INFLUENCE OF ENDURANCE AND RESISTANCE EXERCISE ORDER ON THE POSTEXERCISE HEMODYNAMIC RESPONSES IN HYPERTENSIVE WOMEN

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ABSTRACT

Menêses, AL, Forjaz CL, Lima, PFM, Batista, RMF, Monteiro, MF, and Ritti-Dias, RM. Influence of endurance and resistance exercise order on the postexercise hemodynamic responses in hypertensive women. J Strength Cond Res 29(3): 612–618, 2015—The study aims to evaluate the effects of the order of endurance and resistance exercises on postexercise blood pressure (BP) and hemodynamics in hypertensive women. Nineteen hypertensive women underwent 3 sessions: control (50 minutes rest), endurance (50–60% of heart rate reserve) followed by resistance exercise (50% of 1 repetition maximum) (E + R), and resistance followed by endurance exercise (R + E). Before and 30 minutes after each session, BP, peripheral vascular resistance, cardiac output, stroke volume, and heart rate were measured. Postexercise increases in systolic (E + R: +1 ± 3 mm Hg and R + E: +3 ± 3 mm Hg), diastolic (E + R: +3 ± 1 mm Hg and R + E: +3 ± 2 mm Hg), and mean BP (E + R: +3 ± 1 mm Hg and R + E: +3 ± 2 mm Hg) were significantly lower after the exercise sessions compared with the control session (p ≤ 0.05). The exercise sessions abolished the increases in peripheral vascular resistance (E + R: +0.00 ± 0.04 mm Hg·min⁻¹·L⁻¹ and R + E: +0.05 ± 0.05 mm Hg·min⁻¹·L⁻¹) and the decreases in cardiac output (E + R: +0.04 ± 0.21 L·min⁻¹ and R + E: −0.26 ± 0.28 L·min⁻¹) observed after the control session (p ≤ 0.05). After the exercise sessions, stroke volume decreased (E + R: −14 ± 3 ml and R + E: −9 ± 4 ml) and heart rate increased (E + R: +5 ± 1 b·min⁻¹ and R + E: +4 ± 1 b·min⁻¹) in comparison with the control session (p ≤ 0.05). For all the variables, there were no significant differences between the exercise sessions. Regardless of the order of the end and resistance exercises, combined exercise sessions abolished increases in BP observed in a control condition due to a reduction in peripheral vascular resistance and increases in cardiac output. Thus, combined exercises should be prescribed to individuals with hypertension to control their BP, regardless of the order they are accomplished.

KEY WORDS hypertension, blood pressure, vascular resistance, cardiac output, exercise therapy

INTRODUCTION

Hypertension is a major risk factor for cardiovascular diseases, heart attack, and stroke (34), which are the currently leading causes of deaths worldwide (20). Hypertension affects more than 30% of all adults (28) and is considered a public health problem (45). Hypertension is a main concern for the female population, as women have more risk factors (27) and higher mortality rates (45) compared with men. Therefore, strategies for treatment and control of hypertension among women are mandatory.

Exercise has been recommended for patients with hypertension because of its benefits on cardiovascular health and physical fitness (29,44). A single bout of endurance or resistance exercise reduces blood pressure (BP) to levels below those observed before exercise or on a day that exercise is not performed. This phenomenon, called postexercise hypotension (13), is clinically relevant because the postexercise reduction in BP is of a significant magnitude and lasts for several hours (11). Postexercise hypotension has been observed in hypertensive women after acute sessions of endurance or resistance exercises at an intensity of 60% of the maximum oxygen consumption (30) and 40–50% of 1 repetition maximum (1RM) (8,24), respectively.

Endurance exercise reduces BP (4,30,38), and it is the primary exercise modality prescribed for the treatment, control or prevention of hypertension (1,29). Resistance
exercise is also recommended because it improves musculoskeletal fitness (1,29). Usually, both exercise modalities are performed within the same exercise session; generally, endurance exercise precedes resistance exercise (2,7). In normotensive subjects, an exercise session combining endurance (65–75% of peak oxygen uptake (18,41) or 60–70% of heart rate reserve (39)) and resistance exercises (50–80% of 1RM (18,41) or sets of 12RM (39)) elicits similar levels of post-exercise hypotension observed after endurance exercise alone and greater postexercise hypotension compared with resistance exercise alone (18,39,41).

