Effect of Exercise Training on Peak Aerobic Power, Left Ventricular Morphology, and Muscle Strength in Healthy Older Women

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The effect that aerobic (AT) and/or strength training (ST) has on altering peak aerobic power (VO2peak), muscle strength, left ventricular (LV) morphology, and diastolic filling in healthy older women is not known. We assessed the effects of 12 weeks of AT, ST, combined aerobic and strength training (COMT), or no training (NT) on VO2peak, muscle strength, LV morphology, and diastolic filling in 31 healthy women (68 ± 4 years). Relative VO2peak was significantly greater after 12 weeks of AT, ST, or COMT. Upper and lower extremity strength were significantly higher after 12 weeks of ST or COMT with no change after AT or NT. LV morphology and diastolic filling were not altered after 12 weeks of AT, ST, COMT, or NT. Twelve weeks of ST or COMT are as effective as 12 weeks of AT for increasing relative VO2peak, however, ST and COMT are more effective than AT for improving overall muscle strength.

Methods

Participants

The participants consisted of 35 women between 60 and 78 years of age who met the following inclusion criteria: a) no clinical evidence of cardiovascular disease; b) normal resting electrocardiogram (ECG); c) normal ECG response to graded exercise; d) no requirement or use of cardiovascular medications; e) no regular participation in AT and/or ST; and f) absence of any cerebrovascular or orthopedic disability that would limit exercise training. Ethical approval was obtained from the biomedical ethical review panel of the University of Alberta, and written informed consent was obtained prior to study participation.

Baseline Assessments

Incremental exercise test.—The incremental exercise test was performed on an electronically braked cycle ergometer; during this test, a continuous 12-lead ECG was obtained. The initial power output was set at 15 W and was increased by 15 W every 2 minutes until the participant was exhausted.Expired gas analysis was acquired with a commercially available metabolic cart (Parvomedics, Salt Lake City, UT), and VO2peak was calculated as the highest oxygen consumed over a 1-minute period.

LV morphology and diastolic filling.—Echocardiographic images were acquired with a Hewlett Packard (Andover, MA) 5500 ultrasound machine with a 3.5 MHz transducer. Measurements were obtained from the parasternal long-axis view and were averaged over three cardiac cycles. All measures were obtained in accordance with the American Society of Echocardiography guidelines (18) and included
LV systolic and diastolic cavity dimensions and posterior and ventricular septal wall thickness. LV mass and end-systolic wall stress were calculated using standard formulas (19,20). Doppler echocardiographic examination of LV transmural filling was performed in accordance with the Canadian consensus recommendations for the measurement and reporting of diastolic dysfunction (21) and included peak early filling velocity, peak atrial filling velocity, and early- to late-filling velocity ratio. An experienced sonographer who was blinded to the random assignment of participants performed all of the echocardiograms and analysis.

Maximal muscular strength.—Upper and lower extremity maximal muscular strength were assessed as a voluntary one-repetition maximum (1RM) using the following exercises: 1) leg press; 2) leg extension; 3) leg curl; 4) chest press; 5) shoulder press; 6) latissimus dorsi pulldown; 7) triceps pushdown; and 8) unilateral arm curl. The strength exercises was retested every 4 weeks, and the intensity increased by 2.5% every week. The 1RM for all strength exercises was 0 kg at baseline, and increased progressively increased to 75% of 1RM.

Randomization and Exercise Training
After baseline testing, participants were randomly assigned to 12 weeks of AT, ST, COMT, or NT. The exercise groups performed three supervised exercise sessions per week while the NT participants continued with their normal activities of daily living and did not perform any exercise training. The AT participants performed cycle exercise at an intensity between 60% and 80% of heart rate reserve, with the initial exercise duration set at 15 minutes and increased by 2.5 minutes every week up to a maximal duration of 42.5 minutes. The ST participants performed 2 sets of 10 repetitions of the previously described strength exercises. The initial intensity was set at 50% of the baseline 1RM and increased by 2.5% every week. The 1RM for all strength exercises was retested every 4 weeks, and the intensity was progressively increased to 75% of 1RM. The COMT participants performed the same programs of AT and ST described above for the AT and ST participants, respectively.

Statistics
Statistical analysis was performed with a two-way repeated measure analysis of variance. If a significant effect was found, then a Newman–Kuels significance test was performed. The alpha level was set at \( p < .05 \) with all tests. Data are presented as mean ± SD.

