Comparison of energy expenditure estimates from doubly labeled water, a physical activity questionnaire, and physical activity records1–3

Joan M Conway, James L Seale, David R Jacobs Jr, Melinda L Irwin, and Barbara E Ainsworth

ABSTRACT

Background: Various methods are used by epidemiologists to estimate the energy cost of physical activity; these include physical activity records and recalls. However, there is limited validation of these methods against the doubly labeled water technique for determining energy expenditure (EE).

Objective: We compared EE as estimated by indirect methods (physical activity records and recall questionnaires) used in epidemiologic studies with EE obtained from doubly labeled water (EEDLW) in free-living men.

Design: We determined EEDLW, energy intake at weight maintenance, and EE from 7-d physical activity records (EERec) and a 7-d physical activity recall questionnaire (EERecall) in 24 men aged 41 ± 2.0 yr (x ± SEM) with a body mass index (in kg/m2) of 25.1 ± 0.5.

Results: There was excellent agreement between EEDLW (13.27 ± 0.35 MJ/d) and energy intake (13.19 ± 0.36 MJ/d), with a difference of 0.5 ± 1.0% (x ± SE). The indirect measures of physical activity and EE were 14.17 ± 0.37 MJ/d for EERec (difference from EEDLW: 7.9 ± 3.2%) and 17.40 ± 1.45 MJ/d for EERecall (difference from EEDLW: 30.6 ± 9.9%).

Conclusions: Seven-day physical activity records provide an acceptable estimate of EE in free-living adults compared with EEDLW, but 7-d physical activity recalls have limited application to estimate daily EE. For optimal validity, the 7-d physical activity records require good subject compliance and the provision of careful instructions for their use. Am J Clin Nutr 2002;75:519–25.

KEY WORDS Exercise, energy intake, Stanford 7-d physical activity questionnaire, physical activity records, physical activity recall, doubly labeled water, basal metabolic rate, men

INTRODUCTION

Disease prevention strategies currently include recommendations for both eating a healthy diet and engaging in physical activity (1). Although many methods for assessing physical activity in free-living individuals have been proposed and directly or indirectly validated (2–4), energy expended during physical activity has proven difficult to measure. According to the FAO/WHO/UNU (5), physical activity is considered as including occupational activities, discretionary activities, optional household tasks, socially desirable activities, and activity for physical fitness and the promotion of health. This great variety of activities and the ability of humans to change their activity at will contribute to the difficulty in measuring physical activity in free-living humans.

Before designing and implementing nutrition education and disease prevention strategies, it is important to test the validity of epidemiologic methods that are currently used for estimating energy expenditure (EE), ie, physical activity questionnaires and records (6–9), against a criterion method. Although epidemiologic surveys can provide information about populations, they are conducted with less precision than what is required for metabolic studies of individuals.

Many data show that free-living EE can be measured under laboratory (3, 10–12) and field (13) conditions by use of deuterium- and 18O-labeled water (2H218O). However, few epidemiologic methods for estimating EE from physical activity records and recalls have been cross-validated simultaneously against the doubly labeled water method under well-controlled conditions (14–16). In the present study, we sought to provide independent estimates of EE from 7-d physical activity records (EERec) and a 7-d physical activity recall (EERecall) with use of the Stanford 7-d physical activity questionnaire, measures of energy intake (EI) at weight maintenance, and measures of doubly labeled water (EEDLW). Our null hypothesis was that there would be no significant difference between EE estimated by the 2 previously

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validated physical activity methods, ie, the 7-d physical activity record (17) and recall (7), and EE_{DLW} measurements.

SUBJECTS AND METHODS

Subjects

Twenty-seven men were recruited for participation in this study from a larger ongoing feeding study. One subject dropped out before completing the study and 2 subjects were eliminated because of questionable compliance with the dietary portion of the study. As a result, a total of 24 subjects aged 27–65 y participated in the study. Subjects were originally recruited by advertisement at the Beltsville Agricultural Research Center in Beltsville, MD; at the Goddard Space Flight Center in Greenbelt, MD; and from the laboratory’s computerized database of persons known to be interested in participating in human studies.

