Published in final edited form as:

Int J Sports Med. 2012 July ; 33(7): 537–542. doi:10.1055/s-0032-1304659.

Leg Strength is Associated with Ventilatory Efficiency in Older Women

J. U. Gonzales¹, S. H. Tucker², M. J. Kalasky², and D. N. Proctor²

¹Health, Exercise and Sport Sciences, Texas Tech University, Lubbock, United States

²Kinesiology, Pennsylvania State University, University Park, United States

Abstract

The aim of the present study was to determine if leg function is associated with ventilatory efficiency during exercise in healthy older adults. 24 women and 18 men aged 60–80 years performed treadmill exercise to fatigue for calculation of ventilatory efficiency using the ratio of ventilation to carbon dioxide at the anaerobic threshold (VE/VCO₂@AT). On a separate day, participants performed leg strength testing and graded single-leg knee extension exercise. The VE/VCO₂@AT was higher in women than men (33 ± 3 vs. 30 ± 3; p = 0.03). After adjustment for age and VO_{2max}, leg strength (knee extensor isometric force) was inversely associated with VE/VCO₂@AT in women (r = −0.44, p = 0.03) while no relationships were found for men. Strength-matched women and men had similar VE/VCO₂@AT indicating that the correlation between leg strength and VE/VCO₂@AT was strength-but not sex-specific. During knee extensor exercise, women with lower leg strength had increased VE/VCO₂ slope across 0–15 W as compared to higher strength women (38 ± 8 vs. 31 ± 3; p < 0.05), while no differences were found for men. These results find leg strength to be associated with ventilatory responses to exercise in healthy older women, a finding that might be related to lower leg strength in women than men.

Keywords

aging; ventilation; sex differences; muscle strength

Introduction

Ventilatory efficiency, as assessed by the relationship between ventilation (VE) and carbon dioxide production (VCO₂), indicates matching of lung ventilation to perfusion. During moderate exercise, prior to significant metabolic acidosis, VE changes to regulate arterial PCO₂ at a set point thus VE and VCO₂ are tightly coupled. However, in conditions associated with impaired lung gas exchange the ratio of VE/VCO₂ during exercise is increased indicating disproportionately higher VE for a given VCO₂. Several measures have been used to study ventilatory efficiency during exercise; the most commonly used are the VE vs. VCO₂ slope and VE/VCO₂ at the anaerobic threshold (VE/VCO₂@AT). Both methods provide similar absolute values [19,22], but the VE/VCO₂@AT has been shown to be less variable in healthy adults [19]. Previous studies have used the VE/VCO₂@AT to assess the impact of cardiopulmonary disease [14,22] and aging [13,19] on the control of breathing. It is currently unclear what factors contribute to decreased ventilatory efficiency during exercise with aging, but evidence is emerging that muscle strength may play a role.

Aging is associated with the progressive loss of skeletal muscle mass and strength that has been collectively termed sarcopenia [4]. Recently, a longitudinal study in older adults found muscle strength to decline at a greater rate than the concomitant loss of muscle mass in women and men [5]. Reduced muscle strength with advancing age impacts the capacity of older adults to perform activities of daily living [3], is related to breathlessness during exercise [13], and is found to correlate with mortality even after accounting for muscle mass [12]. Interestingly, poor leg strength and endurance have been shown to associate with ventilatory inefficiency during exercise in patients with heart failure [2,17]. The neural link between impaired skeletal muscle function and the lung is thought to be overactive skeletal muscle afferents sensitive to metabolic abnormalities in skeletal muscle producing an abnormally high ventilatory drive [15]. Older adults have altered skeletal muscle function including fiber type shifts and age-related declines in force production and motor unit discharge rate [10,21].

Since aging is associated with significant changes to skeletal muscle contractile quality, we sought to determine if skeletal muscle function is associated with $\dot{V}E/\dot{V}CO_2$ during exercise in healthy older adults. We hypothesized that decreased leg strength and peak leg oxygen uptake would be associated with ventilatory inefficiency during exercise in older women and men consistent with findings in heart failure patients [2,17].

Methods

Subjects

24 women and 18 men between the ages of 60–80 year participated in this study. Subjects were healthy as determined by medical history questionnaire, physical examination, resting electrocardiogram, body mass index $< 31 \text{ kg}\cdot\text{m}^{-2}$, and resting blood pressure ($< 140/90 \text{ mmHg}$). No subjects were taking any form of hormone therapy or taking drugs that affect cardiorespiratory function at the time of the study. All subjects provided written consent to participate after being explained all experimental procedures and possible risks associated with the study. This study was approved by the Office for Research Protections at Pennsylvania State University in agreement with the guidelines set forth by the Declaration of Helsinki along with the ethical standards in sports and exercise science research [8].