RESULTS
Thirty-one women completed the investigation. Three women (1 AT and 2 COMT) could not make the time commitment for the study, and withdrew from the investigation. One ST participant withdrew from the study because of shoulder discomfort and migraine headaches. One COMT participant suffered a lower extremity injury not related to the study, and was unable to perform the post-training VO\(_{2}\)peak or lower extremity 1RM tests. Finally, 1 AT participant could not tolerate the mouthpiece used to collect the expired gases during the post-training incremental exercise test, and stopped cycling prior to reaching a peak score. No significant difference was found between the groups for age (AT: 66 ± 3 years; ST: 70 ± 4 years; COMT: 68 ± 6 years; NT: 67 ± 4 years) or body surface area (AT: 1.8 ± 0.0 kg/m\(^2\); ST: 1.8 ± 0.0 kg/m\(^2\); COMT: 1.7 ± 0.0 kg/m\(^2\); NT: 1.8 ± 1 kg/m\(^2\)). There was no significant difference in body weight between the groups before (pre-) or after (post-) the training program (AT pre: 71.1 ± 7.4 kg vs post: 70.3 ± 5.3 kg; ST pre: 72.6 ± 18.4 kg vs post: 72.9 ± 17.2 kg; COMT pre: 69.8 ± 19.2 kg vs post: 70.2 ± 19.6 kg; NT pre: 75.3 ± 11.7 kg vs post: 75.3 ± 12.2 kg).

Table 1. Effect of Exercise Training on Peak Power Output, Ventilation, and Heart Rate

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>AT</th>
<th>COMT</th>
<th>ST</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power, W</td>
<td>Pre</td>
<td>107 ± 20</td>
<td>96 ± 29(^1)</td>
<td>88 ± 15(^1)</td>
<td>95 ± 15</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>120 ± 17(^1)</td>
<td>123 ± 25(^1)</td>
<td>105 ± 20(^3)</td>
<td>95 ± 13</td>
</tr>
<tr>
<td>Peak ventilation, L/min</td>
<td>Pre</td>
<td>70 ± 12</td>
<td>59 ± 20(^1)</td>
<td>59 ± 12(^1)</td>
<td>63 ± 13</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>69 ± 13(^*)</td>
<td>67 ± 14(^*)</td>
<td>69 ± 13(^*)</td>
<td>57 ± 10</td>
</tr>
<tr>
<td>Peak heart rate, beats/min</td>
<td>Pre</td>
<td>155 ± 12</td>
<td>159 ± 17</td>
<td>157 ± 9</td>
<td>157 ± 15</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>159 ± 7</td>
<td>162 ± 13</td>
<td>159 ± 16</td>
<td>154 ± 18</td>
</tr>
</tbody>
</table>

Notes: \(^*p < .05\) vs NT; \(^*p < .05\) vs AT; \(^*p < .05\) vs ST; \(^*p < .05\) vs pre.

\( AT \) = aerobic training; \( ST \) = strength training; \( COMT \) = combined AT and ST; \( NT \) = no training.