Reduced BP after exercise has been attributed to decreased cardiac output and peripheral vascular resistance. Teixeira et al. (41) demonstrated that in normotensive subjects, peripheral vascular resistance did not change after endurance exercise. It did, however, increase after combined (endurance + resistance) exercise, suggesting that performing resistance exercise after endurance exercise increases postexercise peripheral vascular resistance. Because endurance exercise leads to decreased peripheral vascular resistance in individuals with hypertension (4,30,38), the authors hypothesized that peripheral vascular resistance would decrease if endurance exercise is performed after resistance exercise, leading to postexercise hypotension.

Interestingly, the influence of exercise order on post-exercise BP has been previously investigated in normotensive, and no difference was found in the BP changes after distinct exercise order (22). However, it remains unclear whether similar responses would be observed in hypertensive subjects who are known to present alterations in the cardiovascular system. Thus, the aim of this study was to evaluate the effects of the order of endurance and resistance exercises on postexercise BP and hemodynamics in hypertensive women.

**METHODS**

**Experimental Approach to the Problem**

This study was designed to evaluate the effects of the order of endurance and resistance exercises performed in a single session on the determinants of postexercise BP regulation. Recent studies have suggested that normotensive individuals experience postexercise increases in peripheral vascular resistance when performing resistance exercise after endurance exercise (41). Because endurance exercise leads to decreased peripheral vascular resistance in hypertensive individuals, it was hypothesized that peripheral vascular resistance would decrease if endurance exercise was performed after resistance exercise, enhancing postexercise hypotension.

**Subjects**

Nineteen hypertensive women recruited through media and community publicity accepted to participate in the study. All subjects were postmenopausal women without hormone replacement therapy using concomitant antihypertensive medication (except beta-blockers or non-dihydropyridine calcium channel blockers). Subjects were excluded if they were diabetic, a smoker (presently smokes or has quit within 6 months), or physically active (engaged in 30 minutes of moderate-intensity activity more than 3 days a week for at least 3 months) (1); presented an abnormal resting or exercise electrocardiography; or presented resting systolic/diastolic BP ≥160/105 mm Hg. The characteristics of the hypertensive women enrolled in the present study are shown in Table 1.

All subjects gave written informed consent to participate in this study, which was approved by the Ethics Committee of the University of Pernambuco, Recife, Brazil (CEP/UPE, 232/11). All procedures during the trial were conducted in accordance with the Helsinki Declaration of 1975, as revised in 1983.

**Procedures**

Before the experiments, the subjects underwent treadmill maximal exercise testing (Ergolife Professional, São Paulo, Brazil) using the Bruce protocol (23) and 1RM (21) to determine the intensity of the endurance and resistance exercises, respectively. In a previous visit, the subjects were familiarized with the exercise session protocol, including treadmill walking (30 minutes at a speed of 4.0 km·h⁻¹) and 7 resistance exercises (2 sets of 10 repetitions with the minimum load allowed by the weight machines).

**Table 1. Characteristics of the hypertensive women enrolled in the study (n = 19).*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>57 ± 2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74 ± 3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>157 ± 1</td>
</tr>
<tr>
<td>Body mass index (kg·m⁻²)</td>
<td>29.9 ± 0.9</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>94.2 ± 2.47</td>
</tr>
<tr>
<td>Waist-hip ratio</td>
<td>0.87 ± 0.02</td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
</tr>
<tr>
<td>Dyslipidemia, n (%)</td>
<td>8 (44.4)</td>
</tr>
<tr>
<td>Obesity, n (%)</td>
<td>15 (83.3)</td>
</tr>
<tr>
<td>Antihypertensive medications</td>
<td></td>
</tr>
<tr>
<td>Inhibitors of angiotensin converting</td>
<td>11 (57.9)</td>
</tr>
<tr>
<td>enzyme, n (%)</td>
<td></td>
</tr>
<tr>
<td>Diuretics, n (%)</td>
<td>6 (31.6)</td>
</tr>
<tr>
<td>Antagonists of angiotensin II, n (%)</td>
<td>4 (21.1)</td>
</tr>
<tr>
<td>Calcium channel blockers</td>
<td>3 (15.8)</td>
</tr>
<tr>
<td>dihydropyridine, n (%)</td>
<td></td>
</tr>
<tr>
<td>Receptor agonists central α2-adrenergic, n (%)</td>
<td>1 (5.30)</td>
</tr>
<tr>
<td>Combined antihypertensive therapy, n (%)</td>
<td>8 (44.4)</td>
</tr>
<tr>
<td>Other medications</td>
<td></td>
</tr>
<tr>
<td>Statins, n (%)</td>
<td>6 (31.6)</td>
</tr>
<tr>
<td>Levothyroxine (T4), n (%)</td>
<td>3 (15.8)</td>
</tr>
</tbody>
</table>

