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Standardized MET value underestimates the energy cost of treadmill running in men

Running head: Metabolic equivalents in exercise prescription

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Acknowledgements: This research was partially supported by grants from the Carlos Chagas Filho Foundation for the Research Support in Rio de Janeiro State and Brazilian Council for the Technological and Scientific Development.

Abstract

The main purpose of the present study was to compare the reference metabolic equivalent (MET) value and observed resting oxygen uptake (VO_2) for defining cardiorespiratory fitness (VO_{2max}) and characterizing the energy cost of treadmill running. A heterogeneous cohort of 114 healthy men volunteered to participate. In Part 1 of the study, 114 men [mean ± SD, age: 24 ± 5 years; height: 177.1 ± 7.9 cm; body mass: 75.0 ± 10.0 kg] visited the laboratory twice for assessment of resting and maximal VO_2 values to compare the reference MET value vs. observed resting VO_2 and to investigate the association between resting VO_2 and VO_{2max}. In Part 2, 14 of the 114 men visited the laboratory once more to perform a 30-min bout of running at 8.0 $km \cdot h^{-1}$/8.3 METs. The mean observed resting VO_2 of 3.26 $mL \cdot kg^{-1} \cdot min^{-1}$ was lower than the reference MET value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ ($P < 0.001$). Resting and maximal VO_2 values relative to total body mass and fat-free mass were positively correlated (R = 0.71 and 0.60, respectively; $P < 0.001$). The maximal MET and energy cost of treadmill running were consequently underestimated when calculated using the reference MET value only for those with low VO_{2max} ($P = 0.005$ to $P < 0.001$). In conclusion, the reference MET value considerably overestimated observed resting VO_2 in men with low VO_{2max}, resulting in underestimations of the maximal MET, exercise intensity prescription, and the energy cost of running.

Keywords: aerobic exercise; energy expenditure; resting metabolic rate; compendium of physical activities; intensity classification; cardiorespiratory fitness.

Introduction

The metabolic equivalent (MET) has been used in various important applications relating to exercise and health, such as defining levels of cardiorespiratory fitness [17], prescribing physical exercise [11], and quantifying the energy cost of a wide variety of physical activities [1]. By convention, one MET is defined as a resting oxygen uptake (VO_2) of 3.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. A potential limitation in the application of this reference MET value, is that it seems to have been derived from the observed resting VO_2 of a single 40-year-old man with a body mass of approximately 70 kg [7,14,30]. There is a growing body of empirical evidence that the reference MET value significantly overestimates mean resting VO_2 in healthy adults [7,10,19]. A study involving 642 women and 127 men aged 18-74 years, for example, observed that the mean resting VO_2 of 2.56 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ was 29% lower than the reference MET value [7]. Savage et al. [27] assessed the resting VO_2 in a group of 109 (60 men and 49 women) overweight individuals with coronary heart disease. The mean VO_2 at rest was 2.6±0.4 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. This value was 36% lower than the widely accepted MET value of 3.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ and was similar to that reported by Byrne and Hills [6]. In another study with 125 healthy males aged 17-38 years, the mean resting VO_2 of 3.21 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ was significantly lower (8.3%) than the standard MET value of 3.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ [10]. Errors when employing the reference MET value for different practical applications are therefore likely to occur. However, the extent of such errors has not been established.

Another issue is that a large inter-individual variation in resting VO_2 has been observed. Age, sex, and body composition are well-established in explaining some of this variation [3,24,29], but a factor that could help identify unexplained variance that has received little attention is cardiorespiratory fitness, as represented by the maximal oxygen uptake (VO_{2max}). Kozey et al. [19] categorized 118 men and 134 women according to quintiles of VO_{2max}. The mean ± SD resting VO_2 of 2.7 ± 0.28 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ observed in the lowest VO_{2max} quintile was 18% lower than the 3.3 ± 0.39 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ in the highest VO_{2max} quintile, and 23% lower than the reference MET value of 3.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. A limitation of this study, however, is that VO_{2max} was not directly assessed, but estimated using an equation proposed by Matthews et al. [22] based on age, height, sex, body mass, and a self-reported indicator of physical activity status. Further support for the influence of VO_{2max} on resting VO_2 comes from a study that directly assessed VO_{2max} in a group of 26 highly trained cyclists with mean ± SD VO_{2max} of 70.9 ± 1.2

$mL·kg^{-1}·min^{-1}$ [21]. The observed mean ± SD resting VO_2 of 4.3 ± 0.2 $mL·kg^{-1}·min^{-1}$ was 29% higher than the reference MET value of 3.5 $mL·kg^{-1}·min^{-1}$. To our knowledge, however, the relationship between directly assessed VO_{2max} and resting VO_2 in a heterogeneous cohort has not been investigated.

