Metabolic equivalent: one size does not fit all

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1School of Human Movement Studies, Queensland University of Technology, Kelvin Grove, Australia; 2Department of Nutrition Sciences, Division of Physiology and Metabolism, and 3Department of Human Studies, University of Alabama at Birmingham, Birmingham, Alabama; and 4Institute of Physiology, Faculty of Medicine, University of Lausanne, Lausanne, Switzerland

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Byrne, Nuala M., Andrew P. Hills, Gary R. Hunter, Roland L. Weinsier, and Yves Schutz. Metabolic equivalent: one size does not fit all. J Appl Physiol 99: 1112–1119, 2005. First published April 14, 2005; doi:10.1152/japplphysiol.00023.2004.—The metabolic equivalent (MET) is a widely used physiological concept that represents a simple procedure for expressing energy cost of physical activities as multiples of resting metabolic rate (RMR). The value equating 1 MET (3.5 ml O2·kg−1·min−1 or 1 kcal·kg−1·h−1) was first derived from the resting O2 consumption (V˙O2) of one person, a 70-kg, 40-year-old man. Given the extensive use of MET levels to quantify physical activity level or work output, we investigated the adequacy of this scientific convention. Subjects consisted of 642 women and 127 men, 18–74 yr of age, 35–186 kg in weight, who were weight stable and healthy, albeit obese in some cases. RMR was measured by indirect calorimetry using a ventilated hood system, and the energy cost of walking on a treadmill at 5.6 km/h was measured in a subsample of 49 men and 49 women (26–45 kg/m²; 29–47 yr). Average V˙O2 and energy cost corresponding with rest (2.6 ± 0.4 ml O2·kg−1·min−1 and 0.84 ± 0.16 kcal·kg−1·h−1, respectively) were significantly lower than the commonly accepted 1-MET values of 3.5 ml O2·kg−1·min−1 and 1 kcal·kg−1·h−1, respectively. Body composition (fat mass and fat-free mass) accounted for 62% of the variance in resting V˙O2 compared with age, which accounted for only 14%. For a large heterogeneous sample, the 1-MET value of 3.5 ml O2·kg−1·min−1 overestimates the actual resting V˙O2 value on average by 35%, and the 1-MET of 1 kcal/h overestimates resting energy expenditure by 20%. Using measured or predicted RMR (ml O2·kg−1·min−1 or kcal·kg−1·h−1) as a correction factor can appropriately adjust for individual differences when estimating the energy cost of moderate intensity walking (5.6 km/h).

exercise prescription; body composition; exercise intensity; energy expenditure

When a scientific convention gains widespread acceptance, there is the risk that its underlying premise may no longer be questioned. As a result, the limitations inherent in its assumption are overlooked, and, subsequently, the risk of misusing the convention may increase. The metabolic equivalent (MET) is a widely used physiological concept that is considered to be a simple procedure for expressing the energy cost of physical activities as a multiple of resting metabolic rate (RMR) (1, 3, 35). MET is commonly viewed as a measure that has the advantage of providing a common descriptor of workload levels across most modalities and all populations (2).

Definitions of MET are somewhat varied. Morris et al. (27) identified MET as “the quantity of oxygen consumed by the body from inspired air under basal conditions and is equal on average to 3.5 ml oxygen/kg per min.” The citation provided for this definition was Jette et al. (20), who defined MET as “... the resting metabolic rate, that is, the amount of oxygen consumed at rest, sitting quietly in a chair, ~3.5 ml O2/kg/min.” Importantly, information on how and when the MET value of 3.5 ml O2·kg−1·min−1 was derived remains somewhat elusive. Howley (17) cited an 1890 text that outlined a MET-like concept, and provided O2 consumption (V˙O2) data of a male subject sitting, standing, walking, and running expressed relative to lying V˙O2. Subsequently, on discussing the limits to aerobic capacity in 1936, Dill (7) suggested that individual work capacity might be conceptualized as the ratio of work metabolic rate to basal metabolic rate (BMR) or RMR. Dill also proposed that moderate work be confined to activity that is less than 3 times BMR, hard work between 3 and 8 times BMR, and for the ordinary person maximal work might be 10 times BMR, whereas for the athlete this might be as high as 20 times BMR. In 1941, Gagge et al. (11) devised a system of units to describe human heat exchange with the environment. It was proposed that a thermal activity unit equating 50 kcal·h−1·m−2 body surface area is the metabolism of a subject resting in a sitting position under conditions of thermal neutrality. Thus Gagge et al. appear to be the first to coin the term mets. Wasserman et al. (41) and Howley (17) concur that the data on which the 1-MET value was derived was from the resting V˙O2 for one 70-kg, 40-year-old man and its value is 3.5 ml O2·min−1·kg body wt−1. More recently, Gunn et al. (12, 13) have noted in modest samples (12 men and 12 women, and 36 men, respectively) that the resting V˙O2 is significantly <3.5 ml O2·kg−1·min−1.

