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Inverse relationship between changes of maximal aerobic capacity and changes in walking economy after weight loss

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Abstract

Purpose—The aims of this study were to: 1) determine the relationships between maximum oxygen uptake ($\dot{V}O_{2\max}$) and walking economy during non-graded and graded walking among overweight women and 2) examine potential differences in $\dot{V}O_{2\max}$ and walking economy before and after weight loss.

Methods—One-hundred and twenty four premenopausal women with a body mass index (BMI) between 27–30 kg/m² were randomly assigned to one of three groups: a) diet only; b) diet and aerobic exercise training; and c) diet and resistance exercise training. All were furnished with standard, very-low calorie diet to reduce BMI to < 25 kg/m². $\dot{V}O_{2\max}$ was measured using a modified-Bruce protocol while walking economy (1-net $\dot{V}O_2$) was obtained during fixed-speed (4.8 k·h⁻¹), steady-state treadmill walking at 0% grade and 2.5% grade. Assessments were conducted before and after achieving target BMI.

Results—Prior to weight loss, $\dot{V}O_{2\max}$ was inversely related ($P < 0.05$) with non-graded and graded walking economy ($r = -0.28$ to -0.35). Similar results were also observed following weight loss ($r = -0.22$ to -0.29). Additionally, we also detected a significant inverse relationship ($P < 0.05$) between the changes (, after weight loss) in $\dot{V}O_{2\max}$, adjusted for fat-free mass, with non-graded and graded walking economy ($r = -0.37$ to -0.41).

Conclusions—Our results demonstrate $\dot{V}O_{2\max}$ and walking economy are inversely related (cross-sectional) before and after weight loss. Importantly though, $\dot{V}O_{2\max}$ and walking economy were also found to be inversely related, suggesting a strong synchrony between maximal aerobic capacity and metabolic cost of exercise.

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Author Contribution Statement

JB wrote the manuscript and performed data and statistical analysis. SC reviewed and edited the manuscript. HS reviewed and edited the manuscript. GH conceived and designed research, wrote, and reviewed and edited the manuscript. All authors read and approved the manuscript.

Keywords

Efficiency; $\dot{V}O_{2\max}$; walking oxygen uptake; walking energy cost

Introduction

Maximal oxygen uptake ($\dot{V}O_{2\max}$) and exercise/work economy are key features closely connected with sport-related endurance performance and requisite tasks for daily-living (Hunter et al. 2005). Since aerobic exercise training is known to improve $\dot{V}O_{2\max}$ (McArdle et al. 2010), as well as, exercise/work economy (Hunter et al. 2008; Fisher et al. 2013; Montero and Lundby 2015), a positive relationship between the two can be postulated. However, previous studies have reported an inverse relationship between $\dot{V}O_{2\max}$ and exercise/work economy during different weight-bearing and non-weight bearing activities including running (Pate et al. 1992; Morgan and Daniels 1994; Shaw et al. 2015), walking (Hunter et al. 2005; Sawyer et al. 2010), and cycling (Lucía et al. 2002). In other words, individuals with a high $\dot{V}O_{2\max}$ tend to perform a given activity with low exercise/work economy (i.e., higher $\dot{V}O_2$ cost) though the implications for this phenomenon are unclear.

A recent study by Shaw and colleagues (Shaw et al. 2015) described a positive relationship between $\dot{V}O_{2\max}$ and running economy among a group of highly trained male and female runners. However, it is important note the positive relationship reported was between $\dot{V}O_{2\max}$ and the energy cost of running, which is the *opposite* of exercise economy. Nevertheless, it is unclear whether the relationship between $\dot{V}O_{2\max}$ and exercise economy is altered among individuals who undergo significant weight loss. Given the importance of participation in free-living activity for cardio-metabolic health and proper weight maintenance (Hunter et al. 2015), it is of interest to determine if improved $\dot{V}O_{2\max}$ may lead to poorer exercise/work economy after weight loss.