Errors of overestimation and underestimation of resting VO_2 have clear potential to influence the categorization of fitness when using the maximal MET, and determination of the energy cost of treadmill running. Hence the main purpose of the present study was to compare the reference MET value and observed resting VO_2 with respect to these applications and the extent to which VO_{2max} is associated with resting VO_2. We hypothesized that the resting VO_2 would be lower than the standard value in individuals with low VO_{2max}, therefore resulting in underestimations of the classification of fitness based on the maximal MET, exercise intensity prescription, and energy cost of running.

Materials and methods

Participants

A total of 114 apparently healthy men recruited from two university communities and fitness centers located in Rio de Janeiro, regardless of training status (i.e. physically active or sedentary), volunteered to participate in the study. Exclusion criteria were: a) use of medication influencing the cardiovascular or metabolic responses to exercise; b) smoking or use of ergogenic substances that could affect exercise performance; and c) any cardiovascular, respiratory, bone, muscle, or joint problems that could compromise the safety of physical exercise; and/or positive response to the Physical Activity Readiness Questionnaire. The study was performed in accordance with the ethical standards required by the journal [12] and was approved by institutional ethics committee board (reference 3082/2011). All participants provided written informed consent.

Procedures

In the first part of the study, 114 participants visited the laboratory on two occasions. During the first visit resting VO_2 was determined, anthropometric measurements were taken, and participants were familiarized with the equipment and test protocols. On the second visit a maximal cardiopulmonary exercise test (CPET) for determining VO_{2max} was performed. The first part of the study allowed to compare the reference MET value vs. observed resting VO_2 and to investigate the association between resting VO_2 and VO_{2max}. In the second part of the experiment, 14 of the total 114 participants volunteered for one additional visit to perform a submaximal exercise bout with continuous work rate. This allowed to investigate the accuracy of the reference MET value to determine the energy expenditure of the submaximal running as proposed by the Compendium of Physical Activities [1]. All running tests were performed on the same motorized treadmill (Inbramed™ Super ATL, Porto Alegre, RS, Brazil).

Anthropometry

Total body mass and height were assessed respectively by digital balance scales (Welmy™, São Paulo, Brazil) and a stadiometer graded in millimeters (American Medical do Brazil™, São Paulo, Brazil). Skinfold thicknesses were obtained at three sites (chest, abdomen and thigh) using a Lange™ compass (Beta Technology Incorporated, Cambridge, Maryland, EUA) and body density and percentage body fat were estimated using the equations of Siri [28] and Jackson and Pollock [16]. Fat mass and fat-free mass were derived from total body mass and percentage body fat values. The same experienced investigator obtained all skinfold measurements.

Resting VO_2 assessment

The resting VO_2 was determined in accordance with the recommendations of Compher et al. [8]: abstention of physical exercise, alcohol, soft drinks and caffeine in the 24 h preceding the assessment, fasting for 8 h preceding the assessment, and minimum effort when travelling to the laboratory. In the laboratory, the participants laid in a calm thermoneutral environment (mean ± SD temperature, 22.5 ± 1.5°C) for an acclimation period of 10-min, after which the VO_2 was measured for 30-min in a supine position. The resting VO_2 was taken as the average of the last 5 min of steady-state data (i.e. coefficient of variation ≤10% during 5 min), since this time period has been previously shown to elicit a VO_2 steady-state and high test-retest reliability [9].