In terms of energy expenditure, MET is also defined as the ratio of work metabolic rate to a standard RMR of 1.0 kcal (4.184 kJ)·kg−1·h−1 (1). Physical activities have been described in a compendium by Ainsworth et al. (1) as multiples of this standard resting energy value (1 MET), ranging from sleeping (0.9 MET) to running at 17.4 km/h (18 METs). All activities are assigned an intensity level in METs, and the energy cost of that physical activity is calculated as the MET level multiplied by the standard RMR value (1.0 kcal·kg−1·h−1). Hence, in the examples above, sleeping would receive a MET value of 0.9, walking 3.5, and running 18. Thus, for the broad range of activities studied, the MET value of 3.5 ml O2·kg−1·min−1 was proposed that a thermal activity unit equating 50 kcal·h−1·m−2 body surface area is the metabolism of a subject resting in a sitting position under conditions of thermal neutrality. Thus Gagge et al. appear to be the first to coin the term mets. Wasserman et al. (41) and Howley (17) concur that the data on which the 1-MET value was derived was from the resting V˙O2 for one 70-kg, 40-year-old man and its value is 3.5 ml O2·min−1·kg body wt−1. More recently, Gunn et al. (12, 13) have noted in modest samples (12 men and 12 women, and 36 men, respectively) that the resting V˙O2 is significantly <3.5 ml O2·kg−1·min−1.

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1 Although the SI unit for energy is the joule, MET-related human energy expenditure is most commonly discussed in terms of kilocalories per kilogram per hour. For ease of comparison with other literature pertaining to the MET concept, energy expenditure will be discussed in conventional units in some places.

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equate 0.9 kcal·kg\(^{-1}\)·h\(^{-1}\) and running at 17.4 km/h would equate 18 kcal·kg\(^{-1}\)·h\(^{-1}\). It is recognized that the precision of this system (sometimes referred to as the factorial method) (3, 4, 31) in quantifying human energy expenditure is a function of the accuracy of recall of the physical activity done and accuracy of the assigned MET level (23). However, another issue regarding the accuracy of the estimated energy expenditure using the factorial system may be how well the value of 1.0 kcal·kg\(^{-1}\)·h\(^{-1}\) reflects RMR across individuals.

Ainsworth et al. (1) stress that the compendium was not developed to determine the precise energy cost of physical activity within people but rather as an activity classification system to standardize MET intensities in survey research. However, the MET system is used by researchers, clinicians, and practitioners to identify and prescribe physical activities, particularly those rated to be of moderate intensity (1, 28, 40).

According to Montoye et al. (26), among exercise physiologists, it is almost universally accepted to use the MET system to express energy expenditure in relation to body weight. The American College of Sports Medicine (28) has defined light, moderate, and heavy physical activity to equate with specific MET levels, and tables have been developed to enable prescription of exercise intensity (1). However, there is evidence that the factorial system may be inaccurate for estimating activity energy expenditure in people of different body mass and body fat percentage (16, 29). Furthermore, Ainsworth et al. (1) advise that, when calculating the energy cost of physical activities, the MET (factorial) system does not take into account individual differences that impact on, and thus may alter, the energy cost of movement. As a consequence, Ainsworth et al. (1) have purported that a correction factor may be required to adjust for individual differences when estimating the energy cost of physical activity.

