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Advantage of distance- versus time-based estimates of walking in predicting adiposity

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Abstract

Purpose—Physical activity recommendations are defined in terms of time spent being physically active (e.g., 30 minutes brisk walking, five days a week). However, walking volume may be more naturally assessed by distance than time. Analyses were therefore performed to test whether time or distance provide the best metric for relating walking volume to estimated total and regional adiposity.

Methods—Linear and logistic regression analyses were used to relate exercise dose to body mass index (BMI), body circumferences, and obesity in a cross-sectional sample of 12,384 female and 3,434 male walkers who reported both usual distance walked and time spent walking per week on survey questionnaires. Metabolic equivalent hours per day (METhr/d, 1 MET=3.5 ml O₂•kg⁻¹•min⁻¹) were calculated from the time and pace, or distance and pace, using published compendium values. **Results:** Average METhr/d walked was 37% greater when calculated from time spent walking vs. usual distance in women, and 31% greater in men. Per METhr/d, declines in BMI and circumferences (slope±SE) were nearly twice as great, or greater, for distance- vs. time-derived estimates for kg/m² of BMI (females: -0.58±0.03 vs. -0.31±0.02; males: -0.35±0.04 vs. -0.15±0.02), cm of waist circumference (females: -1.42±0.07 vs. -0.72±0.04; males: -0.96±0.10 vs. -0.45±0.07), and reductions in the odds for total obesity (odds ratio, females: 0.72 vs. 0.84; males: 0.84 vs. 0.92), and abdominal obesity (females: 0.74 vs. 0.85; males: 0.79 vs. 0.91, all comparisons significant).

Conclusion—Distance walked may provide a better metric of walking volume for epidemiologic obesity research, and better public health targets for weight control, than walking duration. Additional research is required to determine whether these results, derived in a sample that regularly walks for exercise, apply more generally.

Keywords

obesity; energy; physical activity; exercise volume; guidelines

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Disclosures

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Introduction

Walking is the most commonly performed moderately intense exercise in the United States [28], is the preferred choice in sedentary individuals who begin exercising [10], and is specifically recommended by physical activity guidelines for both general health and to prevent unhealthy weight gain [9,11,14,15,19,26,31,36]. The health benefits of walking are well documented. We have shown in men and women that both body mass index (BMI) and regional adiposity (circumferences of the waist, hip, and chest) decrease in a dose-dependent manner with distance walked [33,34]. Others have also shown their inverse relationship when walking is measured from duration (time) and intensity on survey questionnaires [12,13,29].

The energy expended by walking and other physical activities is often expressed as metabolic equivalents (METs), which represent their X-fold increase in energy expenditure relative to sitting at rest ($1 \text{ MET} = 3.5 \text{ ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) [1]. Walking is a moderately intense physical activity, meaning that it expends between 3 and 6-fold the energy expenditure of sitting at rest [21]. Activities requiring greater energy expenditure are classified as vigorous, whereas those requiring less are classified as light [21]. Public health guidelines for physical activity are framed in terms of MET*minutes/week of physical activities, which is the sum total of the average minutes per week spent on each activity times its MET value [1]. The National Institutes of Medicine recommend 45 to 60 minutes per day of moderate to vigorous physical activity to prevent transition to overweight or obesity, and 60–90 min of moderate-intensity physical activity per day to prevent weight gain after substantial weight loss [15]. These recommendations have been endorsed by the American Heart Association (AHA) and the American College of Sports Medicine (ACSM) public health recommendations [14,19], the 2008 Physical Activity Guidelines for Americans [31], and the World Health Organization [36].

Defining the public health guidelines in terms of activity duration (time) provides a simple algorithm for calculating energy expenditure that is applicable to a variety of different physical activities [1,14,31]. However, objective measurement of physical activity shows that people overestimate their physical activity when based on duration and intensity [8,16], suggesting a need for better self-assessment. Many studies suggest that a 10,000-steps per day target yields larger increases in physical activity than a 30 minute per day target for walking [4], particularly when used in conjunction with a pedometer. This may be only partially the result of the feedback provided by the pedometer; it may also reflect the difficulty in using a time-based metric for implementing the guidelines. Whatever the reason, it is unrealistic to expect the majority of the population will obtain and wear pedometers, hence the desirability of identifying an alternative metric for walking for self-assessment and epidemiologic research that is assessed more accurately, and does not require additional equipment.

The purpose of this paper is to compare the distance-based calculation of MET*hours per day of walking (MET*hr/d) to its traditional time-based calculation, in terms of its associations with clinically relevant weight variables: BMI, body circumferences, non-healthy weight ($\text{BMI} > 25 \text{ kg/m}^2$), and total and abdominal obesity. Specifically, we hypothesize that estimates of the exercise dose from reported distance walked per week will show stronger associations with total and regional adiposity than its traditional estimation from time. If true, then this would suggest that distance walked may provide a better research metric for epidemiologic research on obesity, and better public health targets for weight control, than walking duration. This could also mean that a simple reformulation of public health recommendations could substantially improve their efficacy.

A second purpose of this paper is to test the exchangeability premise of the physical activity recommendations, i.e., whether different physical activities may be exchanged to meet guideline activity levels so long as they produce the same total MET*hours [1,14,21]. It is not known whether substitution of equivalent METhr/d of other activities for walking produces the same health benefits as walking. To this end, the associations METhr/d with BMI and body circumferences are compared for walking versus all other non-walking exercise, and walking versus non-walking moderate exercise, and walking versus vigorous exercise, to assess their equivalence.