Maximal and submaximal exercise tests

A ramp protocol was used to determine the VO_{2max}. The workload increments were individualized to elicit each subject's limit of tolerance in 8-12 min [5]. The tests were considered maximal if at least three of the four following criteria were satisfied: a) maximum voluntary exhaustion defined by attaining a 10 on the Borg CR-10 scale; b) 90% of predicted HR_{max} [220–age] or presence of heart rate plateau (ΔHR between two consecutive work rates ≤4 beats·min^{-1}); c) presence of VO_2 plateau (ΔVO_2 between two consecutive work rates of less than 2.1 mL·kg^{-1}·min^{-1}); and d) maximal respiratory exchange ratio (RER_{max}) > 1.10 [15]. Based on the VO_{2max} values, observed and reference MET_{max} values were calculated (i.e. observed MET_{max} = VO_{2max} ÷ resting VO_2 in mL·kg^{-1}·min^{-1}; reference MET_{max} = VO_{2max} ÷ 3.5 mL·kg^{-1}·min^{-1}).

Seventy-two hours after performing the maximal CPET, a subgroup of 14 participants performed a 30-min bout of running at 8.0 km·h^{-1}, which is an exercise intensity equivalent to 8.3 METs according to the Compendium of Physical Activities [1]. The treadmill grade was set at 1%, which has been found to reflect the energetic cost of outdoor, level overground running [18]. The running bout was preceded by a 5-min warm-up at 5.5 km·h^{-1} and 1% grade. The intensity classification for treadmill running was calculated from two different methods: a) observed METs = average VO_2 during exercise ÷ resting VO_2 in mL·kg^{-1}·min^{-1}; and b) reference METs: average VO_2 during exercise ÷ 3.5 in mL·kg^{-1}·min^{-1}. The energy cost of the running bout was calculated by the following formula: energy cost (kcal) = intensity classification based on observed or reference METs × body mass in kg × duration in hours [1]. To negate the confounding effects of the initial (fast) VO_2 on-kinetics, the data for the first 3-min of the running bout were omitted from all analyses [19].

Expired gases were collected during the maximal CPET and 30-min running bout using a VO2000 analyser (Medical Graphics™, Saint Louis, MO, USA) and a silicone face mask (Hans Rudolph™, Kansas, MO, USA). The gas analysers and pneumotacograph were calibrated according to the manufacturer's instructions. Immediately prior to each exercise bout, the gas analysers were calibrated using a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%), balanced with nitrogen (AGA™, Rio de Janeiro, RJ, Brazil). The flows and volumes of the pneumotacograph were calibrated using a syringe graduated for a 3 L capacity (Hans Rudolph™, Kansas, MO, USA). Heart rate was measured continuously using a cardiotachometer (RS800cx, Polar™, Kempele, Finland) and beat-by-beat data were 30-s stationary time-averaged.

Statistical analyses

All statistical analyses were performed using Statistica 10 software (StatSoft™, Tulsa, OK, USA). Descriptive sample statistics are reported as the mean and standard deviation (SD). One-sample t tests were used to test the null hypotheses that there were no mean differences between the MET value and observed resting VO_2, MET_{max}, MET exercise intensity classification, and the energy cost of the running bout. The Pearson correlation was used to determine the relationship between VO_{2max} and observed resting VO_2. In addition, the median VO_{2max} value was used as the criterion to categorize participants into low and high VO_{2max} groups to investigate the influence of VO_{2max} on the differences between the reference MET value and observed resting VO_2 [lower VO_{2max} (1st part of the study: $n = 55$, $VO_{2max} < 49.9$ mL·kg^{-1}·min^{-1}; 2nd part of the study: $n = 7$, $VO_{2max} < 43.3.0$ mL·kg^{-1}·min^{-1}) and higher VO_{2max} (1st part of the study: $n = 59$, $VO_{2max} \geq 49.9$ mL·kg^{-1}·min^{-1}; 2nd part of the study: $n = 7$; $VO_{2max} \geq 43.3$ mL·kg^{-1}·min^{-1})].