*Values are reported as the mean ± SE or frequency distribution.
All subjects completed 3 experimental sessions in a random order: control (C), endurance exercise followed by resistance exercise (E + R), and resistance exercise followed by endurance exercise (R + E). The sessions were initiated between 1 and 2 PM and had an intersession interval of at least 48 hours. The subjects were instructed as follows: (a) avoid physical exercises 24 hours before the session; (b) maintain typical medication use, sleeping, and feeding routines on the day of the session; (c) abstain from caffeine and alcohol on the day of the session; and (d) eat a light meal 2 hours before participating in the experiments.

On arrival to the laboratory, the subjects were referred to the hemodynamic evaluation room (between 20°C and 23°C temperature), where they rested in the supine position for 20 minutes before baseline measurements. They then moved to the exercise room, where they remained for approximately 50 minutes resting in the C session and exercising in the E + R and R + E sessions. Afterward, they returned to the hemodynamic evaluation room, where postintervention measurements were taken in the supine position 30 minutes after completing the C, E + R, or R + E sessions. Subjects were blinded as to which session they were going to perform until the exercise or the rest began.

The endurance exercise protocol consisted of 30 minutes of walking on a treadmill (Ergolife Professional) at 50–60% of heart rate reserve, as previously recommended for hypertensive patients (1,29). Heart rate was continuously monitored during the treadmill exercise (Polar RS800 CX, Polar Electro Oy, Kempele, Finland). The resistance exercise protocol consisted of 3 sets of 10 repetitions for knee extension, rowing machine, leg curl, lateral pull-down, adductor chair, bench press, and biceps curl (New Fit, Cascavel, Brazil) at a workload of 50% of 1RM; this protocol has been previously recommended for hypertensive patients (44). Intervals of 90 seconds elapsed between sets and between exercises. A 2-minute interval was used between protocols, and a 2-minute warm-up and a 2-minute cooldown were performed in both the E + R and R + E sessions. During the C session, the subjects remained still for 30 minutes in the standing position on the treadmill; afterward, they remained inactive in the position of each resistance exercise for a total time of 20 minutes, which was equivalent to the duration of the resistance exercise protocol performed in the E + R and R + E sessions.

Noninvasive beat-to-beat BP was monitored by finger photoplethysmography (Finometer; Finapres Medical Systems BV, Arnhem, Amsterdam, the Netherlands). The right arm BP data were continuously recorded for 10 minutes before and after completing the experiments. Heart rate was automatically calculated from systolic BP intervals. Stroke volume, cardiac output, and peripheral vascular resistance were calculated using Modelflow (40,43), which is an automatic method that computes aortic blood flow from the arterial pressure wave by simulating a nonlinear, time-varying 3-element model of aortic input impedance that incorporates data related to gender, age, height, and body weight. The data generated by Finometer were analyzed using BeatScope 1.1 Software (Windows program; Finapres Medical Systems BV, Amsterdam, the Netherlands).

**Statistical Analyses**

Considering a power of 90%, an alpha level of 0.05 and SD of 3 mm Hg for systolic BP and 0.32 L·min⁻¹ for cardiac output, the minimal sample size necessary to detect changes of 4 mm Hg and 0.32 L·min⁻¹ were calculated to be 10 and 11 subjects, respectively. The values employed for this calculation were reported in previous studies (31,41) and were chosen by comparisons with normal age-matched population, as previously reported (25).

Intraclass correlation coefficient (ICC) and coefficient of variation (CV) indicated a good reproducibility of measurements of systolic BP (ICC = 0.760, p < 0.01,
CV = 6.95 ± 0.01%, diastolic BP (ICC = 0.687, p = 0.01, CV = 6.79 ± 1.13%), mean BP (ICC = 0.669, p = 0.01, CV = 7.05 ± 1.04%), peripheral vascular resistance (ICC = 0.787, p < 0.01, CV = 7.10 ± 2.40%), cardiac output (ICC = 0.864, p < 0.01, CV = 12.97 ± 2.09%), stroke volume (ICC = 0.855, p < 0.01, CV = 13.66 ± 2.17%), and heart rate (ICC = 0.939, p < 0.01, CV = 4.81 ± 0.66%) obtained by finger photoplethysmography.