Therefore, the present investigation had multiple objectives: i) to examine the cross-sectional relationship between $\dot{V}O_{2\max}$ and exercise economy during non-graded and graded walking among premenopausal overweight women (before and after weight loss) and; ii) to examine how changes (i.e., delta, Δ) in body weight (with weight loss) affected the relationship between $\dot{V}O_{2\max}$ and walking economy. It is hypothesized that there will be an inverse relationship between $\dot{V}O_{2\max}$ and walking economy both before and after weight loss. Given that cross-sectional data may be vulnerable to statistical artefact, leading to spurious conjecture, it is important to note changes in variables across two time-points (i.e., baseline and after weight loss) are less likely to be confounded by such instances. Therefore, we also hypothesized that $\dot{V}O_{2\max}$, following weight loss, will be negatively related to walking economy.

Methods

Participants

Fifty-nine European-American (EA) and 65 African-American (AA) healthy premenopausal women (mean of age: 35.1 ± 6.2 years; and height: 165.4 ± 6.6 cm) participated in this

study. BMI ranged between 27 and 30 kg/m² and age ranged from 22 to 46 years. All participants were nonsmokers, had normal menstrual cycles, and normal glucose tolerance, as documented by 2-h postprandial blood glucose challenge following a 75-g oral glucose load. Participants were not using any oral contraceptives or medications known to affect lipid metabolism or body composition. Prior to study participation, all participants provided written informed consent. Study procedures were approved by the local Institutional Review Board for Human Subjects.

Study design

This study is a secondary analysis from a study designed to identify metabolic factors that predispose women to weight gain (Exercise training in post-obese Black and White women). Participants were randomly assigned to three different weight-loss groups: diet only; diet and aerobic exercise training; and diet and resistance exercise training. All food was furnished during the weight-loss and consisted of 800 kcal/day that was 20–22% fat, 18–22% protein, and 58–62% carbohydrate. Participants picked up food at the General Clinical Research Center (GCRC) twice weekly and were instructed to remain on the 800 kcal/day diet until a BMI of < 25 kg/m² was reached.

Prior to evaluations, participants were maintained in weight-stable state for 4 weeks. During those 4 weeks, body weight measurements were made: a) 3 days/week for the first 2 weeks, and b) 5 days/week for the last 2 weeks at visits to the GCRC. During the final 2 weeks, all meals were provided through the GCRC Research Kitchen to ensure weight stability of < 1% variation from the initial weight and to maintain daily macronutrient intake within the range of 20–22% of energy as fat, 18–22% as protein, and 58–62% as carbohydrate. Participants were then admitted to the GCRC for 4 days, during the follicular phase of the menstrual cycle, and underwent assessment of body composition/fat distribution. After all assessments were completed, participants were discharged from the GCRC. Time required to reach goal weight varied between subject (mean of 158 days and a standard deviation of 70 days). However, number of days to reach goal weight was unrelated to $\dot{V}O_{2\max}$ or walking economy (all correlations less than 0.09). It might be speculated that changes in strength may influence the relationship between changes in $\dot{V}O_{2\max}$ and walking economy. After adjusting for changes in knee extension strength both differences in flat walking and grade walking were still significantly related to $\dot{V}O_{2\max}$, showing that it is unlikely that changes in strength are causing the relationships between $\dot{V}O_{2\max}$ and walking economy (analysis not shown).

Aerobic training

Aerobic training entailed continuous walking/jogging on a treadmill, commencing with a warm-up of 3 minutes and 3–5 minutes of stretching. During the first week of training, participants performed 20 min of continuous exercise at 67% maximum heart rate. Each week after the 1st week, duration and intensity was increased so that by the beginning of the 8th week, participants exercised continuously at 80% of maximum heart rate for 40 minutes. Participants were encouraged to increase intensity (either speed or grade) when average exercise heart rate was below 80% of their maximum heart rate. After the exercise session, participants cooled down for 3–5 minutes with gradually decreasing exercise intensity.

