# Absolute and Relative Energy Costs of Walking in a Brazilian Adult Probability Sample

LUIZ ANTONIO DOS ANJOS[1,2], JULIANA DA MATA MACHADO[1], VIVIAN WAHRLICH[1], MAURICIO TEIXEIRA LEITE DE VASCONCELLOS[3,4], and CARL J. CASPERSEN[5]

[1]*Nutritional and Functional Research Laboratory, Department of Social Nutrition, Fluminense Federal University, Niterói, Rio de Janeiro, BRAZIL;* [2]*National School of Public Health, Oswaldo Cruz Foundation, Rio de Janeiro, BRAZIL;* [3]*National School of Statistical Sciences, Brazilian Institute of Geography and Statistics, Rio de Janeiro, BRAZIL;* [4]*Evandro Chagas Clinical Research Institute, Oswaldo Cruz Foundation, Rio de Janeiro, BRAZIL; and* [5]*Division of Diabetes Translation, Centers for Disease Control and Prevention, Atlanta, GA*

**ABSTRACT**

DOS ANJOS, L. A., J. DA MATA MACHADO, V. WAHRLICH, M. T. L. DE VASCONCELLOS, and C. J. CASPERSEN. Absolute and Relative Energy Costs of Walking in a Brazilian Adult Probability Sample. *Med. Sci. Sports Exerc.*, Vol. 43, No. 11, pp. 2211–2218, 2011. **Background**: Walking is commonly recommended for enhancing energy expenditure (EE), a basic principle in weight management, and cardiorespiratory fitness. However, walking EE varies with characteristics of a given population, especially by sex and age. **Purpose**: The study's purpose was to measure EE of walking as influenced by physical and physiological characteristics of a sample of adults (≥20 yr) living in Niterói, Rio de Janeiro, Brazil. **Methods**: Walking EE and HR were measured during a submaximal multistage treadmill test. The test stages lasted for 3 min each and started at a speed of 1.11 $m \cdot s^{-1}$ and a grade of 0%. In the second stage, the grade was maintained at 0%, but the speed was increased to 1.56 $m \cdot s^{-1}$ and maintained at this speed but with grade raised by 2.5% at each stage until 10% at stage 6. We measured resting oxygen consumption ($MET_m$) before the test with the participants sitting quietly. **Results**: $MET_m$ (mL $O_2 \cdot kg^{-1} \cdot min^{-1}$, mean ± SE) was lower both in women (2.85 ± 0.03) and in men (2.97 ± 0.04) by almost 19% and 15%, respectively, compared with the conventionally estimated MET ($MET_e$) of 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$. Walking EE for any given speed and grade had an absolute intensity, expressed as multiples of $MET_m$ or $MET_e$, that was practically equal between sexes and age groups, but it incurred higher individual physiological demand or relative intensity for women and older adults. **Conclusions**: Resting EE reflected by using $MET_e$ is overestimated in the adult population of Niterói. Prescription of activities to counteract the existing worldwide obesity epidemic should be ideally based on individual physiological information, especially among women and older individuals. **Key Words:** WALKING, PHYSICAL ACTIVITY, ADULT, PUBLIC HEALTH, ENERGY EXPENDITURE, BASAL METABOLISM

Obesity is considered one of the major public health problems both in the developed and developing countries, including Brazil (19), affecting more than 300 million people worldwide in 2005 (41). Obesity is defined as excess body fat leading to increased risk for chronic diseases and mortality and occurs after prolonged positive energy balance (40). Changes in lifestyle including dietary modification and increase in physical activity are associated with reduction of obesity-related mortality with or without weight loss (17,26). Walking is a physical activity widely recommended by health professionals because of its low cost, acceptance by all persons without impairments, and positive effect on energy expenditure (EE) and cardiorespiratory fitness among other health benefits (8,10,22,23,32). In fact, in the past, it has been recommended that all adults perform at least 30 min of moderate-intensity aerobic activity (e.g., brisk walk) 5 d each week (18) as a low-intensity method to achieve health benefits of exercise (31,32)—one of many ways to meet current physical activity guidelines (32). A recent meta-analysis of prospective cohort studies has shown that walking at this intensity and duration is inversely associated with cardiovascular disease and all-cause mortality (16), with the effects being stronger for self-reported walking pace than walking volume. It is assumed that this intensity and duration will result in an EE of approximately 837 $kJ \cdot d^{-1}$ (200 $kcal \cdot d^{-1}$), for a very brisk walk pace (5 METs) of a 75-kg individual (32), which is the amount of EE associated with the reduction of mortality due to chronic diseases (18,32).

Notwithstanding potential health effects, the physiological response to any physical activity depends on the characteristics of the population such as body size and composition, age, and hereditary and cardiorespiratory fitness level, which can influence the energy cost of the activity (30). Thus, there

Address for correspondence: Carl J. Caspersen, M.P.H., Ph.D., FACSM, Epidemiology and Statistics Branch, Division of Diabetes Translation, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention (mailstop K-10), 4770 Buford Highway NE, Atlanta, GA 30341-3717; E-mail: cjc1@cdc.gov.
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are some potential problems in using tables with fixed values of EE for each activity that were mostly derived from studies conducted during the second half of the last century in either convenience samples or small numbers of individuals not necessarily representative of a population (7,11,14). Furthermore, the tables of EE show no variability of the values, they originated from preexisting studies not intended to produce descriptive data (14), and it is unknown whether they were derived from activities performed continuously or intermittently (24). Furthermore, the tables provide absolute values of intensity of a particular physical activity, in most cases, in terms of multiples of resting EE (MET), instead of the relative individual response to the activity. Thus, more information on the physiological responses of physical activity in segments of the population from different regions of the world is necessary to better estimate the EE in epidemiological and clinical studies (23). To this end, the purpose of the present study was to assess the physiological response of walking on a treadmill at different intensities by pursuing a probability sampling strategy of adults living in Niterói, a city in the metropolitan area of Rio de Janeiro, Brazil.