The Gaussian distribution of the data was verified by the Shapiro-Wilk test. A logarithmic transformation (log10) was necessary to ensure normality of peripheral vascular resistance. One-way repeated measures analysis of variance (ANOVA) (Statistica for Windows 7.0; Statsoft, Tulsa, OK, USA, 1995) was used to compare preintervention values among the experimental sessions. A 2-way repeated measures ANOVA was used to compare the hemodynamic responses among the sessions, with session (C, E + R, and R + E) and time (preintervention and postintervention) as main factors. Post hoc comparisons were made using the Newman-Keuls test. A value of p < 0.05 was accepted as statistically significant. The data are presented as the mean ± SE for quantitative variables and as a frequency distribution for categorical variables.

RESULTS

Six subjects started the experimental sessions with C, 7 with E + R, and 6 with R + E. Heart rate during endurance exercise was similar between the E + R and R + E sessions (120 ± 2 b·min⁻¹ and 121 ± 2 b·min⁻¹, respectively, p > 0.05).

There was no difference in preintervention values among the C, E + R, and R + E sessions for systolic BP (131 ± 4, 130 ± 3, and 128 ± 3 mm Hg, respectively, p = 0.59), diastolic BP (69 ± 2, 68 ± 1, and 68 ± 2 mm Hg, respectively, p = 0.92), mean BP (93 ± 2, 92 ± 2, and 92 ± 2 mm Hg, respectively, p = 0.93), peripheral vascular resistance (0.81 ± 0.06, 0.84 ± 0.06, and 0.80 ± 0.06 mm Hg·min⁻¹·L⁻¹, respectively, p = 0.61), cardiac output (7.28 ± 0.33, 7.00 ± 0.31, and 7.48 ± 0.40 L·min⁻¹, respectively, p = 0.75), stroke volume (102 ± 6, 100 ± 6, and 101 ± 6 ml, respectively, p = 0.89), and heart rate (74 ± 3, 73 ± 3, and 75 ± 2 b·min⁻¹, respectively, p = 0.69).

Compared with preintervention values, systolic, diastolic, and mean BPs (Figure 1A-C) increased after the C session (9 ± 2, 6 ± 2, and 7 ± 2 mm Hg, respectively, p < 0.01) and did not change after the E + R and R + E sessions (p > 0.05).

Compared with preintervention values, peripheral vascular resistance (Figure 2A) increased after the C session (0.15 ± 0.04 mm Hg·min⁻¹·L⁻¹, p = 0.01) and did not change after the E + R and R + E sessions (p > 0.05), whereas cardiac output (Figure 2B) decreased (0.58 ± 0.28 L·min⁻¹, p = 0.05) after the C session and did not change after the E + R and R + E sessions (p > 0.05).

Compared with preintervention values, stroke volume (Figure 2C) did not change after the C session (p > 0.05) and decreased after the E + R and R + E sessions (14 ± 3 and 9 ± 4 ml, respectively, p < 0.05). However, heart rate (Figure 2D) decreased after the C session (5 ± 1 b·min⁻¹, p = 0.05).
and BP observed in the C session. However, these responses were similar after the E + R and R + E sessions.

After the C session, BP increased; this finding has already been reported in older women with characteristics similar to the subjects of this study (5). This effect may be attributed to the circadian variation of resting BP that induces secondary increases in the afternoon (3,15). However, the combination of endurance and resistance exercises, regardless of their order, prevented the increases in BP that were observed in the control condition; this finding indicates that the combined exercises had a hypotensive effect. Considering that systolic BP increased by 9 mm Hg after the C session and that it increased only by 1 and 3 mm Hg after the E + R and R + E sessions, respectively, the combined exercise had a hypotensive effect of 6–8 mm Hg. This magnitude is similar to that observed in normotensive individuals after combined exercises (17,18,41) and is lower than that reported in individuals with hypertension after endurance exercises alone (4,9,16,36). Thus, the recovery position used in this study might have diminished the magnitude of BP reduction because postexercise hypotension after endurance (19) and resistance (6) exercises is lower in the supine than in the sitting position. Another possible explanation is that postexercise measurements were taken after 30 minutes of recovery; greater BP reduction has been reported after 40 minutes of combined exercise (17,18,39,41).

