund Association.

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