## METHODS

The present study was originally designed to assess the nutritional status and physical activity level in a probability sample of the adult population (≥20 yr) of Niterói, Rio de Janeiro, Brazil. Details of the sampling procedures have been published elsewhere (3,5,30), but basically, it was designed in three stages to identify census enumeration areas (CEAs), households within CEA, and an adult within a household. In the first stage, 110 CEAs were selected with a probability proportional to the number of household dwellings from an ordered list according to the average household income. Doing so allowed an implicit income stratification of the CEA. In the second stage, for each selected CEA, 80 households were selected with equal probability to define a basic list used in the inverse sampling procedure (15) similar to that of the World Health Survey in Brazil (33). The households were visited after the selection order until 16 interviews were completed. In the third stage, for each interviewed household, an adult was selected to participate in the study with equal probability among all adults in the household. To be eligible, the adult had to be free of any cardiac or metabolic condition and under no medication that could alter HR or metabolism. A subsample of five selected participants per CEA ($n$ = 550) were invited to come to the laboratory for EKG monitoring and a series of physiological measurements including basal metabolism and the energy cost of walking on a treadmill measured on two separate visits. Of these, 210 (121 women and 89 men) performed the walking test on the treadmill test, whereas 161 could not perform it (75 based on EKG indications of an existing cardiovascular condition and 86 for some form of physical limitation) and the remaining 179 (32.5% nonresponse) declined to participate. Sample weights were calculated as the inverse of the product of the inclusion probabilities in each selection stage. The Integrated Household Weighting System was used to calibrate the sample weights to adjust the estimates to known population totals by sex and age groups (33). Unfortunately, there is no solution to correct population totals for the proportion of people with altered EKG or physical limitation based on the subsample data, and therefore, the procedure assumes that the total population is only composed of seemingly healthy individuals. However, despite this unrealistic assumption, the calibration corrects the structure of the subsample for age and sex and eliminates the selection biases common in household surveys.

On the first scheduled day, the participant either drove his/her own car or used public transportation to come to the laboratory immediately after waking early in the morning. Each participant also had to have fasted for 12 h, slept for 6–8 h, and neither engaged in vigorous exercise nor consumed alcohol during the preceding 24 h. Upon arrival at the laboratory, the participants signed a written informed consent after which adherence to the protocol for basal metabolic rate (BMR) measurement and body temperature were checked. Participants rested for 15 min in the supine position in a dark, quiet room with ambient temperature controlled around 25°C. After this resting period, oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured for 25 min using a validated (36) portable calorimeter (MedGraphics $VO_{2000}$; St. Paul, MN) with simultaneous HR monitoring (Vantage NV; Polar Oy, Kempele, Finland). BMR was calculated from the last 20 min of measurement using the Weir equation (38). The calorimeter was calibrated before each measurement according to manufacturer instructions. After the BMR measurement, a 12-lead EKG was conducted with the participant in a supine resting state to rule out further cardiovascular disease.

Anthropometric and body composition measurements were done with the participant barefoot and wearing standardized clothes. Body mass (BM) was expressed as the participant's weight as measured with an electronic scale to the nearest 0.2 kg. Stature ($S$) was measured in duplicate on a wooden stadiometer to the nearest 0.1 cm. BM index (BMI) was calculated as the ratio between BM and squared S in meters. Circumferences were measured with an inelastic tape to the nearest 0.1 cm. Percent of body fat was measured using a validated (35) bioimpedance scale (Tanita TBF 305, Tanita Corporation, Tokyo, Japan). Nutritional status was determined according to the World Health Organization (40) using three BMI categories ($kg \cdot m^{-2}$): normal (<25), overweight (25–29.9), and obese (≥30).

The participants with normal EKG and no history of, nor taking any medication for, cardiovascular diseases and physical limitations that would prevent them from walking on the treadmill were scheduled to come to the laboratory a second time after having fasted for 4 h. Before the treadmill test, $\dot{V}O_2$ and $\dot{V}CO_2$ were measured for 10 min while the participant was comfortably seated on a chair. These data were used to calculate a measured resting oxygen consumption ($MET_m$, mL $O_2 \cdot kg^{-1} \cdot min^{-1}$). Immediately thereafter, the EE during walking on a treadmill (ATL model; Inbramed, Porto Alegre, Brazil) was obtained by indirect calorimetry with simultaneous HR monitoring. Before data collection, the test was demonstrated after which the participant performed a practice trial of walking at the speeds and grades used in the test, described next, for approximately 5 min total. Then, the facemask was adjusted to the subject, and the walking test was initiated after the subject's approval, usually after approximately 10 min. The walking test was progressive having as many as six stages, each lasting 3 min, starting at 1.11 $m \cdot s^{-1}$ and 0% grade. Speed was thereafter increased to 1.56 $m \cdot s^{-1}$ with grade maintained at 0%. The speed of the next four stages was maintained at 1.56 $m \cdot s^{-1}$, and the grade was increased by 2.5% until it reached 10%. A 2-min warm-up walk (1.11 $m \cdot s^{-1}$/0%) preceded data collection. The test was carried out until the participant reached a predicted HR of around 60% of the HR reserve ($\%HR_{res}$ = (HR − resting HR) / [(maximal HR) − resting HR] × 100), which is the upper value to classify moderate physical activity (31). Maximal HR was calculated using the equation of Gellish et al. (12): [206.9 − (0.67age)]. The test could also be voluntarily terminated by the participant. Resting HR was previously obtained during BMR measurement. HR was expressed by its absolute value and $\%HR_{res}$.