Resistance training

The resistance training program included a warm-up on the treadmill or bike ergometer for 5 minutes and 3–5 minutes of stretching. After the warm-up, resistance exercises were performed which included squats, leg extension, leg curl, elbow flexion, triceps extension, lateral pull-down, bench press, military press, lower-back extension, and bent-leg sit-ups. After 1 week of familiarization (training with light weight), one repetition maximum (1RM) was measured. In the first week following 1RM tests, one set of 10 repetitions was performed at 65% 1RM, with the percentage of 1RM increasing in subsequent weeks until week 4 intensity was at 80% 1RM. Starting in week 5, two sets of 10 repetitions were attempted at 80% 1RM for each exercise with 2-min rest between sets. Strength was evaluated every 5 weeks, and adjustments in training resistance were made based on the most current 1RM. In both the aerobic and resistance training groups, participants were expected to train 3 days/week.

Dual-energy x-ray absorptiometry

Whole-body bone mineral content, fat mass (FM), lean soft tissue, and fat-free mass (FFM) (as the sum of bone mineral content and FM) were estimated using a dual-energy x-ray absorptiometry (GE Medical Systems Lunar, Madison, WI). The scans were analyzed with the use of ADULT software, LUNAR DPX-L version 1.35 (GE Medical Systems Lunar, Madison, WI).

Resting oxygen uptake

Three consecutive mornings in a fasted state and after an overnight stay in the GCRC, oxygen uptake ($\dot{V}O_2$) at rest was determined between 6:00 and 6:50 AM. Participants remained awake in a quiet, softly lit, and well-ventilated room in which temperature was maintained between 22° and 24° C. Participants lay supine on a comfortable bed, and $\dot{V}O_2$ was measured using a ventilated hood system. After resting for 15 minutes, resting $\dot{V}O_2$ was measured for 30 minutes with a computerized, open-circuit, indirect calorimetry system (Delta Trac II; Sensor Medics, Yorba, CA, USA). The last 20 minutes was used for data analysis. The 2nd morning values of $\dot{V}O_2$ were used in the determination of walking net $\dot{V}O_2$ (i.e., work steady-state $\dot{V}O_2$ - resting $\dot{V}O_2$). Coefficient of variation% for resting $\dot{V}O_2$ is < 4% in our laboratory.

Maximal oxygen uptake

The $\dot{V}O_{2\max}$ was measured using the maximal modified Bruce protocol (Hellerstein and Franklin 1984). Heart rate (HR) was measured using a POLAR Vantage XL HR monitor (Polar Electro Inc., Gays Mills, WI, USA). $\dot{V}O_2$ and carbon dioxide production ($\dot{V}CO_2$) were measured continuously using a MAX-II metabolic cart (Physiodyne Instrument Corporation, Quogue, NY, USA). Gas analyzers were calibrated with certified gases of known concentrations. Standard criteria for HR (HR within 10 bpm of estimated maximum), respiratory exchange ratio (RER) (RER >1.15), and plateauing were used to ensure achievement of $\dot{V}O_{2\max}$. The coefficient of variation for repeated measures of $\dot{V}O_{2\max}$ is < 3% in our laboratory.

Walking economy

The $\dot{V}O_2$ was obtained during submaximal steady-state treadmill walk on the flat (4.8 km per hour), and a 2.5% grade treadmill walk (4.8 km per hour). The duration of each of the tasks was between 4 and 5 minutes, until a plateauing of $\dot{V}O_2$ /steady-state was obtained. No significant difference in oxygen uptake was observed between the last two minutes of walking (either the 3rd and 4th or the 4th and 5th minute). $\dot{V}O_2$ and $\dot{V}CO_2$ were also measured using a MAX-II metabolic cart (Physiodyne Instrument Corporation, Quogue, NY, USA). Net $\dot{V}O_2$ (work steady-state $\dot{V}O_2$ - resting $\dot{V}O_2$) is reported in milliliter O_2 /kg per minute and is considered the walking economy. However, to better examine directional association between $\dot{V}O_{2max}$ and walking economy, values from net $\dot{V}O_2$ were subtracted by 1 ($1 - \text{net } \dot{V}O_2$). Thus, higher net $\dot{V}O_2$ indicated lower walking economy, and lower net $\dot{V}O_2$ indicated higher walking economy.