Given the widespread application of the MET concept, we investigated the adequacy and limitations of this scientific convention in a large cohort of adults heterogeneous in age and body composition. In particular, we determined the variance in the measured resting \(\text{V}_{\text{O}_2}\) (ml \(\text{O}_2\)·kg\(^{-1}\)·min\(^{-1}\)) and resting energy expenditure (kcal·kg\(^{-1}\)·h\(^{-1}\)) and compared these with the recognized values for 1 MET. We also determined the degree to which body size, body composition, age, and gender explained the variance in resting \(\text{V}_{\text{O}_2}\) and energy expenditure.

Furthermore, because walking is one of the most common physical activities for adults (40), we investigated the variance in the measured energy cost of walking at 5.6 km/h, which is categorized as “walking for exercise,” a 3.8-MET level physical activity (1). Finally, we investigated whether there was a simple process or correction factor that may be employed to adjust for the differences between measured and predicted energy cost of walking at 5.6 km/h.

**METHODS**

Two studies were conducted. In the first, subjects consisted of 593 women and 78 men, 18–74 yr of age, representing a wide range of body weights (34.5–186.0 kg). Subjects were weight stable, had no history of anorexia nervosa or bulimia nervosa, and, despite being overweight or obese in some cases, were otherwise healthy. The experimental protocol was in accordance with the Declaration of Helsinki and was approved by the ethical committee of the University of Lausanne. Before inclusion in the study, the objectives and procedures were explained to subjects and written, informed consent was obtained.

Subjects were required to fast for 12 h and not to smoke, take caffeine, or perform any exercise on the day preceding testing. Waist and hip circumferences were measured with 0.5-cm precision at the levels of the greater trochanter and equidistant between the umbilicus and the 12th rib, respectively. Skinfold thickness measurements were obtained at four sites (triceps, biceps, subscapular, and suprailiac), and percent body fat calculated using the equations of Durnin and Womersley (8). All skinfold measurements were obtained by the same investigator (Y. Schutz), who was experienced in the procedure. Total body bioelectrical impedance (21, 25) was assessed by means of a portable system developed at the Institute of Physiology, Lausanne, Switzerland (34). Percent body fat was taken as the mean value from the skinfold and body impedance analysis techniques, from which fat mass (FM) and fat-free mass (FFM) were derived. To validate this body composition assessment approach, a subsample of the population (n = 78) was studied using single-mode dual-energy X-ray absorptiometry (QDR 2200 Hologic, Waltham, MA) (5). Within this subset, there was good agreement (\(r^2 = 0.97\), without bias (\(P > 0.50\)), between percent body fat assessed by dual-energy X-ray absorptiometry and by the combination of skinfold thickness and impedance analysis. This correlation was higher than with skinfold measurements alone (\(R^2 = 0.94\)) or with bioelectrical impedance alone (\(R^2 = 0.94\)).

RMR was measured by indirect calorimetry using a ventilated hood system (18, 19). The measurement period was 45 min with RMR values taken for at least a 25-min period at steady state. Air flow was measured continuously by a pneumotachymeter (4730A Digital Pneumotach, Hewlett-Packard, Waltham, MA), and samples of inlet and outlet air were collected continuously and analyzed using a paramagnetic differential \(\text{O}_2\) analyzer and an infrared carbon dioxide analyzer (Magnos 2T and Uras 2T, Hartmann & Braun, Frankfurt, Germany). After correction for temperature, pressure, and humidity, \(\text{V}_{\text{O}_2}\) and \(\text{CO}_2\) production were obtained, and energy expenditure was calculated (9). Intraindividual variability in the measurement of RMR was 2.5%, as has been previously reported (33). RMR was also predicted using the regression equations of Harris-Benedict (14), Fleisch (10), and FAO/WHO/UNU (32). These equations predict RMR using data of subject height, weight, age, and gender.