Mean EE of walking was calculated using the equation described by Weir (38) for each stage and expressed as 1) kilojoules per minute, 2) multiples of estimated MET ($MET_e$ (mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) /3.5), 3) multiples of $MET_m$ (mL $O_2 \cdot kg^{-1} \cdot min^{-1}$/resting measured $\dot{V}O_2$), and 4) multiples of BMR, an index called the physical activity ratio (PAR) (11), which is used to reflect the absolute intensity of walking. Calculated $\%HR_{res}$ represents the relative intensity of walking. The time to expend 837 kJ (200 kcal) was calculated as 837 divided by the individual mean EE ($kJ \cdot min^{-1}$) of each walking intensity. EE of walking was also estimated using two procedures: 1) the PAR values published by the Food and Agriculture Organization (FAO)/ World Health Organization (WHO) (11) and the predicted BMR using Schofield equations (28) and 2) the MET codes from the Compendium of Physical Activities (1) using individually calculated MET. These latter two EE values could then be compared with at least three tabled PAR values for walking intensity of the former intensity (11), i.e., 3.0 (walking slowly), 3.4 (walking at normal pace), and 5.4 (walking uphill at normal pace), and closely comparable values of the latter using MET compendium–derived codes (1), i.e., 3.0 (1.11 $m \cdot s^{-1}$), 3.8 (1.56 $m \cdot s^{-1}$), and 6.0 (1.56 $m \cdot s^{-1}$ uphill).

Two reference classifications for gauging the intensity of walking were used for comparison: 1) one described by Pate et al. (25) and recommended by the Centers for Disease Control and Prevention and the American College of Sports Medicine (ACSM), which considers moderate activity to be between 3 and 6 METs, and 2) the other one that classifies the intensity of an activity for men depending on age (31). Despite being described for men only, the latter classification was also applied to the women of the present study because of the lack of women-specific intensity levels.

Statistical weighting of the data allowed a representation of a total of 324,671 adults from the Niterói population (145,886 men and 178,785 women). Data analyses included descriptive statistics such as means, SE, 95% confidence interval, and minimum and maximum values. Analyses were preformed using SAS (version 8.2; SAS Institute Inc., Cary, NC) using the appropriate calibrated weight and the complex sample design in the SURVEYMEANS and SURVEYREG procedures. The Institutional Review Board of the Sergio Arouca National School of Public Health, Oswaldo Cruz Foundation approved all research procedures in accordance to the Declaration of Helsinki for protection of human subjects from research risks.

## RESULTS

The age of the 210 study participants varied from 20.2 (Table 1) to 71.3 yr (Table 2). Mean values (±SE) of BM and S were 62.2 ± 1.2 kg and 159.1 ± 0.6 cm for women and 73.7 ± 1.7 kg and 172.4 ± 1.1 cm for men. This results in BMI ($kg \cdot m^{-2}$) values of 24.6 ± 0.5 and 24.8 ± 0.5 for women and men, respectively.

Overweight and obesity prevalences were similar in women (24.5% and 10.3%, respectively) and men (24.0% and 11.4%). However, using waist circumference (WC), 31.4% of the women were assigned to the high-risk group, and 23.8% were assigned to the very high–risk group for metabolic diseases. Among men, these values were 4.6%



TABLE 1. Estimated means, SE, minimum and maximum values, and confidence interval (CI) for physical and physiological variables of adult women (≥20 yr) from Niterói, Rio de Janeiro, Brazil—the Nutrition, Physical Activity, and Health Survey (PNAFS), 2003.

| Physical or Physiological Variable | Mean | SE | Minimum | Maximum | 95% CI |
|---|---|---|---|---|---|
| Age (yr) | 43.8 | 1.6 | 20.4 | 71.3 | 40.6–46.9 |
| BM (kg) | 62.2 | 1.2 | 46.8 | 110.2 | 59.7–64.7 |
| *S* (cm) | 159.1 | 0.6 | 143.9 | 175.2 | 157.9–160.3 |
| BMI ($kg \cdot m^{-2}$) | 24.6 | 0.5 | 18.6 | 40.1 | 23.6–25.5 |
| Percent body fat (%) | 37.7 | 0.6 | 24.4 | 50.5 | 36.5–38.9 |
| Fat-free mass (kg) | 38.3 | 0.5 | 30.8 | 54.6 | 37.3–39.3 |
| Fat mass (kg) | 23.9 | 0.8 | 11.8 | 55.6 | 22.2–25.6 |
| Resting HR ($beats \cdot min^{-1}$) | 65.5 | 0.6 | 45.0 | 87.0 | 64.2–66.8 |
| BMR ($kJ \cdot d^{-1}$) | 4694.7 | 69.3 | 3339.0 | 7116.7 | 4556.4–4833.0 |
| Resting $\dot{V}O_2$ (mL $O_2 \cdot min^{-1}$) | 175.3 | 2.4 | 132.4 | 255.3 | 170.6–180.0 |
| $MET_m$ (mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) | 2.85 | 0.03 | 2.22 | 3.63 | 2.79–2.90 |