Results

Sample descriptive statistics for age, anthropometric variables, resting VO_2, and CPET outcomes are shown in Table 1. The mean observed resting VO_2 of 3.26 (95% CI = 3.17 to 3.34) and 3.07 mL·kg^{-1}·min^{-1} (95% CI = 2.79 to 3.34) for the 1st and 2nd parts of the study were significantly lower than the reference MET value of 3.5 mL·kg^{-1}·min^{-1} (mean difference = 0.25, 95% CI = 0.16 to 0.32, t = 6.02, $P < 0.001$ and mean difference = 0.43, 95% CI = 0.15 to 0.70, t = 3.3, $P = 0.005$, respectively). With regard to the group with lower VO_{2max}, the reference MET value of 3.5 mL·kg^{-1}·min^{-1} was significantly higher than the mean observed resting VO_2 values of 3.01 (mean difference = 0.48, 95% CI = 0.38 to 0.59, t = 9.2, $P < 0.001$) and 2.67 (mean difference = 0.83, 95% CI = 0.60 to 1.05, t = 9.0, $P < 0.001$) mL·kg^{-1}·min^{-1} determined during the 1st and 2nd parts of the study, respectively. However, no statistically significant difference was detected between the reference MET value and observed resting VO_2 values for the groups with higher VO_{2max} (1st part of the study: $P = 0.842$; 2nd part of the study $P = 0.778$).

INSERT TABLE 1

Figure 1 shows the relationships between VO_{2max} and resting VO_2 relative to total body mass (A) and fat-free mass (B), which were strongly positively correlated in the 1st part of the study (R = 0.71, $P < 0.001$; R = 0.60; $P < 0.001$, respectively).

INSERT FIGURE 1

Table 2 shows the MET_{max}, and the exercise intensity classification and energy cost of the 30-min running bout, calculated from the reference MET value and observed resting VO_2. Overall, the values for MET_{max}, exercise intensity, and energy cost of treadmill running were significantly underestimated when derived from the reference MET value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (P = 0.007 to P < 0.001), especially for the groups with lower VO_{2max}. In the 1st part of the study, for example, the mean difference between reference vs. observed MET_{max} values increased from 8% (mean difference: 1.1 METs; P < 0.001) to 17% (mean difference: 2.1 METs; P < 0.001) when considering all participants vs. only the lower VO_{2max} group. In the 2nd part of the study, the level of underestimation of the observed exercise intensity and energy cost increased substantially from 14% (mean difference: 1.3 METs; P = 0.007) to 24% (mean difference: 2.6 METs; P = 0.007) and 15% (mean difference: 62 kcals; P = 0.005) to 24% (mean difference: 101 kcals; P = 0.001) (see Table 2). Unlike the lower VO_{2max} group, there was no significant difference between the reference and observed MET intensities (P = 0.674) and energy cost of the treadmill running bout (P = 0.679) for the higher VO_{2max} group.

INSERT TABLE 2

Discussion

The present study compared the reference MET value and observed resting VO_2 for defining fitness using the maximal MET, prescribing exercise intensity, and quantifying the energy cost of treadmill running in a heterogeneous cohort of healthy men. The extent to which VO_{2max} explained variance in resting VO_2 also was investigated. The main finding was that the reference MET value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ overestimated resting VO_2 in men with low VO_{2max}, which resulted in underestimations of the maximal MET, exercise intensity prescription, and the energy cost of running.

The findings of the present study concur with previous studies [7,10,19] that one MET is not equivalent to a resting VO_2 of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ in heterogeneous adult cohorts. In fact, 74 (65%) of the 114 participants in the present study had observed resting VO_2 values lower than 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$. There was, however, a strong positive correlation between directly assessed VO_{2max} and observed resting VO_2, meaning that overestimation errors in resting VO_2 tended to mostly affect those with low VO_{2max}.

The MET system has been used in research for defining levels of fitness as MET_{max} values, particularly with respect to evaluating its prognostic value in predicting cardiovascular risk [2,23]. The MET_{max} is quantified using tables of the energy cost of running based upon treadmill speed and slope and dividing by the reference MET value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$. The findings of the present study revealed that MET_{max} was significantly underestimated in low cardiorespiratory groups when calculated from the widely accepted reference MET value. The same limitation of the MET system was reported within the context of exercise prescription, where the adoption of the reference MET value resulted in unacceptably large underestimation errors for treadmill running intensity and energy cost compared to when the observed resting VO_2 was used. These errors therefore mostly affect low fitness individuals, which are the least likely to be meeting physical exercise recommendations for promoting health.