Procedures

Subjects were asked to refrain from caffeine for 12 h prior to exercise testing. Each subject performed a modified Balke treadmill test to maximal effort [18]. On a separate day, subjects performed knee extension strength testing and dynamic exercise with the left leg. Maximal isometric force production was measured using a S-beam load cell (LC115, Omega Engineering, Inc., Stamford, CT, USA) at 60° knee extension and was calculated as the average of the 2 highest of 3–5 maximal efforts that were separated by a rest period of 1–2 min. During dynamic knee extensor exercise (40 contractions/min), work rate increased every 3 min by 5 watts and 10 watts for women and men, respectively, until fatigue.

Subjects were instructed on wearing a uniaxial accelerometer (Actigraph model GT1M, Pensacola, FL, USA) that was positioned over the left hip of the subject with an adjustable elastic belt. Participants wore the accelerometer for 4 days (one day was a weekend day) and were asked to take off the accelerometer during bathing, swimming, or sexual activity. The accelerometer was programmed to record physical activity data every 10 s. Data were converted to moderate-to-vigorous physical activity using the cut point of 1952 counts/min [6].

Measurements

Pulmonary gas exchange, VE, end-tidal carbon dioxide tension (PETCO₂), tidal volume, and breathing frequency were measured during treadmill and knee extension exercise using indirect calorimetry (Parvomedics model TrueOne 2 400, Sandy, UT, USA). Calculation of the dead space fraction of tidal volume (VD/VT) was made using formulas described by Jones et al. [9] which used PETCO₂ to estimate PaCO₂ and FECO₂ to estimate PECO₂ in order to calculate dead space. The anaerobic threshold during treadmill exercise was estimated using ventilatory equivalents for oxygen and carbon dioxide and the V-slope methods by 2 independent reviewers [1,16]. The VE/VCO₂ was averaged over a 30 s period at the anaerobic threshold (VE/VCO₂@AT) as a measure of ventilatory efficiency during exercise. The predicted value for VE/VCO₂@AT was calculated as $28.25 + 0.105 \times \text{age} + (1 = \text{women}, 0 = \text{man}) - 0.0375 \times \text{height}$ [19].

Whole body composition was assessed using dual x-ray absorptiometry (model QDR 4 500 W, Hologic, Waltham, MA, USA) while subjects were in the supine position. Total body fat-free mass was measured with standard cut lines while thigh muscle mass was estimated from the ischial tuberosities to the midpoint between the greater trochanter and the knee joint line.

Statistical analysis

Independent sample t-tests were used to test for differences in dependent variables. Pearson correlation coefficients were calculated to estimate the relation between pairs of variables. Partial correlation analysis was performed to test for independent relationships after adjusting for age and treadmill VO_{2max}. 1-way analysis of variance was used to test for differences between tertiles within each sex. Student-Newman-Keuls post-hoc testing was used to make multiple comparisons. Statistical significance was set at $p < 0.05$. Data is expressed as mean $\pm$ standard deviation (SD) unless stated otherwise.

Results

Subject characteristics are presented in Table 1. Women and men were of similar age and had similar anaerobic thresholds (%VO_{2max} and VO₂ at AT) during treadmill exercise. In contrast, women had lower ($p < 0.05$) treadmill VO_{2max}, thigh muscle mass, absolute leg strength, peak leg oxygen uptake, and performed less moderate-to-vigorous daily physical activity as compared to men. VE/VCO₂@AT was higher ($p = 0.03$) in women than men and was related to a lower ($p = 0.01$) PETCO₂ in women. Table 2 shows correlation coefficients for variables in relation to VE/VCO₂@AT. After adjustment for age and cardiorespiratory fitness, absolute leg strength was the only variable associated with VE/VCO₂@AT in women ($r = -0.43$, $p = 0.03$) while no significant correlations were found in men. The association between absolute leg strength and VE/VCO₂@AT is shown in Fig. 1 for both sexes. Sub-analysis ($n = 10$ in each group) of women and men matched for leg strength (women: 327 ± 29 N vs. men: 317 ± 37 N; $p = 0.52$) showed no sex difference in VE/VCO₂@AT (women: 31 ± 3 vs. men: 32 ± 4 ; $p = 0.71$) or percent-predicted VE/VCO₂@AT (women: 105 ± 9 % vs. men: 110 ± 11 %; $p = 0.28$). This indicates that the relationship between leg strength and VE/VCO₂@AT may not be sex-specific.

