Anaerobic Power and Physical Function in Strength-Trained and Non–Strength-Trained Older Adults

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Background. Challenging daily tasks, such as transferring heavy items or rising from the floor, may be dependent on the ability to generate short bursts of energy anaerobically. The purposes of this study were to determine if strength-trained (ST) older adults have higher anaerobic power output compared with non–strength-trained (NST) older adults and to determine the relationship between anaerobic power and performance-based physical function.

Methods. Thirty-five men and women (age 71.5 ± 6.4 years, mean ± SD; NST: n = 18, ST: n = 17) were grouped by training status. Outcome variables included relative anaerobic power (Wingate test), physical function measured with the Continuous Scale Physical Functional Performance Test (CS-PFP, scaled 0 to 100), and anthropometric lean thigh volume (LTV). Analysis of covariance (with age and sex as covariates) was used to determine group differences in the dependent variables listed above. Pearson’s r was used to determine the relationship between anaerobic power, CS-PFP total score (TOT), and CS-PFP lower body strength domain score (LBS).

Results. The ST group had significantly higher mean anaerobic power (NST 58.9 ± 16 W/l, ST 96.3 ± 23 W/l), CS-PFP total (NST 61.2 ± 13, ST 73.7 ± 8), and LBS (NST 54.1 ± 17, ST 70.9 ± 8) compared with the NST group (p < .05). However, LTV was similar for both groups (NST 3.323 ± 0.75; ST 3.179 ± 0.79), which suggests that the ST group had higher muscle quality compared with the NST group. Anaerobic power was significantly related to TOT (r = .611, p = .001) and LBS (r = .650, p = .001).

Conclusions. High levels of physical function in ST older adults may in part be explained by higher levels of anaerobic power associated with strength training.

Sustaining a physical capacity adequate to maintain independence and carry out daily activities is a challenge encountered by many older adults. Age-associated declines in muscle mass (1,2), strength, and aerobic capacity (3,4) contribute to the loss of physical function. Aerobic capacity is an important determinant of function (5,6). Oxygen costs for daily activities have been measured at 0.70 l/min, 0.81 l/min, 0.90 l/min, and 1.4 l/min for slow walking (2 mph), showering, using a bedpan, and walking upstairs, respectively (7). In addition, a peak aerobic capacity of less than 18 ml·kg⁻¹·min⁻¹ has been associated with low levels of self-reported physical function in daily tasks (5). Due to age-related declines in aerobic capacity, older adults may need to rely on anaerobic pathways to complete daily tasks.

Although data support an age-related decline in anaerobic capacity (~7.5% decline per decade) (8–11), energy supplied from anaerobic sources may be important to complete challenging daily tasks. Older adults with diminished aerobic capacities may utilize a high percentage of their aerobic capacity while completing daily tasks, may require more frequent rest breaks, and may be more prone to fatigue. These adults may independently complete serial tasks (combining two or more daily tasks) in spite of low aerobic capacities, but only by taking frequent rest breaks. In addition, more demanding daily tasks, such as getting up from the floor or transferring heavy items, may require quick movement and power, which may require use of an anaerobic pathway. Daily task completion includes short tasks that require less than 30 seconds to complete and long tasks that require more than 30 seconds to complete; both may be challenging for an older adult. The completion of challenging daily tasks as well as serial tasks may be affected by anaerobic abilities.

If anaerobic power is important to the completion of daily tasks, then exercise protocols that increase anaerobic power should be implemented. Strength training is primarily an anaerobic activity and may affect anaerobic power because exercise sets are brief and typically of moderate to high intensity, reflecting the use of ATP-PCr and glycolytic pathways. In contrast, aerobic exercise trains oxidative pathways and enhances the ability to perform sustained work but may not enhance the ability to complete short, high-intensity tasks. Highly strength-trained individuals demonstrate high anaerobic power (11,12), and improvements in anaerobic power have been reported following strength training in younger individuals (13–17). Strength training in older adults may indicate a similar response. The purpose of this article is three-fold: (i) to examine anaerobic power in strength-trained (ST) and non–strength-trained (NST) older adults, (ii) to evaluate physical function in these two groups, and (iii) to determine the relative contribution of anaerobic power to physical function. We hypothesized that ST older adults have higher anaerobic power output compared with NST older adults and that higher anaerobic power is related to higher levels of physical function.
adults would have higher mean and peak anaerobic power and physical function compared with NST older adults. We further hypothesized that anaerobic power would be positively correlated with physical function.