Another issue is the large inter-individual variation in observed resting VO_2 identified in previous research [7,10,19], as well as the participants in the present study (see Table 1). Byrne et al. [7] reported that 62% of this variation could be explained by differences in fat mass and fat-free mass, whilst age explained only 14%. Additionally, BMI was strongly positively correlated with fat mass ($r^2 = 0.93$, $P < 0.001$), and the variance in resting VO_2 was also well explained by a combination of BMI, age and gender. These findings were not supported by Cunha et al. [10], however, as BMI explained only 0.15% of the variance in the resting VO_2 of 125 healthy men. A question therefore arises as to what additional factors might explain the unexplained variance. One factor is VO_{2max}, which is thought to potentiate the energy requirements of tissue thereby increasing resting metabolic rate (RMR) and resting VO_2 [25,26]. Poehlman et al. [25], for example, compared the RMR and resting VO_2 of 18 healthy men aged 18 to 37 yr, who were classified as either trained (n = 9, $VO_{2max} = 70.5 \pm 1.8$ $mL \cdot kg^{-1} \cdot min^{-1}$) or untrained (n = 9, $VO_{2max} = 53.0 \pm 2.4$ $mL \cdot kg^{-1} \cdot min^{-1}$). The authors observed a higher RMR (i.e. 9%) and resting VO_2 (i.e. 18%) in the trained vs. untrained participants (i.e. 1.29 vs. 1.17 $kcal.min^{-1}$ and ~3.69 vs. 3.01 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively). This effect persisted even when participants were matched for body fat content. These authors subsequently observed a strong positive correlation between RMR and VO_{2max} ($r = 0.77$ and $P < 0.01$) in 28 healthy men, aged 19 to 36 yr, and a wide VO_{2max} range of 40 to 80 $mL \cdot kg^{-1} \cdot min^{-1}$ [26]. Our findings concur with those studies; however, other studies reported conflicting findings [4,13,20], which might be accounted for by two methodological issues: a) small sample sizes and insufficient statistical power to detect correlations between resting VO_2 and VO_{2max}; and b) failure to investigate a wide range of VO_{2max}. Indeed, the sample sizes of 14 and 8 participants adopted by LeBlanc et al. [20] and Hill et al. [13], respectively, are limited for investigating associations between resting VO_2 and VO_{2max}. In a cross-sectional study designed to determine the relationship between RMR and VO_{2max}, Broeder et al. [4] included 69 men exhibiting a wide range of VO_{2max} (32.8 to 78.1 $mL \cdot kg^{-1} \cdot min^{-1}$). A significant positive correlation was observed between VO_{2max} and RMR when expressed in kJ·kg total body weight$\cdot hr^{-1}$ (r = 0.68 and $P < 0.001$), but not when expressed relative to kJ·kg fat-free mass$\cdot hr^{-1}$ (r = 0.04 and $P < 0.75$). In addition, there were no significant differences in RMR between high, moderate, and low VO_{2max} groups. Even so, it is feasible that the lack of a statistically significant difference in RMR between the three groups was due to the limited range in VO_{2max} between the low vs. moderate VO_{2max} groups (i.e. only ~10 $mL \cdot kg^{-1} \cdot min^{-1}$ or 19% [41.1 ± 0.6 vs. 51.0 ± 0.6 $mL \cdot kg^{-1} \cdot min^{-1}$]). In the present study the difference between low and high cardiorespiratory groups with respect to minimum and maximum values of VO_{2max} were ~35% (32.5 vs. 50.0 $mL \cdot kg^{-1} \cdot min^{-1}$) and ~26% (49.7 vs. 67.1 $mL \cdot kg^{-1} \cdot min^{-1}$), respectively (see Table 1).

In conclusion, the reference MET value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ overestimated resting VO_2 in a relatively large group of apparently healthy men, aged 18-38 years. In a practical context, the reference MET value demonstrated relatively poor accuracy in defining fitness using the maximal MET, prescribing exercise intensity, and quantifying the energy cost of treadmill running in men with low VO_{2max}, causing underestimation errors with respect to these three applications. On the other hand, minimal errors were observed in participants with high VO_{2max}. Further research needs to be conducted to investigate the applicability of the reference MET value in specific populations.

Conflict of Interest

The authors report no conflict of interest.