TABLE 2. Estimated mean, SE, minimum and maximum values, and CI for physical and physiological variables of adult men (≥20 yr) from Niterói, Rio de Janeiro, Brazil—the PNAFS, 2003.

| Physical or Physiological Variable | Mean | SE | Minimum | Maximum | 95% CI |
|---|---|---|---|---|---|
| Age (yr) | 42.6 | 2.6 | 20.2 | 64.9 | 37.3–47.8 |
| BM (kg) | 73.7 | 1.7 | 52.0 | 104.8 | 70.3–77.1 |
| *S* (cm) | 172.4 | 1.1 | 155.8 | 192.7 | 170.2–174.6 |
| BMI (kg·m$^{-2}$) | 24.8 | 0.5 | 18.3 | 35.0 | 23.8–25.8 |
| Percent body fat (%) | 21.0 | 1.0 | 4.1 | 42.9 | 19.0–23.0 |
| Fat-free mass (kg) | 57.6 | 0.9 | 46.6 | 70.9 | 55.8–59.4 |
| Fat mass (kg) | 16.3 | 1.1 | 2.7 | 37.6 | 14.0–18.6 |
| Resting HR (beats·min$^{-1}$) | 63.3 | 1.4 | 42.0 | 106.0 | 60.6–66.6 |
| BMR (kJ·d$^{-1}$) | 5827.8 | 115.8 | 4224.7 | 7934.7 | 5596.8–6058.9 |
| Resting $\dot{V}O_2$ (mL $O_2$·min$^{-1}$) | 216.7 | 4.3 | 157.3 | 317.2 | 208.2–225.3 |
| $MET_m$ (mL $O_2$·kg$^{-1}$·min$^{-1}$) | 2.97 | 0.04 | 2.36 | 3.80 | 2.89–3.04 |

and 15.5%, respectively. A total of 60.5% of women in the high-risk group and 8.1% in the very high–risk group had BMI values within the normal range. However, all men in the WC risk groups were either overweight or obese.

$MET_m$ (mL $O_2$·kg$^{-1}$·min$^{-1}$) was 2.85 ± 0.03 for women and 2.97 ± 0.04 for men. Both values were significantly lower (−18.6% and −15.1%, respectively) than the arbitrary convention of a MET value of 3.5 mL $O_2$·kg$^{-1}$·min$^{-1}$. Resting $\dot{V}O_2$ was inversely associated with age in men ($R^2$ = 0.16, SEE = 26.3 mL·min$^{-1}$) but not in women ($R^2$ = 0.02, SEE = 20.8 mL·min$^{-1}$). Adding BM improved the prediction of resting $\dot{V}O_2$ (mL·min$^{-1}$) in both women [87.836 − 0.31319 age (yr) + 1.62678BM (kg); $R^2$ = 0.68, SEE = 12.1 mL·min$^{-1}$] and men [109.807 − 0.660age (yr) + 1.8314BM (kg); $R^2$ = 0.79, SEE = 13.1 mL·min$^{-1}$]. The addition of resting HR to the model, an often used estimate to reflect cardiorespiratory fitness, did not improve the prediction substantially ($R^2$ = 0.69, SEE = 11.8 mL·min$^{-1}$ and $R^2$ = 0.80, SEE = 13.0 mL·min$^{-1}$ for women and men, respectively).

Mean values of $\dot{V}O_2$, HR, $\%HR_{res}$, and EE expressed as multiples of $MET_m$ and $MET_e$ increased as the intensity of walking increased (Tables 3 and 4). Measured EE for each walking intensity expressed as $MET_m$ was higher than $MET_e$ by almost 14%–20%. Neither the women nor the men would be likely to expend 837 kJ in 30 min of walking on level ground. This would occur for women only at the highest speed (1.56 m·s$^{-1}$) and grade (10%), whereas for men, this would occur only at grades at or exceeding 5% for the same speed. It is also worth noting that only 19% of the women were able to reach the last stage of walking, whereas more men (80.9%) were able to complete the last walking stage. This finding is reinforced by the age of the women who completed each stage, which decreased with increasing intensity (61.9 ± 4.8 yr for stage 2 to 32.7 ± 3.0 yr at stage 6). The average age of men who completed stage 6 was 41.9 ± 3.2 yr.

For both women and men, the multiple of $MET_e$ was practically constant for all walking intensities with increasing age groups for both women (Fig. 1A) and men (Fig. 1B). Indeed, when EE was expressed as multiples of $MET_m$ to reflect absolute walking intensity, the fifth stage of the walking test (1.56 m·s$^{-1}$ and a grade of 7.5%) was above the upper limit of moderate intensity (e.g., 6 METs) for both women and men. Of note, none of the stages of the walking test was classified as light intensity (e.g., <3 METs). In contrast, using $\%HR_{res}$ to reflect relative walking intensity showed increases with increasing age (Fig. 2) and revealed that, for women only, level walking at 1.56 m·s$^{-1}$ would fit in the moderate range of 45%–59% defined in the Surgeon General's Report (31). For men, at the same walking speed, grades of between 2.5% and 5% would be considered moderate.