Tertiles based on predicted values for VE/VCO₂@AT showed women with values predicted above 110 % had the poorest leg strength among women ($p = 0.02$; Fig. 2). Comparison of ventilatory efficiency at rest and during knee extensor exercise between lower and higher strength groups (divided by median) is presented in Table 3. Women with lower strength presented with inefficient ventilation as demonstrated by greater ($p < 0.05$) VE/VCO₂ at rest and ventilatory responses to 15 W of knee extensor exercise as compared to women with

higher leg strength. Lower strength women also had higher ($p < 0.05$) VE/VCO_2 across similar levels of oxygen consumption during exercise (Fig. 3). In men, no differences in ventilatory efficiency were found between strength groups at rest or during knee extensor exercise (Table 3, Fig. 3).

Discussion

The purpose of the present study was to determine if skeletal muscle function, as reflected by leg strength and peak leg oxygen uptake, is associated with ventilatory responses to exercise in healthy older adults. Similar to previous studies, the present study found age to be a significant predictor of ventilatory efficiency during exercise [7,11,19] and older women to have higher $VE/VCO_2@AT$ as compared to age-matched men [13]. The novel finding of the present study is that leg strength was inversely related to ventilatory efficiency during exercise, as assessed by $VE/VCO_2@AT$, in healthy older women but not in men even after adjusting for age and cardiorespiratory fitness level (treadmill VO_{2max}). The relationship between low leg muscle strength and high ventilatory responses to exercise was observed during both large (treadmill) and small (knee extensions) muscle mass exercise. Our findings suggest that variation in leg strength may influence ventilatory responses to exercise in healthy older women, a finding that might be related to lower leg strength in women as compared to men.

The link between skeletal muscle function and ventilatory responses to exercise is postulated to be group III and IV afferents in skeletal muscle. These sensory receptors provide feedback to the central nervous system regarding mechanical and chemical changes in active skeletal muscle. Interestingly, skeletal muscle afferents are overactive in persons with skeletal muscle dysfunction as demonstrated by excessive ventilation when forearm exercise-produced metabolites are trapped by circulatory occlusion in persons with heart failure [15]. Importantly, decreased leg muscle strength and endurance performance has been shown to correlate with increased VE/VCO_2 during exercise in patients with chronic heart failure [2,17]. The results of the present study extend this finding to a healthy population of older women by demonstrating an inverse relationship between leg muscle strength and elevated ventilatory responses to large and small muscle mass exercise. The absent relationship between muscle strength and the ratio of VE to VCO_2 in older men is likely the result of their higher leg strength as compared to older women since strength-matched women and men had similar $VE/VCO_2@AT$.

In the present study, absolute force production of the quadriceps was most predictive of ventilatory efficiency during exercise in women. It is possible that thigh muscle mass was not a significant predictor due to the age of our subjects since the annual rate of decline in muscle mass is half that of muscle strength after age 60 [20]. However, reduced muscle mass is an unlikely mechanism underlying increased ventilation in the present study since older women had higher leg strength normalized for thigh muscle mass than older men (Table 1), which is consistent with previous work showing greater peak specific tension in Type I and IIa fibers from knee extensor muscles in older women than men [21]. Also, leg strength normalized for thigh muscle mass was not significantly different ($p = 0.15$) between older women with lower and higher muscle strength in the present study (data not shown). Therefore, it is more likely that the mechanism responsible for the relationship between leg strength and ventilatory efficiency is not muscle mass, but rather factors related to muscle afferent excitability such as fiber type shifts [21] and neuromuscular changes with advancing age [10]. Indeed, older women with lower leg strength in the present study had a higher RER at 15W of knee extension exercise indicating greater metabolic stress, and possibly receptor stimulation, within the active leg even during submaximal exercise (Table 3).