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Table 1. Mean ± SD (range) participant characteristics.

	Variable	1st part of study (*n* = 114)	2nd part of study (*n* = 14)
Anthropometric assessment	Age – All participants (yr)	24 ± 5 (18-38)	25 ± 6 (18-36)
	Age – lower VO_{2max} (yr)	25 ± 5 (18-36)	30 ± 4 (23-36)
	Age – higher VO_{2max} (yr)	24 ± 6 (18-38)	26 ± 5 (18-30)
	Height – All participants (cm)	177.0 ± 8.1 (160.8-192.3)	177.3 ±7.4 (165.6-188.8)
	Height – lower VO_{2max} (cm)	177.1 ± 7.9 (160.8-192.3)	177.2 ± 10.1 (165.6-188.8)
	Height – higher VO_{2max} (cm)	177.0 ± 8.4 (162.9-201.5)	177.4 ± 4.0 (169.8-183.0)
	Total body mass – All participants (kg)	75.0 ± 10.0 (52.6-110.9)	74.2 ± 9.0 (61.9-87.7)
	Total body mass – lower VO_{2max} (kg)	77.9 ± 10.6 (52.6-110.9)	76.8 ± 9.8 (62.0-87.7)
	Total body mass – higher VO_{2max} (kg)	72.1 ± 8.6 (54.5-100.8)	71.7 ± 8.1 (61.9-79.6)
	Body mass index – All participants ($kg{\cdot}m^{-2}$)	23.9 ± 2.4 (19.3-33.8)	23.6 ± 2.5 (19.6-28.2)
	Body mass index – lower VO_{2max} ($kg{\cdot}m^{-2}$)	24.8 ± 2.6 (19.3-33.8)	24.5 ± 2.7 (20.6-28.2)
	Body mass index – higher ($kg{\cdot}m^{-2}$)	23.0 ± 1.9 (19.6-27.3)	22.7 ± 2.0 (19.6-24.8)
	Percentage of body fat – All participants (%)	11.1 ± 3.7 (5.0-23.2)	13.2 ± 3.2 (8.5-19.3)
	Percentage of body fat – lower VO_{2max} (%)	12.5 ± 4.0 (6.3-23.2)	14.9 ± 3.2 (10.6-19.3)
	Percentage of body fat – higher VO_{2max} (%)	9.7 ± 2.9 (5.0-20.7)	11.4 ± 2.1 (8.5-15.5)
	Fat-free mass – All participants (kg)	66.5 ± 8.2 (44.8-89.5)	64.3 ± 6.7 (55.2-74.3)
	Fat-free mass – lower VO_{2max} (kg)	68.1 ± 9.0 (44.8-89.5)	65.2 ± 7.6 (55.2-74.3)
	Fat-free mass – higher VO_{2max} (kg)	65.0 ± 7.3 (50.3-87.0)	63.4 ± 6.3 (56.6-70.1)
	Fat mass – All participants (kg)	8.5 ± 3.5 (3.6-21.4)	9.9 ± 3.2 (5.3-14.9)
	Fat mass – lower VO_{2max} (kg)	9.8 ± 3.9 (4.4-21.4)	11.6 ± 3.2 (6.8-14.9)
	Fat mass – higher VO_{2max} (kg)	7.1 ± 2.6 (3.6-14.8)	8.3 ± 2.3 (5.3-12.3)
Resting assessment	Resting oxygen uptake – All participants ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	3.3 ± 0.4 (2.2-4.4) *	3.1 ± 0.5 (2.3-3.8) *
	Resting oxygen uptake – lower VO_{2max} ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	3.0 ± 0.4 (2.2-3.9) *†	2.7 ± 0.2 (2.3-2.9) *†
	Resting oxygen uptake – higher VO_{2max} ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	3.5 ± 0.3 (2.8-4.4)	3.5 ± 0.3 (3.0-3.8)
	Resting oxygen uptake – All participants ($mL{\cdot}kg\ FFM^{-1}{\cdot}min^{-1}$)	3.7 ± 0.4 (2.7-4.8)	3.5 ± 0.5 (2.8-4.3)
	Resting oxygen uptake – lower VO_{2max} ($mL{\cdot}kg\ FFM^{-1}{\cdot}min^{-1}$)	3.5 ± 0.4 (2.2-3.9)	3.1 ± 0.3 (2.8-3.5)
	Resting oxygen uptake – higher VO_{2max} ($mL{\cdot}kg\ FFM^{-1}{\cdot}min^{-1}$)	3.9 ± 0.4 (3.1-4.8)	3.9 ± 0.2 (3.6-4.3)