## DISCUSSION

Walking is a natural activity for human beings making it a nearly perfect physical activity to be recommended for weight control and improvement in cardiorespiratory fitness of the unimpaired general population (16,23,27). The EE of walking increases directly in relation to speed, intensity, and grade, but it also depends on the physical and demographic characteristics of the population. EE is usually expressed relative to resting metabolic rate or BMR. In the first case,

TABLE 3. Estimated means and SE of physiological responses to walking on a treadmill for adult women (≥20 yr) from Niterói, Rio de Janeiro, Brazil—the PNAFS, 2003.

| | Stages | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Speed (m·s$^{-1}$)/grade (%) | 1.11/0 | 1.56/0 | 1.56/2.5 | 1.56/5.0 | 1.56/7.5 | 1.56/10.0 |
| Percent of participants who completed the stage | 100 | 100 | 97.5 | 79.5 | 46.7 | 19.0 |
| | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** |
| HR (beats·min$^{-1}$) | 110.6 ± 1.4 | 127.6 ± 1.4 | 138.8 ± 1.8 | 147.3 ± 1.8 | 154.6 ± 1.9 | 162.36 ± 1.6 |
| $\dot{V}O_2$ (mL·min$^{-1}$) | 670.4 ± 16.0 | 8796.0 ± 19.1 | 1021.1 ± 23.7 | 1142.26 ± 28.8 | 1293.1 ± 30.0 | 1395.6 ± 37.8 |
| EE (kJ·min$^{-1}$) | 13.5 ± 0.3 | 17.9 ± 0.4 | 21.0 ± 0.5 | 23.6 ± 0.6 | 26.7 ± 0.6 | 28.9 ± 0.8 |
| Time (min) to expend 837 kJ | 64.2 ± 1.4 | 48.1 ± 0.9 | 41.1 ± 0.8 | 36.4 ± 0.8 | 32.0 ± 0.7 | 29.5 ± 0.8 |
| $\%HR_{res}$ [a] | 40.7 ± 1.3 | 56.0 ± 1.5 | 66.0 ± 1.9 | 72.3 ± 1.9 | 77.5 ± 1.6 | 81.7 ± 2.2 |
| Multiple of $MET_m$ [b] | 3.8 ± 0.1 | 5.0 ± 0.1 | 5.8 ± 0.1 | 6.5 ± 0.1 | 7.3 ± 0.1 | 8.2 ± 0.1 |
| Multiple of $MET_e$ [c] | 3.1 ± 0.03 | 4.0 ± 0.04 | 4.7 ± 0.04 | 5.3 ± 0.05 | 6.1 ± 0.06 | 6.9 ± 0.07 |
| PAR [d] | 4.1 ± 0.1 | 5.5 ± 0.1 | 6.4 ± 0.1 | 7.2 ± 0.1 | 8.1 ± 0.1 | 9.0 ± 0.2 |

[a] Percentage of $HR_{res}$ = [(HR − resting HR) / ((206.9 − (0.67age)) − resting HR) × 100].
[b] Multiple of $MET_m$ = $\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$) / $MET_m$.
[c] Multiple of $MET_e$ = $\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$) / 3.5 mL $O_2$·kg$^{-1}$·min$^{-1}$.
[d] PAR = EE (kJ·min$^{-1}$) / BMR (kJ·min$^{-1}$).

TABLE 4. Estimated means and SE of physiological responses to walking on a treadmill for adult women (≥20 yr) from Niterói, Rio de Janeiro, Brazil—the PNAFS, 2003.

| | Stages | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Speed ($m \cdot s^{-1}$)/grade (%) | 1.11/0 | 1.56/0 | 1.56/2.5 | 1.56/5.0 | 1.56/7.5 | 1.56/10.0 |
| Percent of participants who completed the stage | 100 | 100 | 100 | 97.6 | 90.3 | 80.9 |
| | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** |
| HR ($beats \cdot min^{-1}$) | 99.3 ± 1.9 | 110.4 ± 1.8 | 116.5 ± 1.8 | 123.4 ± 2.2 | 131.1 ± 1.7 | 141.0 ± 2.0 |
| $\dot{V}O_2$ ($mL \cdot min^{-1}$) | 818.8 ± 19.5 | 1065.4 ± 25.1 | 1231.4 ± 27.6 | 1386.2 ± 31.2 | 1553.0 ± 30.1 | 1724.6 ± 31.7 |
| EE ($kJ \cdot min^{-1}$) | 16.6 ± 0.4 | 21.5 ± 0.5 | 25.0 ± 0.6 | 28.2 ± 0.7 | 31.8 ± 0.6 | 35.5 ± 0.6 |
| Time (min) to expend 837 kJ | 52.5 ± 1.2 | 40.4 ± 1.0 | 34.6 ± 0.7 | 30.4 ± 0.6 | 27.09 ± 0.5 | 24.0 ± 0.4 |
| $\%HR_{res}$ [a] | 31.9 ± 1.6 | 41.6 ± 1.6 | 47.0 ± 1.6 | 53.2 ± 2.2 | 59.4 ± 1.5 | 68.3 ± 2.0 |
| Multiple of $MET_m$ [b] | 3.8 ± 0.1 | 4.9 ± 0.1 | 5.7 ± 0.1 | 6.4 ± 0.1 | 7.2 ± 0.1 | 8.2 ± 0.1 |
| Multiple of $MET_e$ [c] | 3.2 ± 0.07 | 4.1 ± 0.07 | 4.8 ± 0.06 | 5.4 ±0.06 | 6.2 ± 0.06 | 7.0 ± 0.07 |
| PAR [d] | 4.1 ± 0.1 | 5.3 ± 0.1 | 6.2 ± 0.1 | 7.0 ± 0.1 | 7.9 ± 0.1 | 9.0 ± 0.1 |