Figure 1. Effect of 12 weeks of aerobic training (AT), combined aerobic and strength training (COMT), or no training (NT) on peak aerobic power (VO\(_{2}\)peak). \(^*p < .05\) vs NT; \(^*p < .05\) vs pre-training.
Variable | Time | AT | COMT | ST | NT
--- | --- | --- | --- | --- | ---
Diastolic ventricular sepal thickness, mm | Pre | 8.4 ± 2.1 | 8.4 ± 1.7 | 8.4 ± 1.0 | 9.9 ± 1.0 | 6.4 ± 3.2
 | Post | 8.1 ± 1.6 | 7.7 ± 1.2 | 8.2 ± 1.3 | 9.3 ± 1.2 | 5.5 ± 1.6
Diastolic posterior wall thickness, mm | Pre | 8.8 ± 1.8 | 8.7 ± 1.1 | 8.8 ± 0.9 | 9.2 ± 1.2 | 6.4 ± 2.8
 | Post | 8.9 ± 1.0 | 8.0 ± 0.8 | 8.5 ± 1.1 | 9.4 ± 0.7 | 5.2 ± 1.5
Systolic posterior wall thickness, mm | Pre | 15.2 ± 1.3 | 15.1 ± 2.1 | 15.2 ± 1.8 | 15.7 ± 1.5 | 6.6 ± 2.9
 | Post | 15.7 ± 1.7 | 13.5 ± 0.8 | 15.1 ± 1.4 | 16.2 ± 0.9 | 5.5 ± 1.0
Left ventricular diastolic cavity dimension, mm | Pre | 46.0 ± 4.9 | 45.0 ± 5.2 | 43.0 ± 5.2 | 45.0 ± 3.8 | 6.4 ± 2.3
 | Post | 44.0 ± 5.4 | 49.0 ± 6.2 | 47.0 ± 6.4 | 44.0 ± 6.1 | 5.9 ± 1.0
Left ventricular systolic cavity dimension, mm | Pre | 25.3 ± 3.2 | 25.4 ± 2.0 | 22.2 ± 4.6 | 23.2 ± 2.2 | 6.5 ± 1.9
 | Post | 24.6 ± 3.5 | 27.6 ± 5.4 | 24.9 ± 6.0 | 24.7 ± 5.3 | 6.0 ± 1.7
Relative wall thickness | Pre | .39 ± 0.1 | .40 ± 0.1 | .41 ± 0.1 | .41 ± 0.1 | .44 ± 0.1
 | Post | .41 ± 0.1 | .33 ± 0.1 | .37 ± 0.1 | .44 ± 0.1 | .45 ± 0.1
Left ventricular mass, g/m² | Pre | 72.1 ± 9.8 | 65.5 ± 10.4 | 67.8 ± 12.2 | 81.8 ± 10.1 | 6.5 ± 2.2
 | Post | 68.4 ± 9.5 | 68.4 ± 6.1 | 73.3 ± 14.0 | 77.7 ± 21.6 | 6.3 ± 1.8
Left ventricular end-systolic wall stress, g/cm² | Pre | 34.2 ± 4.9 | 39.8 ± 11.4 | 35.8 ± 14.3 | 33.3 ± 3.4 | 6.4 ± 1.4
 | Post | 34.0 ± 11.9 | 45.0 ± 11.3 | 37.5 ± 17.3 | 32.6 ± 10.0 | 6.1 ± 1.3
Early transmitral inflow, cm | Pre | 70.4 ± 15.1 | 83.8 ± 27.3 | 77.6 ± 15.5 | 66.1 ± 14.5 | 6.8 ± 1.6
 | Post | 68.4 ± 6.8 | 79.6 ± 13.2 | 84.9 ± 9.3 | 67.0 ± 14.6 | 6.1 ± 1.2
Atrial velocity, cm | Pre | 63.5 ± 12.6 | 80.6 ± 14.7 | 87.8 ± 19.2 | 85.1 ± 17.5 | 6.8 ± 1.7
 | Post | 64.6 ± 13.0 | 81.0 ± 14.3 | 88.3 ± 28.7 | 77.5 ± 16.5 | 6.8 ± 1.7
E/A ratio | Pre | 1.11 ± 0.1 | 1.04 ± 0.3 | 0.92 ± 0.3 | 0.78 ± 0.1 | 0.88 ± 0.2
 | Post | 1.08 ± 0.1 | 0.99 ± 0.1 | 1.03 ± 0.3 | 1.03 ± 0.3 | 0.88 ± 0.2

Notes: All comparisons *p > .05.
AT = aerobic training; ST = strength training; COMT = combined aerobic and strength training; NT = no training; E = early; A = atrial.

(10.7 ± 1.6 ml/beat) being significantly greater than the preintervention value (9.8 ± 1.6 ml/beat). No significant change in peak exercise heart rate was found after 12 weeks of AT, ST, COMT, or NT (Table 1).

**LV Morphology and Diastolic Filling**

LV systolic and diastolic cavity dimension, wall thickness, end-systolic wall stress, mass, or transmitral filling patterns were not altered after 12 weeks of AT, ST, COMT, or NT (Table 2).

**Upper and Lower Extremity Strength**

A significant increase in leg-press, leg-curl, shoulder-press, chest-press, and latissimus dorsi-pulldown 1RMs were found after 12 weeks of ST or COMT (Table 3). Also, the post-training leg-press, shoulder-press, chest-press, and latissimus dorsi-pulldown 1RMs were significantly greater in the ST or COMT groups compared to those in the AT or NT groups. Tricep-pushdown and left-arm-curl 1RMs were significantly greater after 12 weeks of ST and COMT, respectively. No significant difference was found for leg-extension or right-arm-curl 1RMs after 12 weeks of AT, ST, COMT, or NT (Table 3).