Maximal cardiopulmonary exercise test	Maximal oxygen uptake – All participants ($mL·kg^{-1}·min^{-1}$)	48.4 ± 7.3 (32.5-67.1)	45.6 ± 6.8 (35.3-56.6)
	Maximal oxygen uptake – lower VO_{2max} ($mL·kg^{-1}·min^{-1}$)	42.4 ± 4.7 (32.5-49.7)	40.0 ± 3.0 (35.3-42.0)
	Maximal oxygen uptake – higher VO_{2max} ($mL·kg^{-1}·min^{-1}$)	54.3 ± 3.7 (50.0-67.1)	51.2 ± 4.1 (43.6-56.6)
	Maximal oxygen uptake – All participants ($mL·kg\ FFM^{-1}·min^{-1}$)	54.4 ± 7.6 (35.4-71.2)	52.4 ± 6.6 (43.7-64.2)
	Maximal oxygen uptake – lower VO_{2max} ($mL·kg\ FFM^{-1}·min^{-1}$)	49.3 ± 5.0 (35.4-61.1)	47.0 ± 3.0 (43.7-51.3)
	Maximal oxygen uptake – higher VO_{2max} ($mL·kg\ FFM^{-1}·min^{-1}$)	60.2 ± 4.1 (53.7-71.2)	57.8 ± 4.1 (51.6-64.2)

FFM = fat-free mass. * Significantly lower than the reference MET value of 3.5 $mL·kg^{-1}·min^{-1}$ ($P < 0.01$). † Significantly lower than the observed resting VO_2 for the higher VO_{2max} group ($P < 0.001$).

Table 2. Sample mean ± SD MET_{max}, MET intensity, and energy cost of running computed from the reference MET value and observed resting VO_2 values. The mean difference (Mean diff), confidence interval (95% CI), and test statistic t (t-test) between the reference vs. observed outcomes also are included.

Variable	Sample size (*n*)	Reference Mean ± SD (range)	Observed Mean ± SD (range)	Reference-Observed differences Mean diff	95% CI	*t*-test	*P*-values
Maximal cardiopulmonary exercise test							
MET_{max} – All participants	(114)	13.8 ± 2.1 (9.3-19.2)	14.9 ± 1.7 (11.2-19.7)	1.1	0.7, 1.4	6.1	< 0.001
MET_{max} – lower VO_{2max} group	(55)	12.1 ± 1.4 (9.3-14.2)	14.2 ± 1.7 (11.2-19.7)	2.1	1.6, 2.6	8.8	< 0.001
MET_{max} – higher VO_{2max} group	(59)	15.5 ± 1.1 (14.3-19.2)	15.6 ± 1.3 (12.6-19.1)	0.1	0.3, 0.5	0.6	0.552
30-min running bout at 8.0 km·h^{-1}							
MET intensity – All participants	(14)	8.3	9.5 ± 1.8 (7.3-13.5)	1.3	0.4, 2.3	3.2	0.007
MET intensity – lower VO_{2max} group	(7)	8.3	10.7 ± 1.5 (9.4-13.5)	2.6	1.6, 3.6	6.1	< 0.001
MET intensity – higher VO_{2max} group	(7)	8.3	8.2 ± 0.9 (7.3-9.7)	0.1	-0.5, 0.7	0.4	0.718
Energy cost (kcal) – All participants	(14)	302 ± 44 (241-352)	354 ± 90 (237-522)	53	17, 88	3.1	0.008
Energy cost (kcal) – lower VO_{2max} group	(7)	313 ± 49 (241-352)	414 ± 82 (301-522)	101	57, 145	5.6	0.001
Energy cost (kcal) – higher VO_{2max} group	(7)	291 ± 38 (243-340)	295 ± 49 (237-386)	4	-20, 28	0.4	0.679