The second study involved 49 men and 49 women matched for age (38 ± 5 yr) and body mass index (BMI; 32 ± 4 kg/m\(^2\)). The experimental protocol was in accordance with the Declaration of Helsinki and was approved by the University Ethics Committee of the Queensland University of Technology. Before inclusion in the study, the objectives and procedures were explained to subjects and written, informed consent was obtained. RMR was measured as outlined above. The energy cost of walking at 5.6 km/h, a speed defined as 3.8 MET (1), was measured via indirect calorimetry. After a familiarization session (on a previous day), subjects were fitted with a Hans-Rudolf headset with two-way breathing valve and pneumotach and a nose clip. Subjects walked at 5.6 km/h for a 4-min period until steady state was reached (defined as plateau in \(\text{V}_{\text{O}_2}\) and \(\text{CO}_2\) production), data were collected for a 4-min period, and the average \(\text{V}_{\text{O}_2}\) and \(\text{CO}_2\) production values per minute were determined. Respiratory gases were collected throughout the test using a Q-PLEX Gas Analysis System (Quinton Instrument, Seattle, WA). \(\text{O}_2\) and \(\text{CO}_2\) analyzers were calibrated before each test against known gas concentrations, and the flowmeter was calibrated against a 3.0-liter syringe.

**Statistical analysis.** Statistical analyses were performed using SAS (version 8.2) software, and descriptive data are presented as means ± SD, unless indicated otherwise. Stepwise multiple regression analyses were employed to determine the factors that best explained the variance in resting \(\text{V}_{\text{O}_2}\) and energy expenditure (ml \(\text{O}_2\)·kg\(^{-1}\)·min\(^{-1}\) and kcal·kg\(^{-1}\)·h\(^{-1}\)). With subjects classified by BMI group (<20, 20–24.9, 25–29.9, 30–39.9, and ≥40 kg/m\(^2\)), between-group differences in resting values were determined after adjusting for age by...
Table 1. Characteristics of subjects

<table>
<thead>
<tr>
<th></th>
<th>Women (n = 593)</th>
<th>Men (n = 78)</th>
<th>Total (n = 671)</th>
</tr>
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<tbody>
<tr>
<td>Age, yr</td>
<td>38.2±13.0 (18–74)</td>
<td>38.3±11.8 (18–70)</td>
<td>38.2±12.8 (18–74)</td>
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<tr>
<td>Weight, kg</td>
<td>80.5±20.5 (34.5–168.0)</td>
<td>98.0±29.7 (40.5–186.0)</td>
<td>82.6±22.4 (34.5–186.0)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>30.1±7.5 (13.8–57.5)</td>
<td>31.2±9.0 (14.0–51.5)</td>
<td>30.2±7.7 (13.8–57.5)</td>
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<tr>
<td>Percent body fat</td>
<td>37.5±7.8 (71–50.4)</td>
<td>27.5±10.7 (27–44.1)</td>
<td>36.3±8.8 (27–50.4)</td>
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<td>Fat-free mass, kg</td>
<td>49.2±7.6 (30.8–83.8)</td>
<td>66.5±11.4 (41.5–99.6)</td>
<td>51.2±9.8 (30.8–99.6)</td>
</tr>
<tr>
<td>RMR, kcal/day</td>
<td>6,473±1,013 (3,912–10,665)</td>
<td>8,192±1,615 (3,573–11,548)</td>
<td>6,673±1,230 (3,573–11,548)</td>
</tr>
<tr>
<td>RMR pred.1, kcal/day</td>
<td>6,456±803 (4,385–10,088)</td>
<td>8,510±1,699 (5,577–13,719)</td>
<td>6,694±1,155 (4,385–13,719)</td>
</tr>
<tr>
<td>RMR pred.2, kcal/day</td>
<td>6,435±732 (4,351–9,347)</td>
<td>7,812±1,100 (5,586–10,807)</td>
<td>6,594±900 (4,351–10,807)</td>
</tr>
<tr>
<td>RMR pred.3, kcal/day</td>
<td>6,531±920 (4,376–10,648)</td>
<td>8,569±1,640 (5,431–12,979)</td>
<td>6,770±1,218 (4,376–12,979)</td>
</tr>
<tr>
<td>RMR, ml O₂·kg⁻¹·min⁻¹</td>
<td>2.54±0.39 (1.67–3.87)</td>
<td>2.67±0.47 (1.61–4.05)</td>
<td>2.56±0.40 (1.61–4.05)</td>
</tr>
<tr>
<td>RMR, kcal·kg⁻¹·h⁻¹</td>
<td>0.83±0.13 (0.54–1.28)</td>
<td>0.87±0.16 (0.55–1.35)</td>
<td>0.83±0.13 (0.54–1.35)</td>
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</tbody>
</table>