Statistical analysis

Comparison of changes in $\dot{V}O_{2max}$ and walking economy have previously been reported (Hunter et al. 2015), therefore only pooled data from the three groups are included in this paper. Mean $\pm$ standard deviation (SD) was used for descriptive analyses. The Shapiro-Wilk test was used to verify data normality. Based on normality, paired Student's *t* test or Wilcoxon signed-rank test was used to compare differences in physical characteristics between baseline and after weight loss. Bivariate Pearson's or Spearman's coefficient of correlation (*r*) was used to verify the relationship between $\dot{V}O_{2max}$ and walking economy at baseline and after weight loss, and between $\dot{V}O_{2max}$ and walking economy after weight loss. SPSS version 22.0 (IBM SPSS Statistics for Windows, Armonk, NY, USA) was used for statistical analysis. The significance level was set at $\alpha = 0.05$.

Results

Participant characteristics, at baseline and after weight loss, are shown in Table 1. We observed significant decreases for weight, BMI, FFM, net $\dot{V}O_2$ during flat walking, relative and absolute FM after weight loss. In addition, improvements for $\dot{V}O_{2max}$ were observed when adjusted for body weight. However, no differences were observed for $\dot{V}O_{2max}$ adjusted for FFM, $\dot{V}O_2$ during flat walking, $\dot{V}O_2$ during grade walking and for net $\dot{V}O_2$ during grade walking after weight loss.

Table 2 shows significant inverse relationships between $\dot{V}O_{2max}$ adjusted for body weight or FFM with flat/grade walking economy at baseline and after weight loss. Interestingly, we also observed significant inverse relationship between delta of $\dot{V}O_{2max}$ adjusted for FFM with delta of flat walking economy (Fig. 1A); and between delta of $\dot{V}O_{2max}$ adjusted for FFM with delta of grade walking economy (Fig. 1B).

Discussion

Consistent with our hypotheses, the main finding of this study revealed an inverse relationship between $\dot{V}O_{2max}$ and walking economy (during non-graded and graded walking) before and after weight loss. Interestingly, with weight loss, we observed a stronger inverse correlation between $\dot{V}O_{2max}$ and walking economy (non-graded and graded). Our

data also show that the negative relationship between $\dot{V}O_{2\max}$ and walking economy persists despite significant weight loss among premenopausal women. It appears that not only does the relationship exist in overweight premenopausal women but exists after weight loss, as well as with changes in $\dot{V}O_{2\max}$ and changes in walking economy.

The inverse relationship between aerobic capacity and exercise economy is consistent across modalities and subject groups. Previous results show similar relationships in trained runners (Pate et al. 1992; Morgan and Daniels 1994; Shaw et al. 2015), trained cyclists (Lucía et al. 2002), and untrained participants (Hunter et al. 2001, 2005) while walking and during isometric contractions as well as across time. In addition, we previously have shown the presence of an inverse relationship between aerobic capacity and exercise economy using three different technologies (indirect calorimetry while walking, force/ATP turnover using ^{31}P MRS during isometric contractions, and muscle biopsy citrate synthase activity with both ^{31}P MRS isometric contractions and oxygen uptake while walking) (Hunter et al. 2005). Finding similar results with different technologies across time and with deltas decreases the likelihood that these relationships are happenstance. The negative relationship between $\dot{V}O_{2\max}$ and walking economy seems counter-intuitive, specifically because exercise training usually results in increased aerobic capacity and often increased exercise economy (Hunter et al. 2008; McArdle et al. 2010; Fisher et al. 2013; Montero and Lundby 2015). The present results suggest, as previously postulated, training-induced improvements in economy may be the result of increased strength and/or altered biomechanics rather than improved aerobic capacity (i.e., $\dot{V}O_{2\max}$).