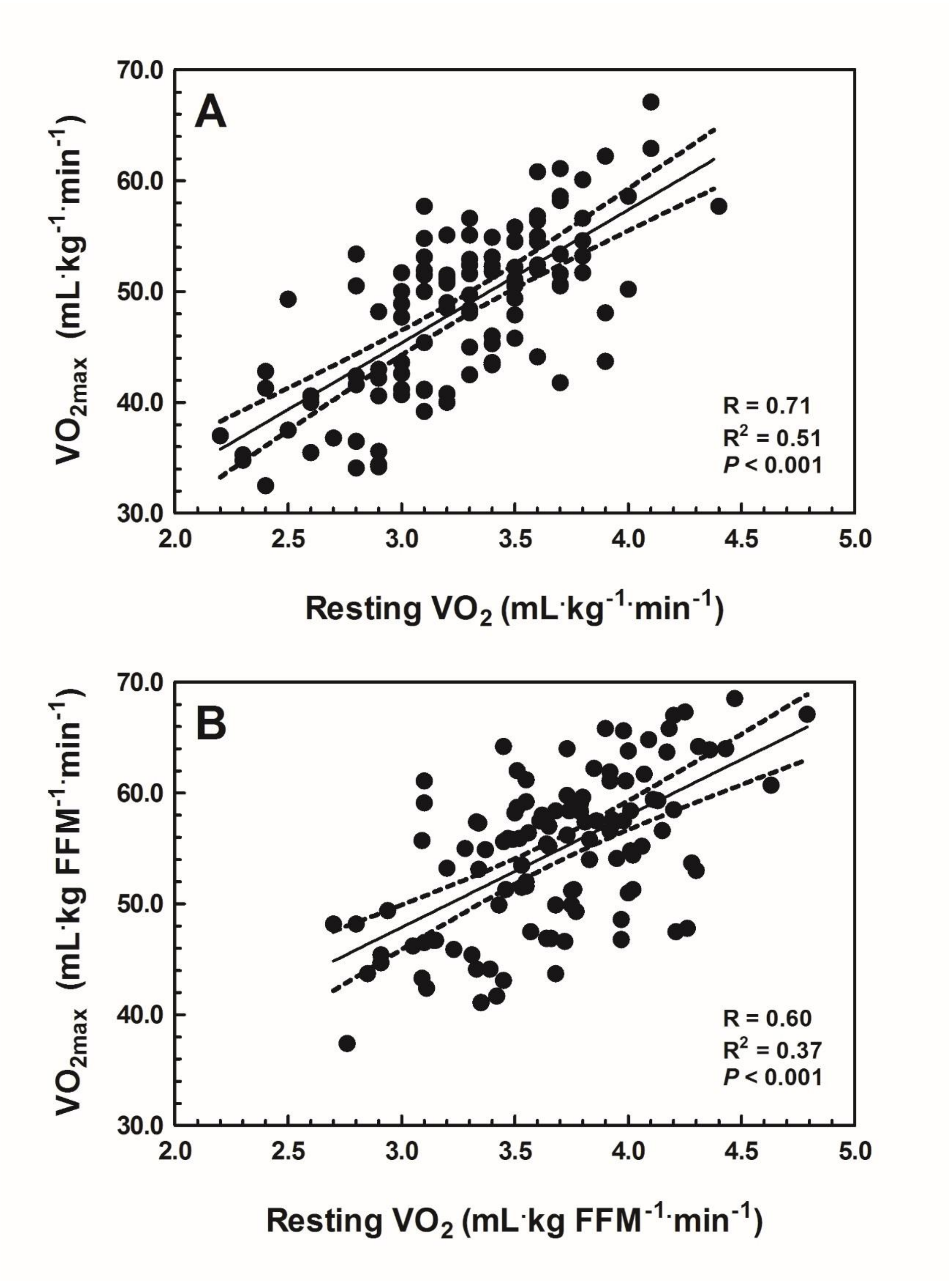

Figure 1. Relationship between maximal and resting VO_2 values relative to total body mass (A) and fat-free mass (B) in the 1st part of the study (N = 114). The dashed lines represent the 95 limits of agreement of the best-fit line. Each point represents an individual participant. Pearson correlation coefficient is given.