### Table 3. Effect of 12 Weeks of Exercise Training on Upper and Lower Extremity Strength

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>AT</th>
<th>COMT</th>
<th>ST</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg-press 1RM, kg</td>
<td>Pre</td>
<td>191.7 ± 59.0</td>
<td>169.1 ± 41.0</td>
<td>202.6 ± 55.2</td>
<td>200.5 ± 36.3</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>187.9 ± 37.0</td>
<td>263.6 ± 89.0</td>
<td>272.1 ± 45.2</td>
<td>203.8 ± 43.2</td>
</tr>
<tr>
<td>Leg extension 1RM, kg</td>
<td>Pre</td>
<td>45.2 ± 11.4</td>
<td>43.2 ± 13.8</td>
<td>43.5 ± 5.8</td>
<td>42.4 ± 5.6</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>44.9 ± 10.4</td>
<td>47.5 ± 10.0</td>
<td>51.0 ± 8.9</td>
<td>39.6 ± 6.5</td>
</tr>
<tr>
<td>Leg curl 1RM, kg</td>
<td>Pre</td>
<td>36.7 ± 7.7</td>
<td>31.4 ± 11.4</td>
<td>25.5 ± 4.4</td>
<td>31.5 ± 7.1</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>37.1 ± 6.0</td>
<td>42.7 ± 9.9</td>
<td>37.7 ± 5.0</td>
<td>29.5 ± 7.2</td>
</tr>
<tr>
<td>Shoulder press 1RM, kg</td>
<td>Pre</td>
<td>28.7 ± 8.4</td>
<td>29.5 ± 10.3</td>
<td>29.8 ± 5.9</td>
<td>32.3 ± 6.2</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>26.4 ± 5.6</td>
<td>39.0 ± 9.6</td>
<td>41.0 ± 6.9</td>
<td>29.5 ± 6.0</td>
</tr>
<tr>
<td>Latissimus dorsi pulldown 1RM, kg</td>
<td>Pre</td>
<td>36.1 ± 4.9</td>
<td>34.1 ± 6.3</td>
<td>34.9 ± 5.3</td>
<td>36.6 ± 3.5</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>36.1 ± 2.8</td>
<td>41.3 ± 6.5</td>
<td>43.5 ± 8.8</td>
<td>33.6 ± 3.3</td>
</tr>
<tr>
<td>Chest press 1RM, kg</td>
<td>Pre</td>
<td>34.4 ± 7.8</td>
<td>31.3 ± 9.0</td>
<td>34.1 ± 6.9</td>
<td>38.6 ± 8.0</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>35.2 ± 11.1</td>
<td>45.5 ± 8.1</td>
<td>46.6 ± 7.6</td>
<td>31.3 ± 4.2</td>
</tr>
<tr>
<td>Tricep pushdown 1RM, kg</td>
<td>Pre</td>
<td>17.7 ± 2.7</td>
<td>16.4 ± 3.5</td>
<td>17.3 ± 2.1</td>
<td>16.8 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>17.5 ± 2.4</td>
<td>18.9 ± 4.0</td>
<td>21.9 ± 3.8</td>
<td>17.0 ± 1.8</td>
</tr>
<tr>
<td>Left arm curl 1RM, kg</td>
<td>Pre</td>
<td>8.6 ± 1.0</td>
<td>7.4 ± 2.6</td>
<td>8.2 ± 1.0</td>
<td>7.9 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>8.4 ± 1.0</td>
<td>9.2 ± 1.3</td>
<td>9.5 ± 1.3</td>
<td>8.5 ± 1.2</td>
</tr>
<tr>
<td>Right arm curl 1RM, kg</td>
<td>Pre</td>
<td>8.5 ± 1.2</td>
<td>8.6 ± 3.3</td>
<td>8.9 ± 0.6</td>
<td>8.3 ± 1.3</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>8.7 ± 1.2</td>
<td>9.3 ± 1.3</td>
<td>9.5 ± 1.3</td>
<td>8.8 ± 1.3</td>
</tr>
</tbody>
</table>

Notes: *p < .05 vs NT; †p < .05 vs AT; ‡p < .05 vs ST; §p < .05 vs pre.
AT = aerobic training; ST = strength training; COMT = combined aerobic and strength training; IRM = one-repetition maximum.

**Discussion**

The major new finding of this study was that 12 weeks of ST or COMT were as effective as 12 weeks of AT for...
increasing relative VO_2peak; however, ST and COMT were more effective than AT in improving upper and lower extremity strength in healthy older women. A second finding was that 12 weeks of AT, ST, or COMT did not alter LV systolic or diastolic cavity dimension, wall thickness, mass, or diastolic filling.