To date, the underlying mechanisms responsible for the potential causes of the negative relationship are unknown. However, Pate et al. (1992) first showed this relationship over 25 years ago. Factors such as body mass, ventilatory rate, heart rate, stride frequency and age have been reported to affect walking economy (Pate et al. 1992; Malatesta et al. 2003). An inverse relationship between $\dot{V}O_{2\max}$ and respiratory exchange ratio suggests more fit individuals preferentially use a higher percentage fat oxidation at any submaximal work rate (Pate et al. 1992). Thus, it can be postulated that individuals with high $\dot{V}O_{2\max}$ probably require higher $\dot{V}O_2$ at submaximal work levels because less energy is released with consumption of a liter of oxygen for fat oxidation compared to carbohydrate oxidation (Pate et al. 1992; Hunter et al. 2005). However, this is unlikely to be the cause in our study. Previously, we have shown that ^{31}P MRS determined muscle economy (force/ATP ratio) is negatively related to the maximum rate of ATP produced in skeletal muscle by oxidative phosphorylation (Hunter et al. 2005). This shows the relationship is present at the muscle level while by-passing differences in relative oxidative rates of different fuels. In addition, we show in the present study that the negative correlation between $\dot{V}O_{2\max}$ and walking economy persists after adjusting for respiratory quotient (index of relative carbohydrate and lipid oxidation rates).

The proportion of muscle fiber type is a factor that may influence exercise economy. Type I muscle fiber distribution is positively associated with cycling economy (Coyle et al. 1992), while Type II muscle fiber distribution is negatively related to exercise economy (Hunter et al. 2001, 2005). In addition, contrary to popular belief, type IIa muscle fiber may be positively related to $\dot{V}O_{2\max}$ at least in non-athletes (McCully et al. 1993; Larson-Meyer et

al. 2001; Hunter et al. 2005). If this were the case it is possible that increased demand for energy of inefficient type II muscle fibers may lead to increased oxidative phosphorylation during both steady-state and maximal exercise. These results for cycling and walking economy, as well as, the result of the ^{31}P MRS studies on muscle are suggestive that the negative relationship between aerobic capacity and exercise economy are mediated at the muscle level via the mitochondria.

It should be pointed out that the amount of variance in the walking economy measures accounted for by $\dot{V}\text{O}_{2\text{max}}$ is modest (5 – 12%, i.e. R^2 varying from 0.05 to 0.12) for the cross-section analyses. This is not too surprising since factors other than physiological variation affect walking economy. Factors such as walking biomechanics probably play a large role in economy during walking. The observation that the amount of variance in change in walking economy accounted for by change in $\dot{V}\text{O}_{2\text{max}}$ (14–17%, i.e. R^2 varying from 0.14 – 0.17) is larger than the cross-sectional relationships is supportive of this hypothesis, if it is assumed that biomechanic differences would change less than physiological differences following training.

Conclusions

In the present study we report an inverse relationship between $\dot{V}\text{O}_{2\text{max}}$ and walking economy before and after weight loss. In addition, we also observed a significant negative relationship between $\dot{V}\text{O}_{2\text{max}}$ and walking economy. Our findings strengthen the assertion that aerobic capacity is negatively related to walking economy and is consistent with previous findings that aerobic capacity is negatively related to running and cycling economy.

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Abbreviations

$\dot{V}\text{O}_{2\text{max}}$	Delta of maximum oxygen uptake
walking economy	Delta of waking economy
Net $\dot{V}\text{O}_{2\text{flat walking}}$	Net oxygen uptake during flat walking
Net $\dot{V}\text{O}_{2\text{grade walking}}$	Net oxygen uptake during grade walking
$\dot{V}\text{CO}_2$	Carbon dioxide production
$\dot{V}\text{O}_2$	Oxygen uptake
$\dot{V}\text{O}_{2\text{flat walking}}$	Oxygen uptake during flat walking
$\dot{V}\text{O}_{2\text{grade walking}}$	Oxygen uptake during grade walking
$\dot{V}\text{O}_{2\text{max}}$	Maximum oxygen uptake