The study protocol was approved by the Institutional Review Board at the Johns Hopkins University School of Medicine and by the Human Studies Committee of the US Department of Agriculture’s Agricultural Research Service. Subjects were invited to attend an informational meeting, and those interested in participating in the study provided written informed consent. At the beginning of the original aforementioned feeding study, each potential subject received a medical evaluation by a physician, which included the measurement of blood pressure, height, and weight and analysis of fasting blood and urine samples to screen for the absence of metabolic diseases. The present study was conducted at the US Department of Agriculture/Agricultural Research Service/Beltsville Human Nutrition Research Center in Beltsville, MD.

Experimental design

Each subject was studied over a 2-wk period. On day 1, the doubly labeled water (H\textsubscript{2}^{18}O) was administered to subjects and urine was collected over the next 14 d. Physical activity records were kept during either the first or second week of the H\textsubscript{2}^{18}O protocol and whole-body calorimetry was performed during the opposite week. The 7-d physical activity recalls were administered on day 7 and again on day 14 of the H\textsubscript{2}^{18}O protocol.

Body composition

Weight was measured to the nearest 0.01 kg by use of an electronic balance (August Sauter, Ebgingen, Germany) and height was measured to the nearest 0.1 cm by use of a stadiometer (Holtain Limited, Crymych, United Kingdom). Body mass index (BMI) was defined as weight divided by height squared (kg/m\textsuperscript{2}). Percentage of body fat and lean body mass were determined by dual-energy X-ray absorptiometry (version 1.3, DPXL; Lunar Corporation, Madison, WI). The subjects were asked to not consume anything ≤3 h before dual-energy X-ray absorptiometry, to dress in metal-free clothing, and to remove all jewelry. The components of total body mass, ie, fat, soft tissue (lean body mass), and bone mineral, were used to calculate percentage body fat. Percentage of body fat was determined as follows:

\[
\text{Percentage of fat} = \frac{(\text{fat mass} + \text{lean mass} + \text{bone mineral mass})}{\text{fat mass}} \times 100\% \quad (J)
\]

Body fat mass was calculated from the percentages of fat and body weight.

Diet

The diet administered to subjects contained foods representative of those typically consumed by North Americans and was fed to maintain body weights within ±1 kg. A 7-d rotating menu was used throughout this dietary feeding study. Energy was distributed within the diet as 35% from dietary fat, 15% from protein, and 50% from carbohydrate. Ten of the 21 meals/wk were consumed under the supervision of research dietitians at the Beltsville Human Nutrition Research Center Human Study Facility. Weekend meals and lunches were prepared for takeout.

The individual EI of each subject was calculated from computer analysis of the diets by using the US Department of Agriculture’s Nutrient Database for Standard Reference (18) in addition to using some information provided by food manufacturers. At the time of the EE measurements, subjects had been consuming the diet for >3 mo.

Indirect calorimetry

EE was determined by using a room-sized indirect calorimeter. The 20.39 m\textsuperscript{3} indirect calorimeter system continuously measured respiratory gas exchange to within 1.5% (10–12); the between-run intrindividual variation of the calorimeter was 4.6% (19). The entire calorimetry protocol is described elsewhere (19); briefly, the subjects entered the calorimeter at 1830, exited the next evening at 1800, and were provided with 3 meals and snacks according to the requirements of the ongoing study. While in the calorimeter, the subjects followed a defined activity protocol. EE was determined from the basal metabolic rate (BMR; EE\textsubscript{BMR}) that was measured immediately after subjects woke and over a 1-h period. Subjects were allowed to use the toilet facilities but were then confined to bed for the measurement of EE\textsubscript{BMR} and were monitored for compliance throughout the hour of measurement.

Doubly labeled water

Average EE was determined by using the doubly labeled water method (EE\textsubscript{DLW}). Baseline samples of urine were collected before the isotope dose (H\textsubscript{2}^{18}O: 0.14 g/kg body wt, H\textsubscript{2}^{1}O: 0.70 g/kg body wt) and daily for 14 d. The urine was analyzed for H\textsubscript{2} at an automated infrared analysis method in our laboratory and for O\textsubscript{18} by a commercial laboratory subcontractor (Metabolic Solutions, Inc, Merrimack, NH). Standards prepared by the investigators, but unknown to the commercial laboratory, were used to monitor the subcontractor’s performance.