**METHODS**

**Participants**

We recruited healthy older adults (aged 60–85) from the Athens, GA community who met the criteria for the ST and NST groups. We attempted to recruit equal numbers of men and women for each group (ST: 10 men, 7 women; NST: 8 men, 10 women). Current participation in a strength-training program (≥ 2 d/wk for 12 or more weeks) consisting of whole-body strength training (≥ 8 exercises including leg extension, leg press, or squat exercise) was used to determine eligibility for the ST group. Aerobic training was not an exclusionary criterion. Exclusion criteria for both groups included uncontrolled diabetes, diseases with variable disorders (neuromuscular conditions such as multiple sclerosis and Parkinson’s disease), recent bone fracture, knee or hip replacement (within 12 months), severe osteopenia, and severe hypertension (resting blood pressure > 160/90). Following a physician’s clearance, the subjects gave written informed consent prior to participation in the research study as approved by the Institutional Review Board at the University of Georgia.

**Physical Performance Measures**

Anaerobic power (mean and peak power) was measured during a cardiologist-supervised Wingate test. The 30-second Wingate test was performed on a friction-braked bike (model 814E; Monark, Varberg, Sweden). An optical sensor was used to detect reflective markers on the flywheel of the cycle ergometer. The sensor was interfaced with a PC equipped with software from Sports Medicine Industries (St. Cloud, MN) to calculate power indices. Measures obtained included peak power (highest 5-second average) and mean power (average power output over 30 seconds). Results are expressed absolute (W) and relative to lean thigh volume (LTV) in liters (W/l). Fat-free mass (FFM) was used to determine a proportional load applied during the Wingate test.

\[
\text{Load (kp)} = \frac{(57.4 \times \text{FFM})}{0.085}
\]

This equation is based on a 70-kg person with 18% body fat (FFM = 57.4 kg) and a load of 0.085 kp/kg body weight.

Before, during, and after the test, 12-lead electrocardiograph and blood pressure were recorded. Each subject performed a 5-minute warm-up at a low resistance, interspersed with 5-second sprints at various resistance settings. The rating of perceived exertion (RPE) was assessed immediately after the test using the Borg scale (18), and heart rate was recorded. A whole-blood sample was obtained 7.5 minutes postexercise from a prewarmed finger. Heparinized samples were processed in duplicate immediately using a lactate analyzer (YSI 2300; Stat Plus, Yellow Springs, OH).

Leg strength was determined from a one-repetition maximum (1-RM) using a double leg press (Alliance Rehab, Chattanooga, TN). 1-RM is defined as the maximal weight that can be lifted through the full range of motion one time while holding to good form. Participants were familiarized with the leg press prior to the 1-RM test with two sets of 5 to 10 repetitions at a moderate resistance (40 to 80 lbs), adjusting the starting position to achieve 90° hip and knee flexion. On a separate day, each subject returned to the lab for the 1-RM test. After one set of 5 to 10 repetitions at a moderate resistance, 1-RM testing commenced, and weight was gradually added until the participant could not press the machine one time. Rest intervals between each 1-RM attempt trial were ≥3 minutes. Maximal strength was measured to the nearest 5-lb increment.

The Continuous Scale Physical Functional Performance Test (CS-PFP) was used to evaluate physical function. In brief, the CS-PFP is a valid and reliable measure of physical function without known ceiling effects, and therefore the CS-PFP is ideal for quantifying function in adults with higher levels of fitness (19). The CS-PFP is comprised of 16 everyday tasks including making a bed, getting down and up from the floor, stair climbing, and transferring laundry according to standardized instruction. A detailed description of the set-up and test administration has been published elsewhere (19,20) and is described on the World Wide Web (http://www.coe.uga.edu/csp-pfp/). Each task contributes to the total CS-PFP score and one or more of the five domains that comprise a total CS-PFP score (TOT), scaled 0 to 100. The domains of the CS-PFP are lower body strength (LBS), upper body strength (UBS), upper body flexibility, balance and coordination, and endurance. CS-PFP interrater reliability for this lab is high \((r = .988, p = .010)\).