VO₂resting**Resting oxygen uptake****References**

- Coyle EF, Sidossis LS, Horowitz JF, Beltz JD. 1992; Cycling efficiency is related to the percentage of type I muscle fibers. *Med Sci Sports Exerc.* 24:782–788. [PubMed: 1501563]
- Fisher G, McCarthy JP, Zuckerman PA, et al. 2013; Frequency of combined resistance and aerobic training in older women. *J Strength Cond Res.* 27:1868–1876. DOI: 10.1519/JSC.0b013e31827367e0 [PubMed: 22996024]
- Hellerstein, HK, Franklin, BA. Exercise testing and prescription. In: Wenger, NK, Hellerstein, NK, editors. *Rehabilitation of the Coronary Patient.* John Wiley & Sons, Inc; New York, NY: 1984. 197–284.
- Hunter GR, Bamman MM, Larson-Meyer DE, et al. 2005; Inverse relationship between exercise economy and oxidative capacity in muscle. *Eur J Appl Physiol.* 94:558–568. DOI: 10.1007/s00421-005-1370-z [PubMed: 15959800]
- Hunter GR, Fisher G, Neumeier WH, et al. 2015; Exercise Training and Energy Expenditure following Weight Loss. *Med Sci Sports Exerc.* 47:1950–1957. DOI: 10.1249/MSS.0000000000000622 [PubMed: 25606816]
- Hunter GR, McCarthy JP, Bryan DR, et al. 2008; Increased strength and decreased flexibility are related to reduced oxygen cost of walking. *Eur J Appl Physiol.* 104:895–901. DOI: 10.1007/s00421-008-0846-z [PubMed: 18758805]
- Hunter GR, Newcomer BR, Larson-Meyer DE, et al. 2001; Muscle metabolic economy is inversely related to exercise intensity and type II myofiber distribution. *Muscle Nerve.* 24:654–661. [PubMed: 11317275]
- Larson-Meyer DE, Newcomer BR, Hunter GR, et al. 2001; Relation between in vivo and in vitro measurements of skeletal muscle oxidative metabolism. *Muscle Nerve.* 24:1665–1676. [PubMed: 11745976]
- Lucía A, Hoyos J, Pérez M, et al. 2002; Inverse relationship between VO₂max and economy/efficiency in world-class cyclists. *Med Sci Sports Exerc.* 34:2079–2084. DOI: 10.1249/01.MSS.0000039306.92778.DF [PubMed: 12471319]
- Malatesta D, Simar D, Dauvilliers Y, et al. 2003; Energy cost of walking and gait instability in healthy 65- and 80-yr-olds. *J Appl Physiol.* 95:2248–2256. DOI: 10.1152/jappphysiol.01106.2002 [PubMed: 12882986]
- McArdle, WD, Katch, FI, Katch, VL. *Exercise physiology: nutrition, energy, and human performance.* 7. Lippincott Williams & Wilkins; Philadelphia, PA: 2010.
- McCully KK, Fielding RA, Evans WJ, et al. 1993; Relationships between in vivo and in vitro measurements of metabolism in young and old human calf muscles. *J Appl Physiol.* 75:813–819. DOI: 10.1152/jappl.1993.75.2.813 [PubMed: 8226486]
- Montero D, Lundby C. 2015; The Effect of Exercise Training on the Energetic Cost of Cycling. *Sports Med.* 45:1603–1618. DOI: 10.1007/s40279-015-0380-1 [PubMed: 26373646]
- Morgan DW, Daniels JT. 1994; Relationship between VO₂max and the aerobic demand of running in elite distance runners. *Int J Sports Med.* 15:426–429. DOI: 10.1055/s-2007-1021082 [PubMed: 8002123]
- Pate RR, Macera CA, Bailey SP, et al. 1992; Physiological, anthropometric, and training correlates of running economy. *Med Sci Sports Exerc.* 24:1128–1133. [PubMed: 1435160]
- Sawyer BJ, Blessinger JR, Irving BA, et al. 2010; Walking and running economy: inverse association with peak oxygen uptake. *Med Sci Sports Exerc.* 42:2122–2127. DOI: 10.1249/MSS.0b013e3181de2da7 [PubMed: 20351592]
- Shaw AJ, Ingham SA, Atkinson G, Folland JP. 2015; The correlation between running economy and maximal oxygen uptake: cross-sectional and longitudinal relationships in highly trained distance runners. *PloS One.* 10:e0123101.doi: 10.1371/journal.pone.0123101 [PubMed: 25849090]

Fig. 1.

Relationship between delta of maximum oxygen uptake ($\dot{V}O_{2\max}$) and delta of flat walking economy after weight loss ($R^2 = 0.14$) (A); and between delta of $\dot{V}O_{2\max}$ and delta of grade walking economy ($R^2 = 0.17$) after weight loss (B).