Methods

The sample used in these cross-sectional analyses was obtained as part of a partial re-survey of the National Walkers' Health Study [33,34] in 2006. The goal of the resurvey was to provide a base population of approximately 50,000 runners and walkers for a future clinical trial, rather than obtaining a high response rate for a more manageable sample size. The 12,384 women and 3,434 men included in the current analyses represent the subset of the 50,000 subjects recruited from the National Walkers' and Runners Health Studies. The participants completed a four page survey on walking history (average weekly mileage over the preceding 5 years, minutes required to walk a mile, frequency of walks per week >10 min, longest usual walk), height, current weight and circumferences of the chest, waist, and hips, diet (vegetarianism and the current weekly intakes of alcohol, red meat, fish, fruit), current and past cigarette use, and history of diseases. Intakes of meat, fish and fruit were based on the questions "During an average week, how many servings of beef, lamb, or pork do you eat", "...serving of fish do you eat", and "...pieces of fruit do you eat". Alcohol intake was estimated from the corresponding questions for 4-oz (112 mL) glasses of wine, 12-oz (336 mL) bottles of beer, and mixed drinks and liqueurs. Alcohol was computed as 10.8 g/4-oz glass of wine, 13.2 g/12-oz bottle of beer, and 15.1 g/mixed drink. Education was solicited by requesting the participant provide "years of education (examples: HS=12; BS or BA = 16; MS or MA = 18; PhD or MD = 20)." The study protocol was reviewed by the University of California Berkeley committee for the protection of human subjects, and all subjects provided a signed statement of informed consent.

Height and weight were determined by asking the participant, "What is your current height (in inches, without shoes)?" and, "What is your current weight (pre-pregnancy weight if pregnant)?" BMI was calculated as weight in kilograms divided by the square of height in meters. Self-reported waist, hip, and chest circumferences were elicited by the question, "Please provide, to the best of your ability, your body circumference in inches: waist____, hip____, and chest____," without further instruction. Elsewhere, we have reported the strong correlations between self-reported and clinically measured heights ($r=0.96$) and weights ($r=0.96$) [32]. Self-reported waist and hip circumferences are somewhat less precise, as indicated by their correlations with reported circumferences on a second questionnaire ($r=0.84$ and $r=0.79$, respectively) and with their clinical measurements ($r=0.68$ and $r=0.63$, respectively) [32]. Body mass index (BMI) between 18.5 and 24.9 kg/m² was classified as healthy weight, between 25.0 and 29.9 kg/m² as overweight, and 30 kg/m² and above as obese [7]. Waist circumferences 102 cm in men and 88 cm in women were classified as abdominally obese [7].

Walking distance during the current survey year was reported in miles walked per week, which was converted to kilometers per day. In addition, the questionnaires asked "On average, how many hours per week do you spend running ____, walking ____, swimming ____, cycling ____, other exercise (describe in detail) ____.", and "During your usual walk, how many minutes does it take to walk one mile?"

Time based calculations of METhr/d of total, vigorous, moderate, and light exercise were calculated as the product of the average number hours per day spent on each activity and the estimated energy expenditure for the activity as listed in the 2000 compendium of physical activities [1]. The compendium gives the MET for walking on a firm flat surface as 2.5 METs at 2.0 mph (slow pace), 3.0 METs at 2.5 mph, 3.3 METs at 3.0 mph (moderate pace), 3.8 METs at 3.5 mph (brisk pace), 5 METs at 4 mph (very brisk pace), and 6.3 METs at 4.5 mph (very, very brisk pace). Time-based calculation of METhr/d walked was the product of the average hours walked per day and the MET value corresponding to their reported pace. Distance-based calculation of METhr/d walked was computed by converting the reported distance into duration (i.e., distance/mph) and then calculating the product of the average hours walked per day and the MET value corresponding to their reported pace. The 8.7% of men and 8% of women who did not provide their usual walking pace had their values estimated by stochastic imputation using a sex-specific function of age. Simply excluding these subjects produced only a one percent change in the regression coefficient, showing that the imputation of missing values had a negligible impact on the analyses. The analyses were also repeated assigning the same walking pace (18.3 min/mi) for all subjects, again with negligible impact on the analyses (not displayed).

Statistical analyses

Statistical analyses were performed using JMP (SAS institute, Cary NC, version 5.1) and Stata (StataCorp LP, College Station TX, version 11). Table 1 presents means $\pm$ SD for all variables assessed; all other statistics are expressed as mean $\pm$ SE or coefficients $\pm$ SE. Least-squares regression was used to estimate the relationships of BMI and body circumferences to METhr/d of walking and other exercise. Logistic regression analyses were used to compute the odds for unhealthy weight (BMI $>$ 25 kg/m²), obesity, and abdominal obesity per METhr/d. Covariates included adjustments for age (age and age²), education, current smoking status, and intakes of meat, fruit, and alcohol. Linear contrasts were used to compare regression coefficients for BMI and body circumferences (JMP) and unhealthy weight, obesity, and abdominal obesity (Stata). As these data are observational and cross-sectional, they cannot prove causality. The use of the terminology “increasing METhr/d” in reference to the independent variable and “decreasing BMI or body circumferences” in reference to the dependent variables pertain only to their mathematical functional relationship and is not intended to imply a causal one.