[a] Percentage of $HR_{res}$ = [(HR − resting HR) / ((206.9 − (0.67age)) − resting HR) × 100].
[b] Multiple of $MET_m$ = $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) / $MET_m$.
[c] Multiple of $MET_e$ = $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) / 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$.
[d] PAR = EE ($kJ \cdot min^{-1}$) / BMR ($kJ \cdot min^{-1}$).

activity EE is usually expressed as multiples of the conventionally accepted MET value of 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$. However, this MET convention has an origin that remains in controversy (13), and its universal use is now seen as questionable (7,13,21).

We have recently documented the energy cost of walking in a small sample of young college-aged women from Niterói, Rio de Janeiro, Brazil (4). In that study, measured resting $\dot{V}O_2$ (MET) was 3.2 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$. For the broader adult population (20–71 yr) of women of Niterói of the present study, the value was 0.65 $mL \cdot kg^{-1} \cdot min^{-1}$ (−18.9%) lower than the conventionally accepted MET value. In a sample of 671 Swiss subjects (593 women) of a roughly similar age range (18–74 yr), Byrne et al. (7) found the resting MET values to be even lower, being 2.54 and 2.67 $mL \cdot kg^{-1} \cdot min^{-1}$ in women and men, respectively,

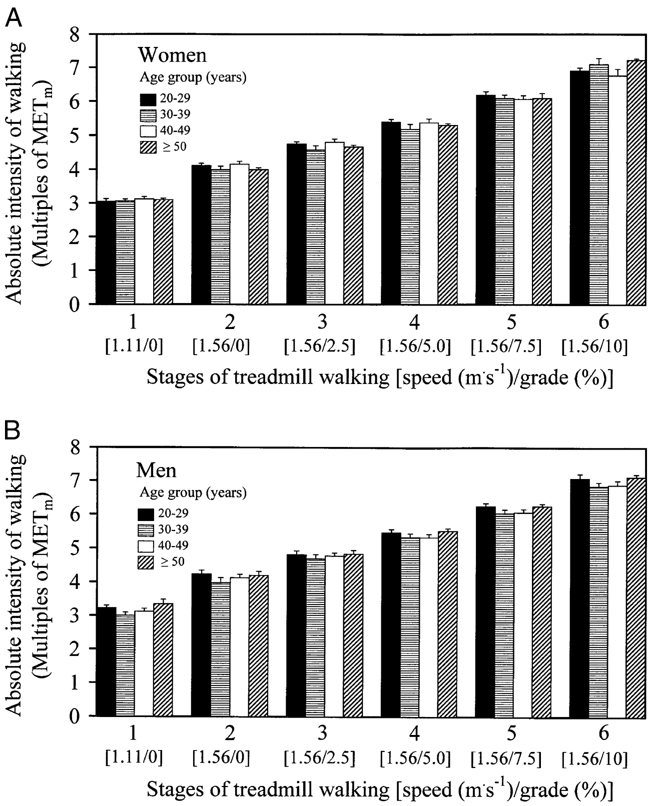


**FIGURE 1—Relationship between absolute intensity of treadmill walking (multiples of $MET_m$) and age for the adult (≥20 yr) female (A) and male (B) population of Niterói, Rio de Janeiro, Brazil—the PNAFS, 2003. The stages of walking (speed ($m \cdot s^{-1}$)/grade (%)) are 1 (1.11/0), 2 (1.56/0), 3 (1.56/2.5), 4 (1.56/5), 5 (1.56/7.5), and 6 (1.56/10).**