Table 1Characteristics of the participants at baseline and after weight loss (Mean $\pm$ SD)

Variable	Baseline	Weight loss		P-value
Weight (kg)	77.5 $\pm$ 7.3	65.4 $\pm$ 6.4	-12.1 $\pm$ 2.5	< 0.001
BMI (kg/m ²)	28.2 $\pm$ 1.3	23.9 $\pm$ 1.1	-4.4 $\pm$ 0.9	< 0.001
%FM	43.5 $\pm$ 3.6	33.4 $\pm$ 4.5	-10.0 $\pm$ 2.4	< 0.001
FM (kg)	33.8 $\pm$ 5.1	22.0 $\pm$ 4.5	-11.8 $\pm$ 2.2	< 0.001
FFM (kg)	43.7 $\pm$ 3.9	43.4 $\pm$ 3.9	-0.3 $\pm$ 1.6	0.028
$\dot{V}O_{2max}$ (ml O ₂ /kg/min)	28.3 $\pm$ 3.8	33.0 $\pm$ 4.9	4.7 $\pm$ 2.3	< 0.001
$\dot{V}O_{2max}$ (ml O ₂ /kg FFM/min)	49.8 $\pm$ 6.2	49.4 $\pm$ 6.5	-0.4 $\pm$ 4.6	0.239
$\dot{V}O_{2resting}$ (ml O ₂ /kg/min)	2.6 $\pm$ 0.2	2.9 $\pm$ 0.3	0.3 $\pm$ 0.2	< 0.001
$\dot{V}O_{2flat walking}$ (ml O ₂ /kg/min)	12.0 $\pm$ 1.3	11.9 $\pm$ 1.5	-0.0 $\pm$ 1.6	0.717
$\dot{V}O_{2grade walking}$ (ml O ₂ /kg/min)	14.7 $\pm$ 1.5	14.8 $\pm$ 1.6	0.1 $\pm$ 1.8	0.552
Net $\dot{V}O_{2flat walking}$ (ml O ₂ /kg/min)	9.4 $\pm$ 1.2	9.1 $\pm$ 1.5	-0.3 $\pm$ 1.6	0.009
Net $\dot{V}O_{2grade walking}$ (ml O ₂ /kg/min)	12.2 $\pm$ 1.5	12.0 $\pm$ 1.6	-0.2 $\pm$ 1.8	0.181

BMI, body mass index; %FM, percentage of fat mass; FM, fat mass; FFM, fat-free mass; $\dot{V}O_{2max}$, maximal oxygen uptake; $\dot{V}O_{2resting}$, resting oxygen uptake; $\dot{V}O_{2flat walking}$, oxygen uptake during flat walking; $\dot{V}O_{2grade walking}$, oxygen uptake during grade walking; Net $\dot{V}O_{2flat walking}$, net oxygen uptake during flat walking; Net $\dot{V}O_{2grade walking}$, net oxygen uptake during grade walking. Values in boldface indicate significant differences ($P < 0.05$).

Table 2

Relationship (R^2 in parentheses) between $\dot{V}O_{2\max}$ with flat and grade walking economy at baseline and after weight loss

	Time	$\dot{V}O_{2\max}$ (ml O ₂ /kg/min)	$\dot{V}O_{2\max}$ (ml O ₂ /kg FFM/min)
Flat walking economy (1-ml O ₂ /kg/min)	Baseline	$-0.35^{\ddagger}$ (0.12)	$-0.32^{\ddagger}$ (0.10)
	Weight loss	$-0.28^{\ddagger}$ (0.08)	$-0.26^{\ddagger}$ (0.07)
Grade walking economy (1-ml O ₂ /kg/min)	Baseline	$-0.29^{\ddagger}$ (0.08)	$-0.28^{\ddagger}$ (0.08)
	Weight loss	-0.22^* (0.05)	$-0.26^{\ddagger}$ (0.07)

$\dot{V}O_{2\max}$, maximal oxygen uptake.

$^{\ddagger}P$ 0.001.

$^{\ddagger}P$ 0.01.

*P 0.05.