**Body Composition**

Percent fat was estimated from the sum of seven skinfold sites using calipers (Lange, Cambridge, MD) and valid sex-specific equations (21,22). LTV was determined using anthropometric procedures as previously described (23). The same tester measured each site twice, and values were recorded within 2 mm and 0.25 cm for skinfolds and circumferences, respectively.

**Statistical Analysis**

Statistical analyses were performed using SPSS for Windows, version 10 (SPSS Inc., Chicago, IL). A one-way ANCOVA was used to examine differences in anaerobic power output and physical function between training groups. Age and sex were used as covariates. The data were analyzed using linear trends analysis. Linear trends were further analyzed using Pearson’s correlation \((r)\). An alpha level of <.05 was used to determine statistical significance.

**Results**

Selected physical characteristics are listed in Table 1. The ST groups were significantly stronger than the NST group \((p = .040; CI: \text{NST 84.4–116.6, ST 110.2–141.4})\), but there were no significant differences in LTV between the groups. The groups averaged a similar number of medications per subject (NST: 1.8 medications; NST: 1.7 medications). Groups also had similar amounts of moderate aerobic activity (NST: 3.0 days per week; ST: 2.8 days per week), which
including bicycling, walking, swimming, and tennis for at least 25 minutes. Subjects in the ST group had been training for 3 months to 40 years (mean 4.89 years, median 5.5 months; mode 3 months) and strength trained an average of 2.8 days per week (range 2–4 days).

Performance values from the Wingate anaerobic test are shown in Table 1. Anaerobic power expressed absolute and relative to body weight was not significantly different between the training groups. However, anaerobic power expressed relative to LTV (W/l) was significantly different between the groups for mean power ($p = .010$; CI: NST 58.8–78.5, ST 79.3–97.6) and peak power ($p = .016$; CI: NST 78.5–107.0, ST 106.0–133.0) (Figure 1).

Following the Wingate test, RPE was equivalent for both groups (ST: 19; NST: 18). Heart rate immediately following the Wingate test averaged 151 and 139 beats per minute for the ST and NST groups, respectively. Blood lactate values are reported in Table 1. A strong positive relationship was observed between absolute peak power and blood lactate ($r = .857$, $p = .01$). The load applied during the Wingate anaerobic test averaged 0.077 kp/kg body weight and 0.067 kp/kg for men and women, respectively, and did not differ between the training groups.

Physical function was significantly greater in the ST group as shown in Figure 2 (TOT $p = .022$; CI: NST 58.8–68.7, ST 67.6–77.4. LBS $p = .023$; CI: NST 51.6–63.5, ST 62.1–74.0. UBS $p = .044$; CI: NST 67.3–77.0, ST 74.9–84.6). The LBS domain score in the female ST group was 50% greater than in the NST women ($p = .002$; mean scores: NST 48.2 ± 15, ST 71.5 ± 7).

A positive linear trend was significant between anaerobic power and LBS (Figure 3) and between anaerobic power and TOT (Table 2). Correlations between anaerobic power, physical function, and age are displayed in Table 2. Mean anaerobic power explained 44.9% of the variance in the lower body strength domain of the CS-PFP.

### DISCUSSION

This study demonstrates that ST adults have greater anaerobic power output and physical function than NST older adults. Although the ST and NST groups had similar LTV, the ST group produced more power relative to their estimated LTV. In addition, relative anaerobic power was positively related to physical function.

Both ST and NST groups reported high levels of exertion (RPE) and also achieved age-predicted maximal heart rate (220 – age ± 1 SD) during the Wingate anaerobic test, indicating an equivalent and near-maximal effort. Blood lactate was significantly related to anaerobic power. Due to the positive relationship between lactate production and anaerobic glycolysis (24), we expected to find higher levels of lactate production with greater levels of anaerobic power.