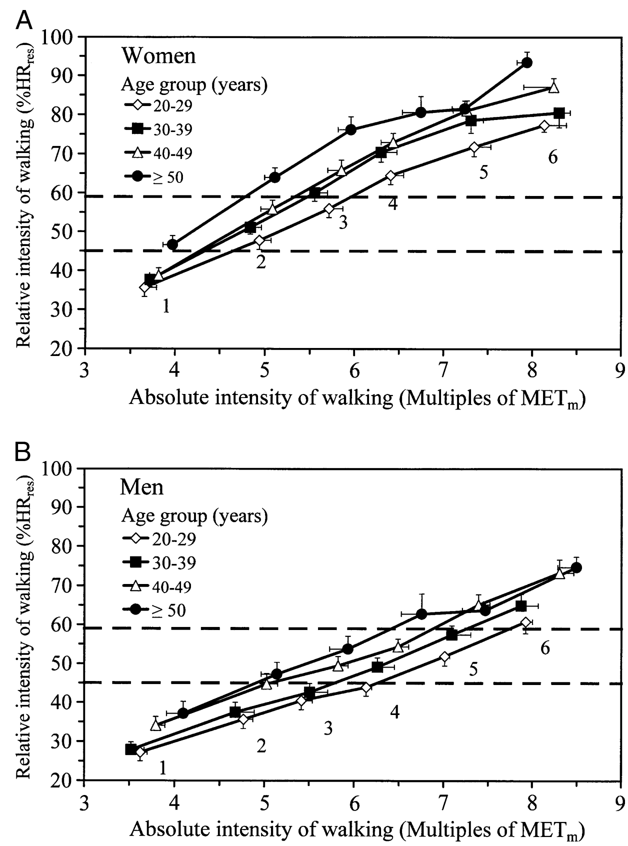


**FIGURE 2—Relationship between relative ($\%HR_{res}$) and absolute (multiples of $MET_m$) intensity of treadmill walking for the adult (≥20 yr) female (A) and male (B) population of Niterói, Rio de Janeiro, Brazil—the PNAFS, 2003. Note that for each line, symbols represent, in order, the six stages of treadmill walking (speed ($m \cdot s^{-1}$)/grade (%)): 1 (1.11/0), 2 (1.56/0), 3 (1.56/2.5), 4 (1.56/5), 5 (1.56/7.5), and 6 (1.56/10). *Horizontal* and *vertical bars* are SE. *Dashed horizontal lines* display moderate relative intensity using $\%HR_{res}$ values of 45% and 59%.**

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and also significantly related to age. Kwan et al. (21) described, in a small sample of Chinese subjects, lower mean MET values in old (≥65 yr) men and women (2.84 and 2.82 mL·kg$^{-1}$·min$^{-1}$, respectively) than in younger (<65 yr) subjects (3.03 and 3.32 mL·kg$^{-1}$·min$^{-1}$, respectively). In a series of measurements in small samples of young adult (14) and older adult Australian men (13) and women (6,39), mean MET values were, on the average, lower in the older subjects. Sergi et al. (29) have recently documented lower values of $MET_m$ in comparison with $MET_e$ in 81 females older than 65 yr. Thus, the results of the present and other studies in the literature confirm that age- and sex-specific values of resting $\dot{V}O_2$ (MET) should be used. To the best of our knowledge, our study represents the first time that MET values were derived from a probability sample anywhere in the world to identify physically able subjects who could safely undergo EE estimates using a treadmill walking protocol. This sampling approach permitted us to develop age- and sex-specific equations to estimate MET values throughout adulthood and may help estimate EE more accurately within the age range studied after more thorough and appropriate validation studies. This seems a desirable prospect given efforts to recommend physical activity to thwart the obesity epidemic.

Because of the difference between $MET_m$ and $MET_e$, EE expressed in terms of multiples of the former is greater by almost 14%–20% than the values presented in tables that use $MET_e$. The difference between EE expressed as multiples of $MET_m$ and $MET_e$ increases as walking intensity increases. This difference is around 0.6 MET units for light walking intensity (1.11 m·s$^{-1}$ and 0% grade) and 1.2 units for more intense walking (1.56 m·s$^{-1}$ and 10% grade). It is interesting to observe that EE of walking expressed as multiples of the resting MET (either measured or estimated) is almost identical in men and women at each stage of walking (difference around 0.1 MET unit and less than roughly 3%). Thus, looking at these results, there would be no rationale for making gender-specific intensity codes when men and women walk at the same speed and grades as was done in the present study. However, when assessing the physiological response to walking, it is crucial to consider age. Although the EE of walking at each intensity when expressed as multiples of MET as absolute intensity did not change appreciably across the age groups, when the relative intensity of walking, expressed as $\%HR_{res}$, was used, there were pronounced increases with increasing age being systematically higher in the oldest age group. This is a critical point, because the percent completing stage 6 was directly associated with the age of the women but not of the men who likely had a higher maximal $\dot{V}O_2$ conducive to performing more physical work (32). Therefore, age becomes an important variable when establishing the intensity of activity for the population. Moreover, with the aging of populations worldwide, our findings have relevance globally.

Gunn et al. (13) found that 55- to 65-yr-old men, when asked to walk at a self-chosen moderate intensity, selected 1.47 m·s$^{-1}$ at a rate of 3.9 METs, being the same speed and EE they found for women of the same age range and nationality (39). In the present study, the energy cost at 1.11-m·s$^{-1}$ speed and 0% grade (approximately 3 METs) agrees with the energy cost values for Americans compiled by Ainsworth et al. (1) in the popular physical activity compendium and used by the ACSM (e.g., 2.9 METs) (2). Unfortunately, it was not possible to perform complete comparisons for the other levels of walking intensities because the speed and grade could not correspond with those of the present study. For example, the Compendium reports a value of 6 METs for walking uphill at 1.56 m·s$^{-1}$, which directly corresponds to our study and grade (e.g., 7.5%) and has similar $MET_e$ for adult women (6.1 METs) and men (6.2 METs) from Niterói. The ACSM tables use the same grades that were used in the present study, but the speed is a little lower (1.52 m·s$^{-1}$). These tabled values were most comparable to the EE of walking expressed as multiples of $MET_m$ only for grades of 7.5% (e.g., around 7.1 METs) and 10% (around 8.3 METs) but were much lower for grades of 0% (3.6 METs), 2.5% (4.8 METs), and 5% (5.9 METs).

The difference in the EE of walking expressed in terms of either $MET_e$ or $MET_m$ is proportionately offset by the difference between the resting $MET_e$ and $MET_m$. Thus, the mean EE of walking found in the present study was similar to the values calculated using the Compendium codes for the same speed and grade. For example, the EE of walking flat at 1.11 m·s$^{-1}$ in women from Niterói was 13.5 kJ·min$^{-1}$ or 405 kJ in 30 min. If calculated using the Compendium codes for the same speed (3.0 METs) and $MET_e$ (3.5 mL $O_2$·kg$^{-1}$·min$^{-1}$), the EE of walking of the women (mean BM = 62.3 kg) would be 13.6 kJ·min$^{-1}$ or 408 kJ in 30 min. In men (mean BM = 73.7 kg), the same calculations would yield EE of 16.2 kJ·min$^{-1}$ or 486 kJ in 30 min for a measured value of 16.7 kJ·min$^{-1}$ or 502 kJ in 30 min. This is also true for the estimation of the EE of walking flat at 1.56 m·s$^{-1}$. Thus, the EE of level walking at these two speeds can be accurately estimated using the MET codes in the Compendium of Physical Activities.