Isotope kinetics were determined by using a multipoint calculation technique (10–12). The H\textsubscript{2} and O\textsubscript{18} zero time intercepts and clearance rates (k\textsubscript{f} and k\textsubscript{o}) were calculated by using least-squares linear regression on the natural logarithm of isotope concentration as a function of elapsed time from dose administration. The zero time intercepts were used to determine the isotope pool sizes at the time of the dose. The H\textsubscript{2}O pool sizes were used to estimate total body water (H\textsubscript{2}O pool size/1.04 and O\textsubscript{18}O pool size/1.01, respectively). Equations were used to calculate the daily production rates of carbon dioxide (rCO\textsubscript{2}) and water (rH\textsubscript{2}O) (10) from the isotope clearance (k\textsubscript{f} and k\textsubscript{o}) rates and total body water as follows:

\[
r\text{CO}_2 = \frac{\text{TBW}}{2} \times (f_2) \times \left(\frac{(1.01 \times k_f) - (1.04 \times k_o)}{1 - (1.05 \times (f_2 - f_1))}\right) \quad \text{L/d} \quad (2)
\]

\[
r\text{H}_2\text{O} = \frac{\text{TBW} \times k_o}{(1 - (1 - f_2) \times [(2.3 \times r\text{CO}_2)/\text{TBW} + k_o])]\quad \text{L/d} \quad (3)
\]
where TBW is total body water and the constant isotope fractionation factors are: \( f_1 = 0.941, f_2 = 0.992, \) and \( f_3 = 1.039. \)

**Physical activity assessment**

We measured physical activity in complementary ways to ensure the accuracy of EE as measured by the different methods. First, we asked individuals to record all physical activity for 7 d, as described by Ainsworth et al (7). Second, we administered the Stanford 7-d recall questionnaire (17). The same investigator (JMC) instructed the subjects in the use of these physical activity records and recall and inspected the completed forms.

**Physical activity records**

Physical activity records identified the type and duration of physical activity performed during the period of time. Computations that were based on metabolic equivalent (MET) intensities presented in the *Compendium of Physical Activities* (7) were used to estimate the energy cost of movement as kilocalories or kilojoules. One MET reflects that ratio of the associated metabolic rate for a specific activity divided by the resting metabolic rate.

Seven 24-h physical activity records were completed by the subjects between days 7 and 14 of the doubly labeled water sample collection. Subjects recorded all activities performed throughout the day in the physical activity record. Each change in activity was a new entry in the physical activity record. Subjects were given detailed instructions for completing the physical activity records and recorded the following in a book (1 book/d): 1) the time of day they started each new activity, 2) body position during the activity (reclining, sitting, standing, or walking), 3) general characterization of the purpose for doing the activity (eg, occupation, household, child care, self care, or walking), 4) a detailed description of the activity (eg, typing, eating, or walking for exercise), and 5) a perceived effort (light, moderate, or vigorous) for the activity.

Instructions were provided to subjects assembled in groups of 5–6 and each record was checked daily for completeness and clarity by the same investigator (JMC). The study staff assigned a 5-digit code to each activity as obtained from the *Compendium of Physical Activities* (7). The 5-digit code linked the purpose, description, and MET intensity for each activity in the physical activity records. Two persons of the study staff (BEA and MLI) coded each physical activity record independently. Differences in assigned compendium codes between the study staff were identified by a third reviewer; in these cases the 3 staff members conferred and a consensus was reached.

Physical activity data were computed in min/d and MET·min/d, calculated as the MET intensity multiplied by the minutes of each activity. EE_{\text{Record}} (in kJ) was computed as follows:

\[
EE_{\text{Record}} = \text{MET} \times \text{min} \times \left[ (\text{body weight (in kg)} \times (4.18660)) \right]
\]  

*(Stanford 7-d physical activity recall)*

The version of the 7-d recall used in the present study was administered by an interviewer and took \( \approx 10 \) min to complete (17). The questionnaire had 14 items that measured the hours and minutes spent sleeping (1.0 MET) and performing moderate- (4.0 METs), hard- (6.0 METs), and very-hard-intensity (10.0 METs) physical activities for weekend and weekdays separately. Time spent in light-intensity activities was equal to 24 h – (the time spent sleeping + time spent performing moderate-intensity activity + time spent performing hard-intensity activity + time spent performing very-hard-intensity activity). The 7-d recall was administered twice, at the beginning of the 7-d measurement period and again at the end of the 7-d period, with scores from the second administration used for data analysis. The recalls were edited for clarity and accuracy by an investigator (JMC) in the presence of the subject. Physical activity data were computed as min/d and MET·min/d, calculated as the MET intensity multiplied by the minutes of each activity. EE_{\text{Recall}} (in kJ) was computed as follows:

\[
EE_{\text{Recall}} = \text{MET} \times \text{min} \times \left[ (\text{body weight (in kg)} \times (4.18660)) \right]
\]

*(Physical activity level)*

Physical activity level, as defined by James et al (20, 21), is equal to total EE divided by BMR. Therefore, we calculated the physical activity level as being equal to EE_{DLW}/BMR. For comparison, we also calculated the ratios of EI, EE_{\text{Record}}, and EE_{\text{Recall}} to BMR.