Values are means ± SD, with range in parentheses. BMI, body mass index; RMR, resting metabolic rate; RMR pred.1, RMR predicted using the Harris-Benedict equation (15); RMR pred.2, RMR predicted using the Fleisch equation (10); RMR pred.3, RMR predicted using the FAO/WHO/UNU equation (32).
Adjusted MET level at 5.6 km/h = 
3.8 \times 1.0 \ (\text{kcal} \cdot \text{kg}^{-1} \cdot \text{h}^{-1})/\text{predicted RMR} \ (\text{kcal} \cdot \text{kg}^{-1} \cdot \text{h}^{-1})

As detailed in Table 4 and Fig. 3, on average, the variance between measured energy cost at 5.6 km/h (4.62 ± 0.53) and the adjusted MET level energy cost was reduced to 4.8 and 2.4\% when adjusting for measured RMR in milliliters of O2 per kilogram per minute and kilocalories per kilogram per hour, respectively. The difference between measured energy cost at 5.6 km/h and the estimated energy cost from MET level was reduced on average to 2.6 and 0.2\% when adjusting for RMR predicted from the Harris-Benedict equation in milliliters of O2 per kilogram per minute and kilocalories per kilogram per hour, respectively.

DISCUSSION

The purpose of this study was to determine the magnitude of the variance in estimating energy expenditure using the MET system and further to identify the factors that explain this variance. The MET system is a simple approach used by clinicians to recommend and prescribe physical activity levels and define the energy cost of these activities. However, the data presented here shows that the use of the 1-MET values of 3.5 ml O2·kg⁻¹·min⁻¹ and 1 kcal·kg⁻¹·h⁻¹ do not equate measured resting VO₂ or RMR and, as such, literally used can overestimate energy expenditure.

Resting data. The main finding of this study was that resting VO₂ is on average 2.6 ± 0.4 ml O2·kg⁻¹·min⁻¹, significantly different from the 1-MET value. These findings concur with recent studies of smaller samples by Gunn et al. (12) that identified the 1-MET value of 12 men and 12 women (35–46 yr, 20–37 kg/m²) to be 2.8 ± 0.3 ml O2·kg⁻¹·min⁻¹ (13) and of 36 men (35–45 yr, 19–33 kg/m²) to be 3.0 ± 0.3 ml O2·kg⁻¹·min⁻¹. Although the studies by Gunn et al. reported slightly higher values than those in the present investigation, the Douglas bag technique was used, with subjects breathing through a respiratory valve and wearing a nose clip. However, despite this difference, the resting VO₂ values from both the Gunn et al. studies and the present investigation are significantly lower than the commonly employed value of 3.5 ml O2·kg⁻¹·min⁻¹. In fact, only 14 (2\%) of the 769 subjects we tested had a resting VO₂ value ≥3.5 ml O2·kg⁻¹·min⁻¹. These 14 subjects were heterogeneous in age, spanning 18–59 yr, but were homogeneous in having low relative weights, i.e., BMI values between 16 and 22 kg/m².

To confirm that the RMR measures were typical of adult subjects and that measurement bias was not responsible for the lower than expected resting values, we predicted the RMRs (kcal/day) using the Harris-Benedict (14), Fleisch (10), and FAO/WHO/UNU (32) equations and compared the estimates with our measured RMR values. On average, the measured values (1,595 ± 294 kcal) differed by 19 kcal/day (1.2\%) from the Fleisch estimations (1,576 ± 215 kcal), 5 kcal/day (<1\%) from the Harris-Benedict estimations (1,600 ± 276 kcal), and only 3 kcal/day (<1\%) from the FAO/WHO/UNU estimations (1,618 ± 219 kcal). Therefore, we can conclude that the resting VO₂ values obtained in the present study are typical for lying, ventilated hood measurements.