Two different tests were used to assess whether the distance-based calculation of METhr/d of walking (Walking_{Distance}) differed from its traditional time-based calculation (Walking_{Time}) in their effect on BMI and body circumferences. Both use a model that simultaneously includes separate regression terms for each calculation of METhr/d for walking:

$$\text{outcome} = \text{intercept} + \alpha \text{Walking}_{\text{Distance}} + \beta \text{Walking}_{\text{Time}} + \text{other activities and covariates.}$$

1) The standard test of significance for whether adding the distance-based estimate significantly improves the model over one that includes only the time-based estimate (i.e., $\alpha=0$), and correspondingly, whether adding the time-based estimate significantly improves the model over one that includes only the distance-based estimate (i.e., $\beta=0$). 2) Direct comparison of the equivalence of the coefficients of the distance-based and time-based estimate via linear contrasts (i.e., $\alpha = \beta$).

Similarly, two different tests were used to assess the exchangeability premise, i.e., whether METhr/d from walking differs from those of other exercise:

$$\text{outcome} = \text{intercept} + \alpha \text{Walking} + \beta \text{Other exercise} + \text{covariates}.$$

1) the significance of $\alpha = 0$ and $\beta = 0$, and 2) significance of $\alpha = \beta$.

Results

Table 1 shows, on average, that the women were eight years younger than the men, consumed less meat and alcohol, but were otherwise similar to the men. The women walked an average of 2.67 km/d in 0.63 hours, men an average of 2.88 km/d in 0.66 hours. Estimated METhr/d of walking activity was 37% greater when calculated from time (hours) vis-à-vis from distance in women, and 31% greater in men. The time-based and distance-based estimates were correlated $r=0.50$ in women and $r=0.52$ in men. Based on reported distance walked, 8.6% of women and 6.9% of men walked 0 METhr/d (i.e., nonwalkers), 52.9% of women and 51.7% of men walked 0.1 to 2.0 METhr/d, 28.1% of women and 28.8% of men walked 2.1 to 4.0 METhr/d, 7.3% of women and 9.0% of men walked 4.1 to 6.0 METhr/d, and 3.2% of women and 3.6% of men walked >6 METhr/d.

BMI and body circumferences

Table 2 presented the coefficients (slopes) from linear regression analyses when METhr/d from walking and non-walking exercise are used to predict BMI and body circumferences. METhr/d from walking was calculated either from self-reported time (Walking_{Time}) or self-reported distance (Walking_{Distance}). For example when calculated from distance, women's BMI declined (slope $\pm$ SE) 0.58 ± 0.03 kg/m² per METhr/d walked when adjusted for non-walking exercise, and declined 0.11 ± 0.01 kg/m² per METhr/d from non-walking exercise when adjusted for walking. The independent contributions of walking and non-walking exercise were each statistically significant. The significance of the difference (i.e., walking vs. non-walking exercise) tests whether the decline in BMI per METhr/d was the same for walking as for other exercise, as postulated by the exchangeability premise. It shows that the decline was significantly greater per METhr/d for walking than non-walking exercise. The analyses were then repeated with non-walking exercise divided into vigorous, other moderate, and light intensity exercise. It also shows that women's BMI declined 0.58 ± 0.03 kg/m² per METhr/d walked when adjusted for the separate effects of vigorous, other moderate, and light intensity exercise, and that vigorous, non-walking moderate and light intensity exercise contributed independently to declining BMI values. Moreover the decline in BMI per METhr/d was significantly greater for walking than for non-walking moderate exercise, in apparent violation of the exchangeability premise. Similar results were observed for women's waist and hip circumferences.

The analyses were then repeated for METhr/d as estimated from the women's reported hours walked per week (Walking_{Time}). The independent effects of both walking and non-walking exercise on BMI continued to be significant. However, the table shows that the decreases in BMI and body circumferences per METhr/d walked were substantially weaker when estimated from time. For example, women's BMI declined (slope $\pm$ SE) 0.58 ± 0.03 kg/m² per METhr/d when calculated from reported distance walked but only 0.32 ± 0.02 kg/m² per METhr/d for its traditional calculation from reported time walked, nearly a 2-fold difference. There was also nearly 2-fold difference for waist and hip circumference. The differences between the effects of walking and non-walking exercise were substantially reduced, albeit still strongly significant, when METhr/d was estimated from reported hours walked per week than reported distance walked per week. This suggests that some of the apparent violation of the exchangeability premise observed for the distance-based

calculation of METhr/d walked was due to different metrics being used, i.e., to METhr/d being estimated from distance for walking and from duration for non-walking exercise.

Similar results were observed for the men, except that the calculated effects of walking on BMI and body circumferences were between 50% and 120% larger for women than for men. In contrast, the effects of non-walking exercise on BMI and body circumferences were similar for the two sexes. This produced smaller differences in the regression slopes for walking vs. other exercise in men than women.

Table 3 displays the multiple linear regression analyses when Walking_{Distance} and Walking_{Time} were included in the same model, which allows for a formal test of their equivalent relationships to BMI and body circumferences. The results for both women and men show that Walking_{Distance} was strongly associated with reductions in BMI and body circumferences when adjusted for Walking_{Time}, whereas Walking_{Time} had a weaker effect when adjusted for Walking_{Distance}. Moreover, for all variables and for both sexes, the effect per METhours per day of walking were significantly greater when calculated from self-reported distance than self-reported time.