**Statistics**

Statistical analyses were performed with PC-SAS (version 6; SAS Institute Inc, Cary, NC). Means were calculated as the measure of central tendency, and SEMs were computed as a determination of variability. Significance was set at \( P = 0.05. \) Physical activity records were scored by using a statistical program written for this study (B Ainsworth).

Comparisons were accomplished by regressions of one intake measure on another, and Bland-Altman plots were made to compare the differences between EE_{\text{Record}} or EE_{\text{Recall}} (22, 23) and EE_{DLW}. The x axis of these plots represents the average of the doubly labeled water and the prediction method against the y axis, which represents the difference between doubly labeled water and the prediction method. The limits of agreement were plotted, which equals 2 SDs of the difference (22, 23) above and below zero.

**RESULTS**

There was a broad range in body weight, BMI, and percentage of body fat in the study population (Table 1). Although some of the subjects were overweight, most were within 130% of ideal body weight on the basis of the 1959 tables of the Metropolitan Life Insurance Company (24).

Measured BMR and comparisons among EE_{DLW}, EI, EE_{\text{Record}}, and EE_{\text{Recall}} are shown in Table 2. EE_{\text{BMR}} ranged from 5.96 to 8.58 MJ/d. EI was in agreement with EE_{\text{DLW}} with \(<0.5\%\) underestimation. This difference was not significantly different from zero.

Seven-day physical activity records overestimated free-living EE_{DLW} by a mean of 7.9%, which was significantly different from zero. The difference between EE_{DLW} and EE_{\text{Record}} was \( \pm 5\% \) in 3 subjects, between 5% and 10% in 7 subjects, between 10% and 20% in 8 subjects, and >20% in 6 subjects. The mean difference (\( \pm \) SEM) between EE_{DLW} and EE_{\text{Recall}} was 0.91 \( \pm 0.42 \) MJ/d (Table 1). There was a 30.6% overestimation with use of the EE_{\text{Recall}} method and the average difference between EE_{DLW} and EE_{\text{Recall}} was significantly different from zero.
The physical activity level or EE\textsubscript{DLW}/BMR ranged from a sedentary level of 1.58 to a very active ratio of 2.05 (Table 1). When similar mean ratios were calculated comparing EE\textsubscript{Record} and EE\textsubscript{Recall} with EE\textsubscript{DLW}, the values were found to be significantly higher.

Graphic comparisons of EE, as determined by the different methods (EE\textsubscript{DLW}, EI, EE\textsubscript{Record}, or EE\textsubscript{Recall}), are shown in Figures 1–3. Because the 7-d recall data from one of the subjects was >42 MJ/d, it was difficult to include these data on the y axis without distorting the graph in Figure 3; therefore, these data were omitted from the Bland-Altman plots but not from the remaining data analysis. Note that the y scale in Figure 3 is 10 MJ/d, so that differences between EE\textsubscript{DLW} and EE\textsubscript{Recall} are visually reduced compared with the same level of difference in Figure 2, which compares EE\textsubscript{DLW} and EE\textsubscript{Record}. The Bland-Altman plot in Figure 3 shows a negative trend, reflecting that a major overestimation by use of EE\textsubscript{Recall} occurred in several individuals.