Some research suggests that casual, seated resting VO₂ approximates 3.6 ml O2·kg⁻¹·min⁻¹ (38). However, the data from these studies were collected over only 5 min and immediately before a maximal exercise test. This is a very short measurement period and one in which the relatively untrained subjects could not be considered to be in a “casual, resting” state. Yet despite these conditions, the preexercise resting measures were on average only 3.1 ml O2·kg⁻¹·min⁻¹ (37). Therefore, it is reasonable to speculate that true resting seated VO₂ would be closer to the 2.6 ml O2·kg⁻¹·min⁻¹ value we found for supine rest than 3.5 ml O2·kg⁻¹·min⁻¹.
It may be argued that the difference between our resting values and the common 1-MET value of 3.5 ml O₂·kg⁻¹·min⁻¹ reflects the energy cost of sitting vs. lying. However, Strickland and Uljiaszek (36) reported that the energy cost for sitting in men was only 7.3% higher than for lying. Another difference between measures taken lying vs. sitting is the measurement procedure; i.e., ventilated hood vs. mouthpiece and nose clip. We selected from our study cohort a subsample of men (N = 16) and women (N = 16) who matched the age and BMI range of the Gunn et al. (12) study to undertake a comparison of the likely group difference between lying V˙O₂ measured using a ventilated hood vs. using a mouthpiece, respiratory valve, and nose clip. The average for the ventilated hood measurements (2.78 ± 0.31 ml O₂·kg⁻¹·min⁻¹) were <1% lower than those reported by Gunn et al. (12) for the mouthpiece system (2.8 ± 0.3 ml O₂·kg⁻¹·min⁻¹). Furthermore, when the resting V˙O₂ prediction equation derived in the present study was applied to the mean data for the Gunn et al. (12) cohort, the predicted resting V˙O₂ value was 2.96 ml O₂·kg⁻¹·min⁻¹ compared with the measured 3.0 ml O₂·kg⁻¹·min⁻¹. Therefore, it is reasonable to conclude that, although there is a difference in resting V˙O₂ measured sitting vs. lying and between ventilated hood vs. mouthpiece protocols, lying with a ventilated hood measurement is likely to be only 8% lower than measures taken while sitting with a mouthpiece and nose clip.

Our results show that the standard 1-MET value of 3.5 ml O₂·kg⁻¹·min⁻¹ overestimates the actual resting value for a heterogeneous study sample, with an average BMI of 30 kg/m², by an average of 35% (or arguably 27% if the 1-MET value reflects seated resting V˙O₂). Given that in Westernized nations such as the United States the proportion of the population who are overweight or obese is almost two-thirds and one-third, respectively (15), these findings are very relevant. However, even for individuals at the lower end of the normal relative weight range (BMI = 20 kg/m²), the overestimation is still 14% on average. In terms of energy expenditure, the difference between 1 MET and the average measured resting value in study 1 (0.84 ± 0.16 kcal·kg⁻¹·h⁻¹) and study 2 (0.81 ± 0.08) was 19 and 23%, respectively. These data are comparable with other studies, including Lof et al. (24) (0.81 ± 0.08) and Leenders et al. (22) (0.85 ± 0.02) and show that this measured resting energy cost is lower than that defined for sleeping energy cost (0.9 MET) by the MET system (1).

It is well recognized that, although aerobic capacity decreases with age, body fat levels increase. Therefore, we were interested to determine the extent to which age, body weight, and body composition influenced the measured resting values. Resting V˙O₂ was significantly related to gender, age, BMI, percent body fat, waist circumference, FM, and FFM. Multiple regression analysis revealed that FM was the strongest predictor of the variability in resting V˙O₂ (ml O₂·kg⁻¹·min⁻¹), explaining 59% of the variance. Collectively (after accounting for collinearity), body composition (FM and FFM) accounted for 62% of the variance in resting V˙O₂ compared with age, which accounted for only 14%. The ability to measure body composition is often limited by time or equipment availability. Accordingly, the BMI is commonly used to measure relative weight and to categorize normal, overweight, and obese states. In the present sample, BMI was strongly positively correlated with FM (R² = 0.93, P < 0.0001), and the variance in resting V˙O₂ was also well explained by a combination of

<table>
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<tr>
<th>Age (yr)</th>
<th>Gender</th>
<th>BMI (kg/m²)</th>
<th>Resting V˙O₂ (ml O₂·kg⁻¹·min⁻¹)</th>
<th>Difference (%)</th>
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<td>Male</td>
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<td>+6.0</td>
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</table>