Unhealthy weight, total obesity, and abdominal obesity

Table 4 presents the logistic regression analyses for the clinically relevant endpoints of unhealthy weight (BMI ≥ 25 kg/m²), obesity, and abdominal obesity. The analyses show strongly significant associations between Walking_{Distance} and lower odds per METhr/d for non-healthy weight and total and abdominal obesity. The odds reductions per METhr/d were significantly greater for walking than for: 1) all non-walking exercise; and 2) most non-walking moderate intensity exercise. However, in men these differences can largely be attributed to the superiority of the distance-based estimation over the time-based estimation of METhr/d walked. Compared to Walking_{Time}, Walking_{Distance} in women was associated with 1.7-fold greater reductions in the odds for unhealthy weight, obesity, and abdominal obesity. The corresponding values in men were 2.2-fold for unhealthy weight, 2-fold for obesity, and 2.3-fold for abdominal obesity. The differences in the apparent effect of walking versus non-walking exercise on BMI and body circumferences were eliminated (men) or reduced (women) for METhr/d from Walking_{Time} rather than Walking_{Distance}. Table 5, which directly compares the relationships of obesity status to METhours per day of walking (independent variables) as estimated from reported distance (Walking_{Distance}) and reported time (Walking_{Time}), shows that the reduction in the odds per METhours per day walked was significantly (P-values) and substantially (confidence intervals) greater when calculated from reported distance than reported time.

Discussion

The current analyses address a fundamental question for epidemiological research and public health promotion of physical activity: on a practical level, whether distance walked provides a better self-assessment of the volume of activity performed than time spent walking. More precisely, which metric, time or distance, provides the strongest association with walking's anticipated health outcomes. Tables 2–5 suggest that walking has a much stronger relationship to excess body weight when described in terms of usual distance walked than when described by duration (time) as currently recommended. Moreover, the analyses suggest that time-based estimates may overestimate a person's exercise dose by 31% to 37% for walking, relative to the distance-based estimates. This estimate would appear to correspond well to the 44% greater energy expenditure calculated for time-based questionnaires than from activity monitors [24]. In contrast, reported walking distance appears to slightly underestimate pedometer estimates of distance walked [2].

The recommended activity doses for maintaining body weight are objectively based on physical activity estimates from doubly labeled water [9,11,15,26]. Presumably, body weight will show the strongest association with the calculation that is closest to the objective measurement, which would be the distance-derived calculations. This suggests that subjects who meet the guideline activity levels by the time-derived estimate may actually fall short of the required dose by 24%. Because walking is the most common exercise in the United States [28], a simple improvement in its prescriptions could substantially improve efforts to reduce unhealthy weight through physical activity promotion. The current analyses suggest that this could be achieved by a simple reformulation of the guidelines to specify walking targets by distance (e.g., 1.75 miles) rather than time (30 min).

Imprecision and bias in self-reported physical activity are well documented, with objective measurements showing people overestimate their physical activity. The National Health and Nutrition Examination Survey (NHANES) reported that only 0.2% of women and 0.4% of men met current guidelines as objectively measured by accelerometry [16] compared to 42% as assessed by time by intensity based calculations from self-reported questionnaire data [27]. Whereas objectively measured physical activity showed significant associations with cardiovascular disease risk factors [16], the time-by-intensity based calculations did not [24]. The Canadian Health Measures Survey reported that only 15% of Canadian adults (17% of men, 14% of women) engaged in 150 minutes or more per week of at least moderately vigorous physical activity in bouts of 10 minutes or longer when objectively measured [8], which is considerably less than the estimated 65% of Canadian adults who met the guidelines for physical activity in 2007 from self-reported time and intensity [5]. Doubly labeled water, among the best objective measures of physical activity, is reported to have a correlation of $r=0.2$ with time-by-intensity physical activity estimates from questionnaires [18], which is substantially less than its correlations of $r=0.5$ and $r=0.6$ with energy expenditure from activity monitors [3,22]. Given the impracticality of distributing pedometers to the population, our results suggest that substantial improvements might also be achieved by simply switching walking recommendations from a self-assessed time-based metric to a distance-based metric.

The physical activity recommendations are probably defined in terms of time (e.g. 30 minutes of moderate-intensity physical activity) rather than walking distance because time is the metric used by almost all epidemiological research questionnaires (Baecke Questionnaire of Habitual Physical Activity; Modified Baecke Questionnaire and for Older Adults; Bouchard Three-Day Physical Activity Record; CARDIA Physical Activity History; Framingham Physical Activity Index; Historical Leisure Activity Questionnaire; the Kuopio Ischemic Heart Disease Study 12-month, 24-hour and occupational questionnaires; Minnesota Leisure-Time Physical Activity Questionnaire; Modifiable Activity Questionnaires; Seven-Day Physical Activity Recall; Tecumseh Occupational Physical Activity Questionnaire; Physical Activity Scale for the Elderly; Yale Physical Activity Survey; Zutphen Physical Activity Questionnaire; Canada Fitness Survey; MONICA Optional Study of Physical Activity; National Children and Youth Fitness Studies; National Health Interview Survey; Youth Risk Behavior Survey). A few questionnaires assess frequency (National Health and Nutrition Examination Survey, Godin Leisure-Time Exercise Questionnaire) [23]. Several have, in fact, recorded distance. The Kuopio Ischemic Heart Disease Study 7-day physical activity recall and the Behavioral Risk Factor Surveillance System collected both time and distance but use walking duration to estimate energy expenditure [23]. Other questionnaires that recorded walking distance include the Aerobics Center Longitudinal Study Physical Activity Questionnaire, the Paffenbarger Physical Activity Questionnaire, and the HIP questionnaire (occupational activity, frequency for non- occupational walking) [23].

We are unaware of any prior analyses from epidemiological studies that compare walking distance vs. walking duration with respect to their association with health outcomes. The fact that various epidemiological studies show that higher METmin/d of physical activity is associated with lower body weight and other health benefits does not necessarily validate time-based calculations of energy expenditure [12,13,29]. Tables 2 and 4 show significant associations between walking and BMI and body circumferences when the time-based calculations are used, however, much stronger associations were observed for the distance-based calculations than for the time-based calculations.