**DISCUSSION**

Because of the importance of routine physical activity and leisure-time exercise in the prevention of disease and the maintenance of health, epidemiologists have developed methods to quantitate physical activity at population levels (2). The present study is one of few (14–16) to test simultaneously the ability of different epidemiologic methods to estimate EE in free-living individuals and the first to test such methods under controlled feeding conditions. The 14-d excretion rates of \(^2\text{H}\) and \(^18\text{O}\) after an oral dose of \(^2\text{H}_2\text{O}\) were used to calculate the free-living EE and served as the criterion method for this investigation. The small difference between mean EE\textsubscript{DLW} and EE\textsubscript{Record} (Table 2) in this study supports the advantage of physical activity records for estimating EE in a population. Although this study was conducted under carefully controlled conditions, the small size of the study population may have been a limiting factor and may explain the lack of significance when EE\textsubscript{Record} was regressed against EE\textsubscript{DLW}. However, in 10 of the subjects the difference between EE\textsubscript{DLW} and EE\textsubscript{Record} was <10%, indicating that physical activity records may be useful in some individuals for estimating free-living EE (Figure 2).

**Physical activity level of population**

The predicted physical activity level factors for light, moderate, and heavy activity were 1.56, 1.78, and 2.10 × BMR respectively (21). We observed a range in EE\textsubscript{DLW}/BMR almost identical to the predicted values of 1.58–2.05, indicating that our population consisted of men who ranged in activity from sedentary to heavy activity.

**Energy expenditure from energy intake at weight maintenance**

Human feeding studies have been conducted for >20 y at the Beltsville Human Nutrition Research Center (25). Long-term feeding studies are frequently conducted with subjects who are free to go about their typical daily activities while consuming a diet provided for them under a specified protocol. These studies differ from metabolic studies that are conducted while the participants are confined to a metabolic ward and from studies in which the participants consume food they procure and maintain records of food intake. During this study, the technique for determining EI at weight maintenance included weighing the subjects once per week. When a subject’s weight changed by >2 kg, EI was adjusted by 837 kJ. This weight range was chosen because we had previously observed a variation in body weight of 2 kg when scientific personnel, who had excellent compliance, were fed a constant diet for 14 d (unpublished observations, JM Conway, 1994). Metabolizable energy intake was calculated from food tables (18) and the amount of energy consumed to maintain body weight was then hypothesized to be equal to the person’s free-living EE or energy requirement.

Previous studies used EI as a prediction of both the energy cost of physical activity (26) and the energy requirements (27). In the present study, EI at weight maintenance was determined from the EI fed during the 2-wk study period, although the subjects had been fed a controlled dietary intake for >12 wk. As seen in Figure 1, the EI in only one subject was greater than 1 SD of the mean difference between EI and EE\textsubscript{DLW}. Because this subject had slowly gained weight, his EI was adjusted

### TABLE 1
Characteristics of the study population

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>41.2 ± 2.0 (27–65)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.5 ± 1.8 (63.9–94.5)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.8 ± 0.01 (1.7–2.0)</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>25.1 ± 0.5 (20.9–31.5)</td>
</tr>
<tr>
<td>Percentage of body fat (%)</td>
<td>21.1 ± 1.4 (9.8–43.3)</td>
</tr>
</tbody>
</table>

\(^{1}\) x ± SEM; range in parentheses. \(n = 24.\)

### TABLE 2
Basal metabolic rate (EE\textsubscript{BMR}) and energy expenditure (EE) as determined by the doubly labeled water method (EE\textsubscript{DLW}), by physical activity records (EE\textsubscript{Record}), and by a physical activity recall (EE\textsubscript{Recall}) and energy intake (EI)

<table>
<thead>
<tr>
<th>Value(^{1})</th>
<th>Difference(^{2})</th>
<th>(R^2)(^{3})</th>
</tr>
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<tbody>
<tr>
<td>MJ/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EE\textsubscript{BMR}</td>
<td>7.33 ± 0.15 (5.96–8.85)</td>
<td>—</td>
</tr>
<tr>
<td>EE\textsubscript{DLW}</td>
<td>13.27 ± 0.35 (10.78–17.22)</td>
<td>—</td>
</tr>
<tr>
<td>EI</td>
<td>13.19 ± 0.36 (10.89–16.75)</td>
<td>−0.08 ± 0.14 (−0.5 ± 1.0)</td>
</tr>
<tr>
<td>EE\textsubscript{Record}</td>
<td>14.17 ± 0.37 (10.41–16.99)</td>
<td>0.91 ± 0.42 (7.9 ± 3.2)(^{4})</td>
</tr>
<tr>
<td>EE\textsubscript{Recall}</td>
<td>17.40 ± 1.45 (10.48–42.89)</td>
<td>4.14 ± 1.36 (30.6 ± 9.9)(^{4})</td>
</tr>
</tbody>
</table>

\(^{1}\) x ± SEM; range in parentheses. \(n = 24.\)

\(^{2}\) x ± SEM; percentage in parentheses. Difference between each method and EE\textsubscript{DLW}. A positive value indicates an overestimation of EE and a negative value indicates an underestimation of EE.