*Percentage difference between adjoining cells (above vs. below).
Although we have shown that resting $\dot{V}O_2$ decreases with age in explaining the variance in this level of differentiation, body composition, or simply BMI, the between-individual variance in RMR (kcal/day), body level (or energy cost in kcal kg\(^{-1}\) h\(^{-1}\)) adjust for individual differences when estimating the energy cost of physical activity. One reason for this underestimation has been attributed to the 1-MET value being higher in overweight and obese individuals than measured RMR. Racette et al. (29) define, recommend, and prescribe physical activity levels (1, 20). FM is considerably less metabolically active than FFM, and expressing resting $\dot{V}O_2$ in milliliters per kilograms per minute does not fully account for these differences in body composition. It is important to note that, in the present study, the highest FM was 2.5 times the lowest FM, whereas the highest FM was 23 times the lowest FM. Furthermore, although there was a twofold range in measured resting $\dot{V}O_2$ from lowest to highest value, Figs. 1 and 2 demonstrate how un-commonly a resting $\dot{V}O_2$ value over 3 ml O\(_2\) kg\(^{-1}\) min\(^{-1}\) is likely to occur.

Exercise data. An additional purpose of the study was to determine the difference between energy expended during moderate paced walking (5.6 km/h) and the predicted energy cost using the MET (factorial) system. As outlined by Ainsworth et al. (1), the MET system was not designed to give precise estimates of the energy cost of physical activity, but rather it was developed as a system for survey research to standardize intensities of physical activities. However, the MET system is commonly used beyond this scope by health educators, clinicians, researchers, and exercise physiologists to define, recommend, and prescribe physical activity levels (1, 26, 28). Using a common physical activity, walking at 5.6 km/h, we investigated whether a correction factor could be derived to adjust for individual differences when estimating the energy cost of this activity.

We have shown that the measured energy cost of walking at 5.6 km/h was on average 22% higher than the predicted energy cost (4.6 ± 0.5 vs. 3.8 kcal kg\(^{-1}\) h\(^{-1}\)). The range in energy cost for this activity of the 49 men and 49 women tested was 3.6–6.5 kcal kg\(^{-1}\) h\(^{-1}\), which is 95–171% of the predicted value. A number of other studies have reported that the MET (factorial) system underestimates the energy cost of physical activity, particularly as body fat levels increase (16, 25, 37). Leenders et al. (22), comparing activity energy expenditure, estimated via the factorial (METs) method with doubly labeled water measures, reported an average underestimate of 24% using the MET system. One reason for this underestimate has been attributed to the 1-MET value being higher in overweight and obese individuals than measured RMR. Racette et al. (29) modified the standard factorial estimation of energy expendi-

### Table 4. Subject characteristics and energy cost of walking at 5.6 km/h

<table>
<thead>
<tr>
<th>Age, yr</th>
<th>Weight, kg</th>
<th>BMI, kg(^{-2})</th>
<th>RMR, kcal kg(^{-1}) h(^{-1})</th>
<th>$\dot{V}O_2$ at 5.6 km/h, ml O(_2) kg(^{-1}) min(^{-1})</th>
<th>EE at 5.6 km/h, kcal kg(^{-1}) h(^{-1})</th>
<th>MET level adjusted for measured RMR*</th>
<th>MET level adjusted for predicted RMR†</th>
<th>MET level adjusted for predicted RMR‡</th>
<th>MET level adjusted for predicted RMR§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>38.0 ± 2.9 (29–47)</td>
<td>85.6 ± 11.8 (65.0–117.6)</td>
<td>31.1 ± 3.5 (26.1–40.6)</td>
<td>2.72 ± 0.25 (2.21–3.39)</td>
<td>0.80 ± 0.07 (0.65–0.99)</td>
<td>16.10 ± 1.77 (13.06–21.43)</td>
<td>4.55 ± 0.53 (3.74–6.50)</td>
<td>4.93 ± 0.45 (3.93–6.01)</td>
<td>4.97 ± 0.33 (4.34–5.66)</td>
</tr>
<tr>
<td>Men</td>
<td>40.0 ± 2.7 (30–47)</td>
<td>104.2 ± 2.1 (78.0–146.0)</td>
<td>31.5 ± 3.8 (26.1–44.7)</td>
<td>2.83 ± 0.28 (2.14–3.45)</td>
<td>0.83 ± 0.08 (0.63–1.01)</td>
<td>15.67 ± 1.78 (12.41–20.90)</td>
<td>4.69 ± 0.53 (3.56–6.17)</td>
<td>4.75 ± 0.48 (3.86–6.21)</td>
<td>4.70 ± 0.53 (3.72–6.27)</td>
</tr>
</tbody>
</table>