Inefficient ventilation (increased VE/VCO_2) is caused by a reduced CO_2 set point and/or by an increased physiological dead space. Since estimated VD/VT was similar between sexes in the present study, increased dead space as a possible cause of higher $VE/VCO_2@AT$ in women is unlikely. Rather, the higher $VE/VCO_2@AT$ in older women as compared to men was associated with a significantly lower $PETCO_2$, in agreement with previous research [11]. Women and men had similar breathing frequency during treadmill exercise (Table 1) indicating that the lower $PETCO_2$ in women was not due to the negative influence of tachypneic breathing pattern on end-tidal values indicative of increased central drive. Rather, we speculate that the relative alveolar hyperventilation leading to a reduced $PETCO_2$ in older women is related to muscle afferent overactivity since the present study finds a significant relationship between skeletal muscle function (isometric force production) and $VE/VCO_2@AT$. Further research is warranted to directly test this hypothesis in healthy older adults.

In conclusion, skeletal muscle strength as measured by maximal isometric knee extensor force production is related to ventilatory efficiency during both large and small muscle dynamic leg exercise in healthy older (60–80 years) women. Lower leg strength coupled with higher ventilatory responses to submaximal exercise in women supports the notion that older women may be at an increased risk of impaired physical function as compared to older men and emphasizes the need for preservation of muscle strength in women as they age.

Acknowledgments

This study was funded in part by grant R01 AG018246 (to D.N. Proctor) from the National Institutes of Health and grant M01 RR10732 (to General Clinical Research Center) from the Division of Research Resources.

References

1. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. *J Appl Physiol.* 1986; 60:2020–2027. [PubMed: 3087938]
2. Clark A, Rafferty D, Arbuthnott K. Relationship between isokinetic muscle strength and exercise capacity in chronic heart failure. *Int J Cardiol.* 1997; 59:145–148. [PubMed: 9158166]
3. Cress ME, Meyer M. Maximal voluntary and functional performance needed for independence in adults aged 65 to 97 years. *Phys Ther.* 2003; 83:37–48. [PubMed: 12495411]
4. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinková E, Vandewoude M, Zamboni M. Sarcopenia: European consensus on definition and diagnosis. *Age Ageing.* 2010; 39:412–423. [PubMed: 20392703]
5. Delmonico MJ, Harris TB, Visser M, Park SW, Conroy MB, Velasquez-Mieyer P, Boudreau R, Manini TM, Nevitt M, Newman AB, Goodpaster BH. Longitudinal study of muscle strength, quality, and adipose tissue infiltration. *Am J Clin Nutr.* 2009; 90:1579–1585. [PubMed: 19864405]
6. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc.* 1998; 30:777–781. [PubMed: 9588623]
7. Habedank D, Reindl I, Vietzke G, Bauer U, Sperfeld A, Gläser S, Wernecke KD, Kleber FX. Ventilatory efficiency and exercise tolerance in 101 healthy volunteers. *Eur J Appl Physiol.* 1998; 77:421–426.
8. Harriss DJ, Atkinson G. Update - Ethical standards in sport and exercise science research. *Int J Sports Med.* 2011; 32:819–821. [PubMed: 22065312]
9. Jones, NL. Clinical exercise testing. Philadelphia, PA USA: W.B. Saunders Company; 1997.
10. Kamen G, Knight GA. Training-related adaptations in motor unit discharge rate in young and older adults. *J Gerontol A Biol Sci Med Sci.* 2011; 59:1334–1338. [PubMed: 15699535]
11. Neder JA, Nery LE, Peres C, Whipp BJ. Reference values for dynamic responses to incremental cycle ergometry in males and females aged 20 to 80. *Am J Respir Crit Care Med.* 2001; 164:1481–1486. [PubMed: 11704600]

12. Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster B, Kritchevsky SB, Tylavsky FA, Rubin SM, Harris TB. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. *J Gerontol Biol Sci.* 2006; 61:72–77.
13. Ofir D, Laveneziana P, Webb KA, Lam YM, O'Donnell DE. Sex differences in the perceived intensity of breathlessness during exercise with advancing age. *J Appl Physiol.* 2008; 104:1583–1593. [PubMed: 18436700]
14. Oudiz RJ, Midde R, Hovanesyan A, Sun XG, Roveran G, Hansen JE, Wasserman K. Usefulness of right-to-left shunting and poor exercise gas exchange for predicting prognosis in patients with pulmonary arterial hypertension. *Am J Cardiol.* 2010; 105:1186–1191.
15. Piepoli M, Clark AL, Volterrani M, Adamopoulos S, Sleight P, Coats AJS. Contribution of muscle afferents to the hemodynamic, autonomic, and ventilatory responses to exercise in patients with chronic heart failure: effects of physical training. *Circ.* 1996; 93:940–952.
16. Reinhard U, Müller PH, Schmölling R-M. Determination of the anaerobic threshold by the ventilation equivalent in normal individuals. *Respir.* 1979; 38:36–42.
17. Saval MA, Kerrigan DJ, Ophaug KM, Ehrman JK, Keteyian SJ. Relationship between leg muscle endurance and VE/VCO₂ slope in patients with heart failure. *J Cardiopulm Rehabil Prev.* 2010; 30:106–110. [PubMed: 19952773]
18. Stevenson ET, Davy KP, Seals DR. Maximal aerobic capacity and total blood volume in highly trained middle-aged and older female endurance athletes. *J Appl Physiol.* 1994; 77:1691–1696. [PubMed: 7836188]
19. Sun X, Hansen JE, Garatachea N, Storer TW, Wasserman K. Ventilatory efficiency during exercise in healthy subjects. *Am J Respir Crit Care Med.* 2002; 166:1443–1448. [PubMed: 12450934]
20. von Haehling S, Morley JE, Anker SD. An overview of sarcopenia: facts and numbers on prevalence and clinical impact. *J Cachex Sarcopenia Muscle.* 2010; 1:129–133.
21. Yu F, Hedström M, Cristea A, Dalén N, Larsson L. Effects of ageing and gender on contractile properties in human skeletal muscle and single fibres. *Acta Physiol.* 2007; 190:229–241.
22. Zhai Z, Murphy K, Tighe H, Wang C, Wilkins MR, Gibbs JS, Howard LS. Differences in ventilatory inefficiency between pulmonary arterial hypertension and chronic thromboembolic pulmonary hypertension. *Chest.* 2011; 140:1284–1291. [PubMed: 21527511]

Fig. 1. Relationship between isometric leg strength and ventilatory efficiency during treadmill exercise in older women (upper panel) and men (lower panel).

Fig. 2.

Differences in leg strength when women and men are classified according to predicted VE/VCO₂@AT during treadmill exercise. Women with ventilatory efficiency values > 110 % predicted (n = 11) had significantly lower (p = 0.02) leg strength than women with percent predicted values of < 101 % (n = 7) and 101-110 % (n = 6). Leg strength was not different between < 101 % (n = 6), 101-110 % (n = 5) and > 110 % (n = 7) predicted groups in men (p = 0.57). Values are mean ± SE. **, significantly different from < 101 % Pred and 101-110 % Pred (p < 0.05).

Fig. 3. Change in ventilatory equivalent of carbon dioxide (VE/VCO₂) across oxygen uptake (VO₂ normalized to thigh muscle mass, TMM) during knee extension exercise in lower and higher strength women (upper panel) and men (lower panel). Subjects were divided into groups based on the median within each sex for maximal isometric knee extension force. Values are mean $\pm$ SE for measurements at rest and during each stage of exercise. *, significant difference between lower and higher strength groups within each sex at a standardized VO₂ of 80 ml/kgTMM/min.

Table 1

Subject characteristics.

	Older Women (n = 24)		Older Men (n = 18)		p-value
	mean±SD	Range	mean±SD	Range	
age (y)	65±6	60–80	65±5	60–78	0.82
<i>body composition:</i>					
body mass index (kg/m ²)	25±2	19–30	26±3	22–30	0.15
fat-free mass (kg)	41±5	33–50	61±7	46–74	<0.01
<i>fitness:</i>					
treadmill VO _{2max} (mL/kg FFM/min)	43±6	30–55	48±9	27–62	0.05
anaerobic threshold (%VO _{2max})	55±9	41–71	52±8	36–66	0.31
VO ₂ at AT (mL/kg FFM/min)	23±5	16–39	24±5	16–34	0.43
moderate-to-vigorous activity (min/d)	32±24	8–93	54±34	11–123	0.02
<i>ventilatory efficiency:</i>					
VE/VO ₂ at rest	39±9	30–73	39±8	30–66	0.88
VE/VCO ₂ at rest	43±5	38–55	43±6	33–53	0.84
VE/VCO ₂ at AT	33±3	27–39	30±3	25–37	0.03
VE/VCO ₂ at AT (%predicted)	113±11	95–137	107±11	88–126	0.09
PETCO ₂ at AT (mmHg)	28±3	23–33	31±3	25–37	0.01
tidal volume at AT (L)	1.2±0.4	0.7–2.2	1.7±0.5	0.9–2.5	<0.01
VD/VT at AT	0.12±0.01	0.09–0.16	0.12±0.02	0.08–0.17	0.74
breathing frequency at AT (per min)	22±4	12–30	21±4	13–27	0.58
<i>leg muscle characteristics:</i>					
thigh muscle mass (kg)	4.2±0.6	3.1–5.4	6.4±0.8	4.9–8.2	<0.01
absolute leg strength (N)	285±46	196–374	378±82	267–560	<0.01
strength per unit muscle (N/kg TMM)	69±11	50–94	59±10	43–74	<0.01
peak knee extension workrate (W)	28±6	15–40	43±10	20–60	<0.01
absolute peak leg VO ₂ (mL/min)	511±115	337–876	862±133	640–1174	<0.01
leg VO ₂ per unit muscle (mL/kg TMM/min)	123±22	83–167	135±15	113–166	0.03