**Exercise Training and VO_2peak, LV Morphology, and Diastolic Filling**

Currently, the independent and synergistic effect of AT or ST on altering VO_2peak, LV morphology, and diastolic filling in healthy older women is not known. Ferretti and colleagues (22) assessed the effect of 12 weeks of AT, COMT, or NT on VO_2peak and submaximal endurance in healthy older women. The primary finding of their study was that AT and COMT were equally effective in improving VO_2peak; however, COMT resulted in a greater improvement in submaximal endurance time. Buchner and colleagues (13) compared the effect of 6–9 months of AT, ST, COMT, or NT on VO_2peak in older men and women. An important finding of their study was that VO_2peak was significantly greater after AT or COMT with no change occurring after ST. In contrast, Frontera and colleagues (8) and others (9,23) found that 9–24 weeks of ST resulted in a significant increase in VO_2peak in healthy older men and women. Our finding that 12 weeks of ST was associated with a significant increase in relative VO_2peak (Figure 1) confirms and extends these observations by demonstrating that this mode of training is as effective as AT in improving VO_2peak in healthy older women.

The mechanism responsible for the improvement in VO_2peak in healthy older women has received minimal attention. The few studies performed to date (24–26) have focused on aerobic based exercise interventions. Overall, the findings of these studies suggest that the increase in VO_2peak associated with AT is due to the improvement in peak arteriovenous oxygen difference, as no significant change was found for heart rate (24,25), end diastolic volume (24), end systolic volume (24), stroke volume (24,25), ejection fraction (24,26), or cardiac output during peak exercise (24,25). Failure of older women to increase their stroke volume after AT has been linked to the inability of the senescent female heart to develop eccentric hypertrophy (27). Consistent with this hypothesis, our results and those of Park and colleagues (28) confirm that AT is not associated with an alteration in LV cavity dimension in healthy older women. Moreover, our finding that 12 weeks of AT or ST did not alter LV wall thickness, end-systolic wall stress, or diastolic filling is consistent with previous studies that found no significant alteration in the above variables after AT (25,29) or ST (20). Lastly, our finding of no favorable cardiac adaptations after AT, ST, or COMT indicates that the increase in VO_2peak was likely due to improvements in skeletal muscle function and morphology. More specifically, a number of investigators have found that AT and/or ST is associated with an increase in skeletal muscle fiber cross-sectional area (8,9,30), capillary density (9,30), capillary-to-fiber ratio (8,9,30), and oxidative enzyme activity (8,30) in older men and women.

**Exercise Training and Maximal Muscular Strength**

Our finding that 12 weeks of ST was associated with a significant increase in leg-press, leg-curl, chest-press, shoulder-press, and lattissimus dorsi-pulldown 1RM's is consistent with the findings from previous ST studies in women between 60 and 86 years of age (31–33). Furthermore, Fatouros and colleagues (34) recently found that the increase in leg-press and chest-press strength was significantly greater after 16 weeks of ST or COMT compared to AT or NT in older men. They also found that the post-16-week chest-press 1RM was greater in the ST compared to the COMT participants. In contrast, Buchner and colleagues (13) found that the percent increase in maximal muscular strength was greater after 6 months of COMT compared to ST. We found that, consistent with the results of Buchner and colleagues (13), the overall change in upper and lower extremity strength was higher in the COMT than in the ST participants. The mechanisms responsible for our improvement in overall muscle strength are likely secondary to neural adaptations and to skeletal muscle hypertrophy (32,35,36).

**Study Limitations**

A limitation of this investigation is that the 12-week training program may have been too brief in duration to result in the most optimal improvement in VO_2peak. Thus, it is possible that AT may have resulted in a greater increase in VO_2peak compared to ST had the duration of training been >12 weeks. However, this result appears unlikely given that the percent increase or absolute change in relative VO_2peak that we found after 12 weeks of training is similar to that previously reported, in healthy older women, after 9–36 weeks of AT performed at a similar frequency and intensity as our aerobically trained participants (13,28,37–39).

**Summary**

Twelve weeks of ST and COMT are as effective as 12 weeks of AT in improving relative VO_2peak; however, ST and COMT are more effective than AT for improving upper and lower extremity strength. In addition AT and/or ST does not alter LV morphology or diastolic function. These findings suggest that for older women to attain an optimal improvement in physical fitness they should perform aerobic and strength training.

**Acknowledgments**

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**References**