Alternative exercise metrics to the 30 minutes per day have been proposed for encouraging physical activity. For example, step counts may be monitored using pedometers [4,30]. Ten-thousand steps per day is estimated to represent an increase of 30 minutes per day of walking (3500 steps) above the 5000 to 7499 steps characteristic of low activity individuals [20]. Meta-analyses of observational and clinical trial data show that pedometer use may significantly increase the number of steps walked per day [4].

A key premise of all the recommendations cited above is the “exchangeability premise”, i.e., that various physical activities can be combined to meet recommendations based on their calculated energy expenditures [14]. Tables 2 and 4 show there are substantial differences in the associations of body weight and circumferences to METhr/d walked vs. METhr/d from non-walking exercise, including other moderately intense activities, when walking volume is estimated by distance. However, the differences are reduced when walking volume is estimated from time. The latter is probably the more appropriate comparison because our questionnaire, like most others, record non-walking activities as reported duration. Our results suggest that the body weight benefits associated with walking are roughly comparable to other moderately intense exercises when both are estimated from the duration of the activity in men, but much less so in women.

Caveats

An inherent limitation of cross-sectional analyses is the uncertainty of whether physical activity preceded body weight or whether the converse occurred. Recommended doses of physical activity for maintaining healthy weight were, in fact, themselves derived primarily from cross-sectional data of BMI and energy expenditure from doubly labeled water [9,11,15,26]. Moreover, prospective data from the Nurses Health Study II show that follow-up physical activity, rather than baseline activity, was the strongest predictor of weight gain during follow-up [17]. The current analyses examines, within individuals, the differences of two different metrics for quantifying the volume of walking performed, and their relationship to body weight. Presumably any tendency for heavier walkers to exercise less would affect both metrics, as well as other exercise. Habitual walkers may also recall their preferred exercise (e.g., walking) better than recall of physical activity in general among non-habitual exercisers, which may also limit generalization. Recognized biases in self-reported physical activity include over-reporting (social desirability bias) and inherent difficulties in assessing intensity [25,35]. Subjects are reported to significantly overestimate the duration of more strenuous physical activities (> 4.5METs) and to underestimate less strenuous activities (2.5 to 4.4 METs) with increasing percent body fat [6]. However, the same intensity factors were used for both the time-based and distance-based calculations of METhr/d walked, so this should not affect their comparison. It is not known whether adiposity-related bias may differ for the self-reporting of distance and time walked.

In addition, the generalizability of the results may be affected by the initial recruitment of walkers through footrace events and subscription lists to walking oriented publications. This is likely to have produced a more health conscious and active sample than the population at large. This strategy was pursued in order to target higher doses of walking than represented

in other population studies. However it is likely that the biological processes that relate walking to body weight would not differ dramatically between this sample and a less selected population, and the same bias would apply to all participants. Nevertheless, it is not known whether the same results would have been obtained in a sample unaccustomed to regular walking. The low smoking rates and relatively high educational attainment both suggest a more health conscious and educated sample than the general population. Finally, detailed dietary data and sedentary behaviors such as sitting, sleep, and other variables that could have affected body weight were not collected [17], however, adjustment for dietary data were not found to affect the physical activity-weight relationships in the Nurses Health Study II [17], and there is no reason to expect that our failure to adjust for these other variables would differentially affect distance- vs. time based calculations of METhr/d.

Conclusions

The analyses show that the calculation of walking energy expenditures from reported distance is more strongly related to body weight and obesity than the traditional time-based calculation. Presumably, the weakness of the time-based estimates is not necessarily restricted to walking. The results suggest that distance walked may provide a better research metric for epidemiologic research, and better public health targets for weight control, than walking duration.

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Table 1Sample characteristics ($\pm$ SD).

	Female	Male
Sample (N)	12,384	3,434
Age (years)	59 $\pm$ 12	67 $\pm$ 11
Education (years)	15.3 $\pm$ 2.6	16.3 $\pm$ 2.8
Smokers (%)	2.9	2.9
Meat (servings/day)	0.4 $\pm$ 0.4	0.5 $\pm$ 0.5
Fruit (pieces/day)	1.6 $\pm$ 1.3	1.6 $\pm$ 2.2
Alcohol (g/day)	5.2 $\pm$ 10.6	9.1 $\pm$ 13.7
BMI (kg/m ²)	26.1 $\pm$ 5.6	27.0 $\pm$ 4.7
Circumferences (cm)		
Waist	81.2 $\pm$ 12.7	94.1 $\pm$ 11.0
Hip	101.4 $\pm$ 11.7	
Non-healthy weight (%)	48%	64%
Obese (%)	19.%	20%
Abdominal obesity (%)	27%	16.%
Walking		
Distance (Km/d)	2.7 $\pm$ 2.3	2.9 $\pm$ 2.4
Duration (hours)	0.6 $\pm$ 0.6	0.7 $\pm$ 0.7
Walking _{Distance} (METhr/d from self- reported distance)	2.0 $\pm$ 1.9	2.1 $\pm$ 1.9
% of total METs	60 $\pm$ 36	64 $\pm$ 36
Walking _{Time} (METhr/d from self- reported duration)	2.7 $\pm$ 2.9	2.8 $\pm$ 2.9
% of total METs	62 $\pm$ 36	64 $\pm$ 36
Non-walking exercise METhr/d		
Total	2.4 $\pm$ 3.7	2.5 $\pm$ 4.3
Vigorous intensity	1.6 $\pm$ 3.2	1.6 $\pm$ 3.5
Other moderate intensity	0.7 $\pm$ 1.8	0.8 $\pm$ 2.2
Light intensity	0.09 $\pm$ 0.45	0.08 $\pm$ 0.71

Abbreviations: BMI, body mass index; MET, metabolic equivalents of energy expenditure; Walking_{Distance}, metabolic equivalent hr/d from walking as estimated from self-reported distance, Walking_{Time}, metabolic equivalent hr/d from walking as estimated from self-reported duration.