VO_{2max}: maximal oxygen uptake; FFM: fat-free mass; AT: anaerobic threshold; VD/VT: dead space fraction of tidal volume; TMM: thigh muscle mass; PETCO₂: end-tidal carbon dioxide tension

Relationship (correlation coefficient r) between age, fitness, skeletal muscle function and VE/VCO_2 @AT in women and men.

Table 2

	Older Women (n = 24)			Older Men (n = 18)		
	unadjusted	adjusted for age	adjusted for age+fitness ^a	unadjusted	adjusted for age	adjusted for age+fitness
age	0.53 *			0.84 *		
body mass index	-0.45 *	-0.33	-0.36	-0.01	0.33	0.32
fat-free mass	-0.51 *	-0.32	-0.34	-0.12	0.08	0.05
treadmill VO_{2max}	-0.46 *	-0.12		-0.55 *	-0.10	
MVPA	-0.47 *	-0.29	-0.26	-0.38	-0.13	-0.09
thigh muscle mass	-0.44 *	-0.21	-0.25	-0.14	0.10	0.10
absolute leg strength	-0.62 *	-0.43 *	-0.44 *	-0.21	-0.04	-0.04
strength per unit muscle	-0.24	-0.17	-0.15	-0.15	-0.10	-0.11
absolute peak leg VO_2	-0.28	-0.10	-0.10	-0.53 *	-0.21	-0.18
leg VO_2 per unit muscle	-0.01	0.01	0.04	-0.58 *	-0.42 †	-0.41

^a fitness = treadmill VO_{2max} ; VO_2 : oxygen uptake; MVPA: moderate-to-vigorous physical activity;

* $p < 0.05$;

† $p = 0.08$

Table 3

Comparison of ventilatory efficiency at rest and during knee extension exercise between strength groups.

	Women		Men	
	Lower Strength	Higher Strength	Lower Strength	Higher Strength
<i>n</i> =	12	12	9	9
absolute leg strength (N)	250±28 *	320±31	311±34 *	444±57
anaerobic threshold (% VO _{2max})	54±9	55±10	52±9	52±7
VO ₂ at AT (mL/kg FFM/min)	21±3	24±6	23±5	26±5
<i>resting:</i>				
ventilation (L/min)	9±2	9±2	11±2	11±2
VE/VCO ₂	48±6 *	43±4	44±4	44±5
PETCO ₂ (mmHg)	20±2 *	22±2	22±2	22±2
tidal volume (L)	0.6±0.2	0.6±0.1	0.8±0.2	0.7±0.2
VD/VT	0.22±0.04 *	0.19±0.03	0.20±0.03	0.21±0.04
breathing frequency (per min)	16±3	15±3	15±4	15±3
<i>exercise:</i>				
	<i>15 Watts</i>		<i>20 Watts</i>	
ventilation (L/min)	16±2 *	14±2	18±3	19±4
VE/VCO ₂	43±6 *	39±3	37±4	39±6
VE/VCO ₂ slope (from 0W to 15/20W)	38±8 *	31±3	30±6	32±5
PETCO ₂ (mmHg)	22±3	24±2	25±3	25±3
tidal volume (L)	0.7±0.1	0.8±0.1	1.1±0.2	0.9±0.2
VD/VT	0.20±0.04 *	0.17±0.02	0.17±0.02	0.18±0.03
breathing frequency (per min)	23±5 *	19±3	17±4	21±8
respiratory exchange ratio	1.0±0.1 *	0.9±0.1	0.9±0.1	0.9±0.1

N: Newton; AT: anaerobic threshold; VO₂: oxygen uptake; FFM: fat-free mass; TMM: thigh muscle mass; PETCO₂: end-tidal carbon dioxide tension; VD/VT: dead space fraction of tidal volume

*, significant difference ($p < 0.05$) between strength groups within each sex