*Values are means ± SD, with range in parentheses. EE, energy expenditure; MET, metabolic equivalent. †MET level (or energy cost in kcal kg\(^{-1}\) h\(^{-1}\)) adjusted for measured RMR (ml O\(_2\) kg\(^{-1}\) min\(^{-1}\)). ‡MET level (or energy cost in kcal kg\(^{-1}\) h\(^{-1}\)) adjusted for measured RMR (ml O\(_2\) kg\(^{-1}\) min\(^{-1}\)). §MET level (or energy cost in kcal kg\(^{-1}\) h\(^{-1}\)) adjusted for predicted RMR (ml O\(_2\) kg\(^{-1}\) min\(^{-1}\)).
ture in obese women by adding a body weight factor to the calculation, giving the following equation: energy cost of physical activity = \( RMR + (\text{MET level} - 1) \times \text{weight} \times (1.0 \text{kcal} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}) \). Without this correction, it was suggested that estimating energy cost of a 3-MET activity in the obese women could lead to a 50% error in estimation. Estimating the energy cost of walking using the equation of Racette et al. (29) in the present study cohort resulted in an estimated energy cost of walking (5.6 km/h) of 3.63 ± 0.06 kcal·kg⁻¹·h⁻¹, a 28% underestimation of the measured values. Although this method did not improve on the estimated energy cost of walking in the present study, it is likely to be attributed to the equation being derived on a small sample \( (N = 14) \) of obese women.

Although our data support the notion that the error in estimating resting \( V\dot{O}_2 \) from 1 MET increases with increasing adiposity (i.e., measured resting \( V\dot{O}_2 \) decreases with increases in body fat), we show that the 1-MET value also overestimates measured resting \( V\dot{O}_2 \) values in normal weight persons. We hypothesized that by accounting for the individual difference in the measured resting \( V\dot{O}_2 \), it may be possible to more accurately predict the energy cost of walking. The results from the present study show, at least for moderate-intensity walking, that using the actual or predicted resting values as a correction factor for 1 MET (ml O₂·kg⁻¹·min⁻¹ or kcal·kg⁻¹·h⁻¹) overcomes the majority of the error in estimating the energy cost of walking at 5.6 km/h (Fig. 3). These adjusted MET level equations are outlined in RESULTS.

The implications of these findings are important when the use of the MET (factorial) system for evaluating current physical activity levels within individuals is considered, and when physical activity doses for individuals are prescribed. The present data show that, even after accounting for body mass, the energy cost of walking at a given pace can vary between individuals by 76%. However, the magnitude of this variance can be reduced markedly by accounting for differences in RMR.

In conclusion, given the extensive use of MET levels to estimate energy cost of physical activity, we investigated the adequacy of this scientific convention. For a large heterogeneous sample, the 1-MET value of 3.5 ml O₂·kg⁻¹·min⁻¹ overestimates the actual \( V\dot{O}_2 \) value on average by 35% and the 1 kcal·kg⁻¹·h⁻¹ value overestimates resting energy expenditure by 20%. Therefore, MET is by convention 3.5 ml O₂·kg⁻¹·min⁻¹ or 1 kcal·kg⁻¹·h⁻¹, but this is not specifically a constant that equates resting values. The measured MET level for moderate-intensity walking in an overweight cohort was on average 4.6 ± 0.5, 22% higher than the compendium defined (1) value of 3.8. However, we show that using measured or predicted RMR (ml O₂·kg⁻¹·min⁻¹ or kcal·kg⁻¹·h⁻¹) as a correction factor can appropriately adjust for individual differences when estimating the energy cost of walking at this speed.

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REFERENCES