Table 2

Cross-sectional regression slopes ($\pm$ SE) of BMI and body circumference measurements versus METhours per day of walking and other physical activities to the test of the exchangeability premise.

Estimation method:	BMI (kg/m ²)		Waist circumference (cm)		Hip circumference (cm)	
	Distance	Time	Distance	Time	Distance	Time
Females						
Model 1						
Walking coefficient	-0.58 $\pm$ 0.03 [¶]	-0.31 $\pm$ 0.02 [¶]	-1.42 $\pm$ 0.07 [¶]	-0.72 $\pm$ 0.04 [¶]	-1.19 $\pm$ 0.06 [¶]	-0.62 $\pm$ 0.04 [¶]
Nonwalking exercise coefficient	-0.11 $\pm$ 0.01 [¶]	-0.13 $\pm$ 0.01 [¶]	-0.25 $\pm$ 0.03 [§]	-0.30 $\pm$ 0.03 [¶]	-0.26 $\pm$ 0.03 [¶]	-0.30 $\pm$ 0.03 [¶]
Walking-nonwalking difference (95% confidence interval)	-0.47 [¶] (-0.53, -0.41)	-0.19 [¶] (-0.23, -0.14)	-1.16 [¶] (-1.31, -1.02)	-0.42 [¶] (-0.52, -0.31)	-0.93 [¶] (-1.07, -0.79)	-0.32 (-0.42, -0.23)
Model 2						
Walking coefficient	-0.58 $\pm$ 0.03 [¶]	-0.32 $\pm$ 0.02 [¶]	-1.42 $\pm$ 0.07 [¶]	-0.72 $\pm$ 0.04 [¶]	-1.19 $\pm$ 0.06 [¶]	-0.63 $\pm$ 0.04 [¶]
Vigorous exercise coefficient	-0.12 $\pm$ 0.01 [§]	-0.14 $\pm$ 0.02 [¶]	-0.26 $\pm$ 0.04 [§]	-0.32 $\pm$ 0.04 [¶]	-0.29 $\pm$ 0.03 [¶]	-0.33 $\pm$ 0.03 [¶]
Nonwalking moderate exercise coefficient	-0.07 $\pm$ 0.03 [‡]	-0.07 $\pm$ 0.03 [‡]	-0.18 $\pm$ 0.07 [‡]	-0.19 $\pm$ 0.07 [‡]	-0.14 $\pm$ 0.06 [*]	-0.14 $\pm$ 0.07 [*]
Light exercise coefficient	-0.46 $\pm$ 0.11 [§]	-0.49 $\pm$ 0.11 [§]	-0.75 $\pm$ 0.26 [‡]	-0.80 $\pm$ 0.26 [‡]	-0.64 $\pm$ 0.24 [‡]	-0.68 $\pm$ 0.24 [‡]
Walking-nonwalking moderate exercise difference (95% confidence interval)	-0.51 [¶] (-0.58, -0.43)	-0.24 [§] (-0.31, -0.18)	-1.24 [¶] (-1.43, -1.05)	-0.53 [§] (-0.69, -0.37)	-1.05 [¶] (-1.23, -0.87)	-0.49 [§] (-0.64, -0.34)
Males						
Model 1						
Walking coefficient	-0.35 $\pm$ 0.04 [¶]	-0.15 $\pm$ 0.03 [§]	-0.96 $\pm$ 0.10 [¶]	-0.45 $\pm$ 0.07 [§]		
Nonwalking exercise coefficient	-0.09 $\pm$ 0.02 [§]	-0.09 $\pm$ 0.02 [§]	-0.25 $\pm$ 0.05 [§]	-0.27 $\pm$ 0.05 [§]		
Walking-nonwalking difference (95% confidence interval)	-0.27 [§] (-0.36, -0.18)	-0.05 (-0.12, 0.01)	-0.71 [§] (-0.94, -0.49)	-0.18 [*] (-0.34, -0.02)		
Model 2						
Walking coefficient	-0.35 $\pm$ 0.04 [¶]	-0.14 $\pm$ 0.03 [§]	-0.96 $\pm$ 0.10 [¶]	-0.46 $\pm$ 0.07 [§]		
Vigorous exercise coefficient	-0.10 $\pm$ 0.02 [§]	-0.11 $\pm$ 0.02 [§]	-0.27 $\pm$ 0.06 [§]	-0.30 $\pm$ 0.06 [§]		
Nonwalking moderate exercise coefficient	-0.07 $\pm$ 0.04 [*]	-0.07 $\pm$ 0.04 [*]	-0.21 $\pm$ 0.09 [*]	-0.21 $\pm$ 0.09 [*]		
Light exercise coefficient	0.03 $\pm$ 0.11	0.05 $\pm$ 0.11	-0.21 $\pm$ 0.28	-0.17 $\pm$ 0.28		

Estimation method:	BMI (kg/m ²)		Waist circumference (cm)		Hip circumference (cm)	
	Distance	Time	Distance	Time	Distance	Time
Walking – nonwalking moderate exercise difference (95% confidence interval)	–0.28 [§] (–0.38, –0.17)	–0.07 (–0.16, 0.01)	–0.75 [§] (–1.02, –0.48)	–0.24 [*] (–0.46, –0.02)		

Adjusted for age, education, current smoking status, and intakes of meat, fruit, and alcohol. Significance of the regression coefficients coded

^{*} P<0.05;

[†] P<0.01;

[‡] P<0.001;

[§] P<0.0001;

[¶] P<10^{–15}, in the model:

Dependent variable=intercept+ WalkingDistance+ Non-walking exercise+ covariates, or Dependent variable=intercept+ WalkingTime + Non-walking exercise+ covariates. Abbreviations: BMI, body mass index; MET, metabolic equivalents of energy expenditure;

Table 3

Cross-sectional regression slopes ($\pm$ SE) of BMI and body circumference measurements (dependent variables) versus METhours per day of walking (independent variables) as estimated from reported distance (Walking_{Distance}) and reported time (Walking_{Time}) to test their equivalent effects.