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**Table 1. Physical Characteristics and Anaerobic Power**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Male NST (n = 7)</th>
<th>Female NST (n = 10)</th>
<th>NST Group (n = 17)</th>
<th>Male ST (n = 10)</th>
<th>Female ST (n = 8)</th>
<th>ST Group (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>76 ± 7</td>
<td>73 ± 7</td>
<td>74 ± 7</td>
<td>71 ± 5*</td>
<td>66.3 ± 3*</td>
<td>69 ± 5*</td>
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<tr>
<td>Height, cm</td>
<td>177.11 ± 9.6†</td>
<td>161.09 ± 6.2</td>
<td>167.69 ± 11.0</td>
<td>174.47 ± 5.8†</td>
<td>158.36 ± 4.5</td>
<td>167.30 ± 9.7</td>
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<tr>
<td>Weight, kg</td>
<td>82.00 ± 7.8†</td>
<td>63.89 ± 7.7</td>
<td>71.35 ± 13.1</td>
<td>81.82 ± 7.7†</td>
<td>71.61 ± 11.3</td>
<td>77.28 ± 10.6</td>
</tr>
<tr>
<td>FFM, kg</td>
<td>61.65 ± 6.8†</td>
<td>42.5 ± 3.29</td>
<td>50.39 ± 10.8</td>
<td>61.08 ± 6.3†</td>
<td>45.44 ± 4.0</td>
<td>54.13 ± 9.6</td>
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<tr>
<td>Lean thigh volume, l</td>
<td>4.024 ± 0.45†</td>
<td>2.792 ± 0.41</td>
<td>3.323 ± 0.75</td>
<td>3.711 ± 0.59†</td>
<td>2.513 ± 0.38</td>
<td>3.179 ± 0.79</td>
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<td>Leg strength (1-RM), kg</td>
<td>129.22 ± 28.3†</td>
<td>64.32 ± 15.5</td>
<td>91.04 ± 39.0</td>
<td>163.64 ± 47.1</td>
<td>98.58 ± 20.6†</td>
<td>134.72 ± 49.6†</td>
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<td>Mean power, W</td>
<td>249.90 ± 49.8‡</td>
<td>164.80 ± 62.4</td>
<td>199.80 ± 70.6</td>
<td>357.10 ± 81.4‡</td>
<td>231.25 ± 31.4</td>
<td>301.22 ± 90.1‡</td>
</tr>
<tr>
<td>Peak power, W</td>
<td>357.00 ± 55.5‡</td>
<td>244.60 ± 96.7</td>
<td>282.09 ± 99.5</td>
<td>467.73 ± 91.3‡</td>
<td>297.13 ± 47.6</td>
<td>391.92 ± 114.0‡</td>
</tr>
<tr>
<td>Lactate, mmol/l</td>
<td>5.39 ± 1.3†</td>
<td>4.01 ± 1.6</td>
<td>4.56 ± 1.6</td>
<td>6.36 ± 1.1†</td>
<td>5.03 ± 0.9</td>
<td>5.77 ± 1.2†</td>
</tr>
</tbody>
</table>

Notes: Values are means ± SD. NST = nonstrength trained; ST = strength trained; FFM = fat-free mass.

†$p < .05$ training group difference, †$p < .05$ sex difference.

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Figure 1. Anaerobic power relative to lean thigh volume (±SEM) for strength-trained (ST) and non–strength-trained (NST) groups. *$p < .05$.

Figure 2. Physical function scores from Continuous Scale Physical Functional Performance test (CS-PFP) in strength-trained (ST) and non–strength-trained (NST) groups (*$p < .05$). Domains of CS-PFP: UBS = upper body strength; UBF = upper body flexibility; LBS = lower body strength; BALC = balance and coordination; END = endurance; TOT = total CS-PFP score.
Our finding of greater anaerobic power without concurrent reflection in muscle mass has been previously documented. Shaw and Snow (25) report increases in peak anaerobic power (13.2% ± 12%) in older women that were not explained by increases in muscle mass following a combined jumping and weight training (lunges, squats, step-ups, and toe raises) program. Higher relative anaerobic power in the ST group suggests that ST adults more fully activate their muscle. Data from both rat (26) and human studies (27–29) show increased specific tension (strength/unit area) following strength training and increased muscle activity through EMG (30), which may account for increased strength associated with neural adaptations. Higher power output through neural adaptation may be achieved through increased recruitment of motor units, synchronization, increased synergistic activation of other musculature, or decreased activation of antagonistic muscle groups. The ST group may also have higher anaerobic enzyme activities or substrates, which have been reported to increase with strength training (31). Muscle composition (percent fast-twitch fibers) may also contribute to higher anaerobic power output (32,33). Although possible, it is unlikely that higher relative anaerobic power output in the ST group resulted from a higher proportion of type II fibers compared with the untrained group. Due to the design of this study, we were unable to determine the mechanism responsible for the higher power output for the ST group.