Compared with responses observed after the C session, cardiac output increased and peripheral vascular resistance decreased after the E + R and R + E sessions. These results are different from those reported by Teixeira et al. (41), who demonstrated decreased cardiac output and no change in peripheral vascular resistance. The postexercise recovery position, which is known to influence BP (6,19,33) and its regulatory determinants (33), may also explain differing results. When measurements are taken in a sitting position, a decrease in venous return is expected (37); this decrease in venous return decreases the stroke volume and cardiac output as well as deactivates the cardiopulmonary reflex, which prevents exercise from reducing peripheral vascular resistance (12). When recovery occurs in a supine position, as in this study, venous return decreases may be blunted (37), thereby decreases in peripheral vascular resistance are facilitated. It is noteworthy that the cardiac output values observed in this study are higher than the values normally reported in the literature, which is explained by the supine position adopted during measurements that are known to increase cardiac output in approximately 18% (37), as a result of the increases in venous return and stroke volume.

After combined exercise sessions, an increase in heart rate and a concomitant reduction in stroke volume were observed. Increased heart rate has been extensively reported after exercise (22,39) and is attributed to increased sympathetic and reduced vagal modulation of the heart (41). In addition, reductions in stroke volume may occur by a decrease in preload (14,36), which is mainly determined increased venous compliance.

In contrast to the initial hypothesis, reduced peripheral vascular resistance was observed after combined endurance and resistance exercises were completed in different orders, which led to similar BP responses. Similar peripheral vascular resistance responses between the E + R and R + E sessions might have occurred because the vasodilatory stimuli of endurance exercises might overcome the vasoconstriction induced by resistance exercises (35,41), regardless of whether endurance exercises were performed before or after resistance exercises. Another possible explanation is that recovery in a supine position may have minimized increases in peripheral vascular resistance, even if resistance exercise is performed alone. Indeed, increases in peripheral vascular resistance after resistance exercises were only described in studies using a sitting recovery position (35,41).

Lovato et al. (22) reported results similar to the findings of the current study, although there were differences in the study populations (young normotensive men), exercise protocols (50 minutes of cycling at 60% peak oxygen uptake and 8 resistance exercises at 60% of 1RM), and hemodynamic assessment methodology (seated auscultatory BP measurement). This result supports the findings that the order of resistance and endurance exercises in combined training sessions has no effect on postexercise hemodynamics, which appears to be independent of the study population and protocol. In practical terms, the evidence reported in this study suggests that combined exercises should be prescribed to control BP in hypertensive patients, regardless of the order in which it is accomplished.

This study has some limitations. First, despite postexercise hypotension evidences in hypertensive subjects of both genders (4,5,8,26,30,38), it is possible to expect differences in postexercise hemodynamics between genders. In normotensive subjects, gender-related differences in the hemodynamic determinants of postresistance exercise hypotension have been reported (32), with decreases in peripheral vascular resistance observed in women and decreases in cardiac output observed in men. Second, the use of antihypertensive drugs was not standardized, and the power of the study was not determined to perform additional analysis of the influence of the different antihypertensive drugs on postexercise cardiovascular responses, which requires further investigation. In addition, most volunteers in this study were obese (83%), and the study sample had a high prevalence of hypercholesterolemia (44%). The presence of these risk factors can attenuate postexercise hypotension (42). However, inclusion of these subjects increases the external validity of the study.
especially when considering that obesity is highly prevalent among hypertensive patients (10).

**Practical Applications**

The order of endurance and resistance exercises performed in combined exercise training sessions does not affect postexercise BP and hemodynamic responses in hypertensive women. Regardless of the order of endurance and resistance exercises, combined exercise sessions abolished increases in BP observed in a control condition because of a reduction in peripheral vascular resistance. This is important from a practical standpoint, suggesting that combined exercises should be prescribed to individuals with hypertension to control their BP, regardless of the order it is accomplished. This study has the potential to make a significant contribution to the limited evidence on exercise and individuals with hypertension who are currently taking BP lowering medications. In addition, it will contribute to the few acute trials examining combined aerobic and resistance exercise and postexercise BP.

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