	BMI (kg/m ²)	Waist circum- ference (cm)	Hip circum- ference (cm)
Females			
Regression coefficients (METhr/d)			
Walking _{Distance}	-0.44 $\pm$ 0.03 [¶]	-1.12 $\pm$ 0.08 [¶]	-0.92 $\pm$ 0.07 [¶]
Walking _{Time}	-0.17 $\pm$ 0.02 [¶]	-0.36 $\pm$ 0.05 [§]	-0.34 $\pm$ 0.04 [§]
Non-walking exercise	-0.11 $\pm$ 0.01 [¶]	-0.26 $\pm$ 0.03 [¶]	-0.27 $\pm$ 0.03 [¶]
<i>Difference: Walking_{Distance} - Walking_{Time} (95% confidence interval)</i>	-0.27 [§] (-0.36, -0.19)	-0.76 [§] (-0.98, -0.55)	-0.58 [§] (-0.78, -0.38)
Males			
Regression coefficients (METhr/d)			
Walking _{Distance}	-0.33 $\pm$ 0.05 [§]	-0.82 $\pm$ 0.12 [§]	
Walking _{Time}	0.03 $\pm$ 0.03	-0.17 $\pm$ 0.08 [*]	
Non-walking exercise	-0.09 $\pm$ 0.02 [§]	-0.26 $\pm$ 0.05 [§]	
<i>Difference: Walking_{Distance} - Walking_{Time} (95% confidence interval)</i>	-0.29 [§] (-0.43, -0.16)	-0.66 [‡] (-1.01, -0.31)	

Adjusted for age, education, current smoking status, and intakes of meat, fruit, and alcohol. Significance coded

* P<0.05;

[†] P<0.01;

[‡] P<0.001;

[§] P<0.0001;

[¶] P<10⁻¹⁵ in the model:

Dependent variable=intercept+ Walking_{Distance}.+ Walking_{Time}.+ non-walking exercise+covariates. Abbreviations: BMI, body mass index; MET, metabolic equivalents of energy expenditure.

Table 4

Odds ratio (95% confidence interval) for unhealthy weight (BMI 25 kg/m²), obesity (BMI 30 kg/m²), and abdominal obesity versus METhours per day of walking and other physical activities to the test of the exchangeability premise.