Our results confirm several previous studies that show that functional performance is improved by strength training (20,34,35). However, to our knowledge, no one has looked at those factors associated with strength training that are important as contributors to functional performance. Our data show that ST adults carried more weight (29%) and moved faster (17%) than the NST group. Specifically, when examining the female groups, the greater LBS scores from the ST group suggest that physical functional performance may be greatly enhanced through strength training. Results of this study indicate that anaerobic power production is related to the ability to complete daily activities. Lower extremity power is highly related to stair climbing, rising from the chair and floor, and walking speed (r = .53–.88) (36,37). Using the CS-PFP to evaluate physical function, we showed that whole-body function (total physical function score) and multi-task lower body function (LBS domain) were significantly related to anaerobic power production. The CS-PFP test may be an ideal measure of physical function for these purposes due to the serial nature of the tasks, the quantification of domains, and the ability to assess high-functioning individuals without a ceiling effect.

Anaerobic power output may be a critical component for completing serial tasks, occasional highly demanding tasks, and emergency tasks (e.g., correcting balance after a trip). Daily tasks, such as transferring wet laundry, carrying groceries, and rising from the floor, can be highly demanding for an older adult. Dutta and colleagues suggest that older adults are challenged by “emergency tasks” in daily life (38). These emergency tasks include correcting balance after a trip, stopping abruptly, transferring heavy items, and rising from the floor. Success in these tasks may depend on adequate anaerobic power. The CS-PFP measure of physical function includes highly demanding or emergency daily tasks (floor sit to stand, a grocery task, a bus-stop task with baggage, and a stair climb), which may be reflective of anaerobic power.

This study shows positive support for strength training in older adults. However, there were some limiting factors. This cross-sectional study design does not provide direct evidence for changes in anaerobic power. Strength training regimens of the ST group differed in the training frequency, intensity, and volume, as well as in the type of exercises regularly completed and the number of months individuals had been strength training.

In conclusion, older adults who strength trained a minimum of 2 d/wk achieved higher anaerobic power than NST adults, independent of age. ST individuals produced more power per unit of LTV and had higher physical function than the NST group, indicating that strength training positively affects muscle quality. High levels of physical function in ST older adults may be explained by an increase in anaerobic power resulting from strength training.

Acknowledgments

This research was supported by the Georgia Gerontology Consortium Seed Grant. We thank Dr. Harry Duval and Dr. Kirk Cureton for providing essential laboratory space and equipment.

Table 2. Pearson Product Correlations Between Physical Function, Anaerobic Power, and Age

<table>
<thead>
<tr>
<th></th>
<th>Peak Power Mean Power</th>
<th>Mean Power Mean Power</th>
<th>Age Mean Power Mean Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS-PFP-TOT</td>
<td>.944** (.550* .611**</td>
<td>−.398*</td>
<td></td>
</tr>
<tr>
<td>CS-PFP-LBS</td>
<td>.627* (.670** −.473**)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak power</td>
<td>1.000</td>
<td>.940** −.658**</td>
<td></td>
</tr>
<tr>
<td>Mean power</td>
<td>1.000</td>
<td>.628*</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: CS-PFP-TOT = total physical function score; CS-PFP-LBS = lower body strength domain of Continuous Scale Physical Function Performance test (CS-PFP); mean and peak power = anaerobic power relative to lean thigh volume (W/l) from the Wingate test.

*p < .05; **p < .01.
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Received April 17, 2001
Accepted July 3, 2001
Decision Editor: John E. Morley, MB, BCh