Another way of expressing EE is based on multiples of BMR, named the PAR, which is used by international agencies such as FAO and WHO (11). These PAR values for light, brisk, and uphill walking were much lower than those found for Niteroians as compared with stages 1, 2, and 6. Consistent with the overestimation of resting EE using the conventionally accepted universal value of MET, there is growing evidence that the predictive equations for BMR suggested for international use by FAO and WHO (11) are inadequate for many populations in the world. This has been documented in segments of the Brazilian population living in the country (9,34) and abroad (37). Therefore, PAR values will be, in general, higher when calculated with measured BMR.

With respect to multiples of the conventionally accepted MET, walking intensity for stages 1 through 4 would be considered of moderate absolute intensity activity on the basis of Pate et al. (25) classification of physical activity

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intensity. However, as suggested by the U.S. Department of Health and Human Services (31), a relative moderate physical activity intensity is defined by a $\%HR_{res}$ between 45% and 59% and would occur among Niteroian women only for stage 2, and among men, only at stages 3 and 4. Classifying the intensity using $\%HR_{res}$ helps to understand why only a small percentage of participants were able to achieve the more advanced walking stages, especially women among whom only approximately 45% reached the fifth walking stage. The latter stage would be considered as moderate absolute intensity on the basis of the Pate et al. (25) MET classification. Only 19% of the women but 80.9% of the men completed the sixth walking stage, which is considered of heavy relative intensity for both sexes using the $\%HR_{res}$ classification.

Percentage of $\dot{V}O_{2max}$ is an important measure to compare physiological responses between subjects. The $\%HR_{res}$ is equivalent to $\%\dot{V}O_{2max}$ (31) and is easy to measure. Because multiples of MET at a given speed and grade of walking do not vary according to age, it is important to evaluate the individual physiological demands of walking. Regardless, whether multiples of measured or conventionally accepted MET or $\%HR_{res}$ were used for classifying walking intensity, it was concluded that 30 min of walking in moderate relative intensity for women would not be sufficient to yield the recommended amount of EE linked to a healthy lifestyle. To expend 837 kJ in 30 min, women from Niterói would require heavy-intensity walking (1.56 $m \cdot s^{-1}$ between 7.5% and 10% grade) of which only between 19% and 46.7% of the Niteroians were able to achieve. However, men walking at a moderate absolute intensity of 1.56 $m \cdot s^{-1}$ and 5.0% grade were able to expend 837 kJ in approximately 30 min. Therefore, if improvement of health is proposed, individualized intensity monitoring should be performed in all subjects willing to engage in any physical activity modality to ensure that the physical activity recommendations would be safe for each person.

Despite being a population-based study, an intrinsic strength of the present article, there are some limitations inherent to this type of study. First, there was an overestimation of the total estimates due to the impossibility of correcting the population totals used in the calibration process. However, its effect on means and proportions is negligible. Second, it is well documented that women are more prone to accept health-related research procedures, particularly in household surveys. Thus, more women were assessed than men, but this sample imbalance was compensated by calibrating the results to known population totals by sex and age. In addition, we excluded participants with known cardiac or metabolic diseases or who were under any medication that could alter HR or metabolism. It is likely that such persons would not make it to stages 5 and 6. Nonetheless, most women did not reach this intensity of walking, which may indicate poor cardiorespiratory fitness of the female population of Niterói, a finding that must be confirmed. Because of the historical lack of cardiorespiratory fitness norms for women (20), we were forced to use the age-specific men-only classification of intensity for an activity provided in the Surgeon General's Report (31). The difference in the relationship between absolute and relative intensities of walking found in the present study indicates that it may be wise to establish an appropriate intensity activity classification for women across the age span. Finally, the walking test was conducted in a laboratory setting and not in a real-life field situation. It is possible that the actual energy costs of walking in a real-life setting may yield different estimates than was measured in a controlled environment and should be kept in mind when interpreting our findings.

In conclusion, resting EE expressed by the conventionally accepted MET value (3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) was higher by more than 15% compared with a directly measured MET value for a probability sample of the adult population from Niterói. The associated errors in estimating EE for a common activity like walking, when coupled with the prevailing controversy found from recent empirically derived data worldwide, calls into question the value of using the conventional MET standard. Caution is warranted, especially for women and older individuals, not only when relying on estimated walking EE as a means to counteract the existing worldwide obesity epidemic but also from the potential untoward health consequences of pursuing recommended levels of walking, the relative intensity demands of which may have been seriously miscalculated.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention. L. A. Anjos, M. T. L. Vasconcellos, and V. Wahrlich planned the research. M.T.L. Vasconcellos designed the sample and calculated the natural and calibrated sampling weights. L. A. Anjos, J. M. Machado, and V. Wahrlich supervised the field data collection and were in charge of the data analyses and interpretation with C. J. Caspersen. J. M. Machado wrote the first draft of the article, which was revised and approved by all authors.

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