Estimation method:	Unhealthy weight (BMI 25)		Obese (BMI 30)		Abdominal Obesity	
	Distance	Time	Distance	Time	Distance	Time
Females						
Model 1						
Walking odds ratio	0.81 [¶] (0.79, 0.82)	0.89 [¶] (0.88, 0.90)	0.72 [¶] (0.70, 0.75)	0.84 [¶] (0.82, 0.86)	0.74 [¶] (0.72, 0.77)	0.85 [¶] (0.83, 0.87)
Nonwalking exercise odds ratio	0.96 [§] (0.95, 0.97)	0.96 [§] (0.95, 0.97)	0.95 [§] (0.93, 0.96)	0.93 [¶] (0.92, 0.95)	0.96 [§] (0.94, 0.97)	0.95 [§] (0.93, 0.96)
<i>Walking-nonwalking difference, odds ratio (95% confidence interval)</i>	0.84 [¶] (0.81, 0.86)	0.93 [§] (0.92, 0.95)	0.76 [¶] (0.73, 0.80)	0.90 [§] (0.87, 0.92)	0.78 [¶] (0.75, 0.81)	0.90 [¶] (0.88, 0.92)
Model 2						
Walking coefficient	0.80 [¶] (0.79, 0.82)	0.89 [¶] (0.88, 0.90)	0.72 [¶] (0.70, 0.75)	0.84 [¶] (0.82, 0.86)	0.75 [¶] (0.72, 0.77)	0.85 [¶] (0.83, 0.87)
Vigorous exercise odds ratio	0.97 [§] (0.95, 0.98)	0.96 [§] (0.94, 0.97)	0.94 [§] (0.92, 0.96)	0.92 [§] (0.90, 0.94)	0.96 [§] (0.94, 0.97)	0.94 [§] (0.93, 0.96)
Nonwalking moderate exercise odds ratio	0.96 [‡] (0.94, 0.98)	0.96 [‡] (0.94, 0.98)	0.97 (0.94, 1.00)	0.97 [*] (0.94, 1.00)	0.97 [*] (0.94, 1.00)	0.97 [*] (0.94, 0.99)
Light exercise odds ratio	0.85 [‡] (0.78, 0.93)	0.85 [‡] (0.78, 0.93)	0.78 [‡] (0.68, 0.91)	0.78 [‡] (0.67, 0.90)	0.88 [*] (0.78, 0.98)	0.87 [*] (0.78, 0.98)
<i>Walking - nonwalking moderate exercise difference (95% confidence interval)</i>	0.84 [¶] (0.81, 0.86)	0.93 [§] (0.90, 0.95)	0.74 [¶] (0.71, 0.78)	0.86 [§] (0.83, 0.90)	0.77 [¶] (0.73, 0.80)	0.88 [§] (0.85, 0.92)
Males						
Model 1						
Walking odds ratio	0.89 [§] (0.86, 0.93)	0.95 [§] (0.93, 0.97)	0.84 [§] (0.79, 0.89)	0.92 [§] (0.89, 0.95)	0.79 [§] (0.74, 0.85)	0.91 [§] (0.87, 0.95)
Nonwalking exercise odds ratio	0.97 [‡] (0.95, 0.99)	0.97 [‡] (0.95, 0.99)	0.94 [§] (0.91, 0.96)	0.93 [§] (0.90, 0.96)	0.93 [‡] (0.90, 0.97)	0.93 [§] (0.90, 0.96)
<i>Walking-nonwalking difference, odds ratio (95% confidence interval)</i>	0.92 [§] (0.88, 0.96)	0.98 (0.95, 1.01)	0.89 [‡] (0.84, 0.95)	0.99 (0.95, 1.03)	0.85 [§] (0.79, 0.92)	0.98 (0.93, 1.04)
Model 2						
Walking odds ratio	0.90 [§] (0.86, 0.93)	0.95 [§] (0.93, 0.97)	0.84 [§] (0.79, 0.89)	0.92 [§] (0.89, 0.95)	0.80 [§] (0.74, 0.86)	0.91 [§] (0.87, 0.95)
Vigorous exercise odds ratio	0.97 [‡] (0.95, 0.99)	0.96 [‡] (0.94, 0.98)	0.92 [§] (0.89, 0.96)	0.91 [§] (0.88, 0.95)	0.92 [‡] (0.88, 0.97)	0.91 [§] (0.87, 0.96)
Nonwalking moderate exercise odds ratio	0.98 (0.95, 1.01)	0.98 (0.95, 1.01)	0.95 [*] (0.90, 1.00)	0.95 [*] (0.90, 1.00)	0.94 [*] (0.88, 1.00)	0.93 [*] (0.88, 0.99)
Light exercise odds ratio	1.03 (0.92, 1.15)	1.03 (0.92, 1.16)	1.07 (0.96, 1.19)	1.07 (0.97, 1.20)	1.04 (0.93, 1.17)	1.05 (0.93, 1.18)
<i>Walking - nonwalking moderate exercise difference (95% confidence interval)</i>	0.92 [‡] (0.87, 0.96)	0.97 (0.93, 1.01)	0.89 [‡] (0.82, 0.96)	0.97 (0.91, 1.04)	0.85 [‡] (0.77, 0.94)	0.97 (0.90, 1.05)

Adjusted for age, education, current smoking status, and intakes of meat, fruit, and alcohol. Significance of the regression coefficients coded

* P<0.05;

[†] P<0.01;

[‡] P<0.001;

[§] P<0.0001;

[¶] P<10^{−15}, in the model:

Dependent variable=intercept+ WalkingDistance+ Non-walking exercise+ covariates, or Dependent variable=intercept+ WalkingTime + Non-walking exercise+ covariates.

Abbreviations: BMI, body mass index; MET, metabolic equivalents of energy expenditure;

Table 5

Odds ratio (95% confidence interval) for unhealthy weight (BMI>25 kg/m²), obesity, and abdominal obesity (dependent variables) per METhours per day of walking (independent variables) as estimated from reported distance (Walking_{Distance}) and reported time (Walking_{Time}) to test their equivalent effects.

	Unhealthy weight (BMI 25)	Obese (BMI 30)	Abdominal Obesity
Females			
Regression coefficients (METhr/d)			
Walking _{Distance}	0.85 [¶] (0.82, 0.87)	0.78 [¶] (0.75, 0.81)	0.80 [¶] (0.77, 0.83)
Walking _{Time}	0.94 [§] (0.93, 0.96)	0.92 [§] (0.89, 0.94)	0.92 [§] (0.90, 0.95)
Non-walking exercise	0.96 [§] (0.95, 0.97)	0.94 [§] (0.93, 0.96)	0.96 [§] (0.94, 0.97)
<i>Difference: Walking_{Distance} - Walking_{Time}</i>	<i>0.90[§] (0.87, 0.93)</i>	<i>0.85[§] (0.80, 0.91)</i>	<i>0.86[§] (0.82, 0.91)</i>
Males			
Regression coefficients (METhr/d)			
Walking _{Distance}	0.91 [§] (0.87, 0.95)	0.86 [§] (0.80, 0.91)	0.81 [§] (0.74, 0.88)
Walking _{Time}	0.98 (0.95, 1.01)	0.97 (0.93, 1.01)	0.98 (0.93, 1.03)
Non-walking exercise	0.97 [‡] (0.95, 0.99)	0.93 [§] (0.91, 0.96)	0.93 [§] (0.90, 0.97)
<i>Difference: Walking_{Distance} - Walking_{Time}</i>	<i>0.93[‡] (0.87, 0.99)</i>	<i>0.88[‡] (0.80, 0.97)</i>	<i>0.83[‡] (0.73, 0.93)</i>

Adjusted for age, education, current smoking status, and intakes of meat, fruit, and alcohol. Significance coded

* P<0.05;

[‡] P<0.01;

[‡] P<0.001;

[§] P<0.0001;

[¶] P<10⁻¹⁵ in the model:

Dependent variable=intercept+ Walking_{Distance}+ Walking_{Time}+ non-walking exercise+covariates. Abbreviations: BMI, body mass index; MET, metabolic equivalents of energy expenditure.