\(^{3}\) Significantly different from zero, \(P = 0.05.\)

\(^{4}\) Regression of each measure against doubly labeled water.
after the 14-d study period. Had we averaged EI and EE_{DLW} over a longer period of time, the agreement between EI and EE_{DLW} for this subject would have been <0.5 MJ/d. Nevertheless, it is remarkable that the maximum difference between EI and EE_{DLW} was 1.5 MJ/d.

Energy expenditure from physical activity

Physical activity record

The uniformity in treatment of the physical activity records would tend to minimize the role of instruction and analysis in the error. In the present study, the observation that one-half of the 24 subjects had EE_{Record} values within 11.2% of the mean EE determined by doubly labeled water strongly suggests that the MET values obtained from the Compendium of Physical Activities (7) for activities performed by the subjects were reasonable estimates of true energy cost. The error in determining the energy cost of physical activity from physical activity records in the other 12 subjects may be attributed to factors such as misreporting, body weight, degree of overweight, and environment (28). Earlier reports (14, 29) found that the MET intensities listed in the Compendium of Physical Activities (7) for overweight individuals may be inaccurate and that the inaccuracies may be different for weight- and non-weight-bearing activities. Estimation of EE from the frequency, duration, and type of activities recorded in the physical activity record may contribute errors, which could explain the observed $R^2$ of 0.10 between EE_{DLW} and EE_{Record}. The high level of agreement between the 7-d physical activity records and the 14-d assessment made by the doubly labeled water methods partly reflects the overlapping time intervals; the present study did not assess how closely 7-d physical activity records reflect usual activity.

Both published reports on the Compendium of Physical Activities (7, 30) provide discussions on the recommendations for use and the limitations of the Compendium. However, it is worth restating here that the Compendium of Physical Activities was not developed to estimate the precise energy cost of physical activity for individuals, but rather to provide an activity classification.
system that standardizes the MET intensities for use in epidemiologic research. Furthermore, “this limits the use of the Compendium in estimating the energy cost of physical activity among individuals in ways that account for differences in body mass, adiposity, age, sex, efficiency of movement, geographic and environmental conditions in which the activities are performed. Thus, individual differences in EE for the same activity can be large and the true energy cost for a person may or may not be close to the stated mean MET level as presented in the Compendium” (30).

The present study also supports the commonly held belief that subject compliance is a key limiting factor in the use of physical activity records. For example, the subject in Figure 2, who had the highest EEDLW of 17.22MJ/d and one of the higher differences (19.1%) between EE DLW and EE Record commented that he was so active it was hard for him to stop and record his activity.

Seven-day physical activity recall surveys

The mean difference between EEDLW and EE Recall was much higher and had greater individual variation (Table 2) than that between EE DLW and EE Record or EI. When using the 7-d recall, physical activity was overestimated by >20% by 10 subjects and by >10% and <20% by 7 subjects, whereas the recall estimations of EE in 7 additional subjects were within 10% of EE DLW. The largest overestimations of the time spent in hard- and very-hard-intensity physical activity were made by one subject (204%) whose occupation was to detail cars with an 18-kg (40-lb) machine to buff the vehicles and one subject (116%) who was a carpenter. These data indicate that most subjects overestimated their physical activity when left to their own perceptions of level of exertion, ie, moderate, hard, and very hard. The level of overestimation could be lessened by scoring the 7-d recall differently, namely, by awarding a lower intensity than 6 and 10 METs/min to hard- and very-hard-intensity activity. Taken together, the general overestimation of EE by the 7-d recalls (Figure 3) and the mean ratio of EE Recall/BMR of 2.36 indicate that the recall method has limited usefulness in the estimation of individual EE and is also limited in small groups. These results are mirror images to those of dietary recalls, which significantly underestimate EI (25).

By using basic principles of physiology and energetics, Black et al (31, 32) calculated EI cutoffs “below which a person of a given sex, age and body weight could not live a normal lifestyle.” The minimal plausible level of habitual EI was reported as 1.35 × BMR. Because the physiologic value of EI and EE are identical for an individual in energy balance, this value of 1.35 × BMR can serve as a validity cutoff for any estimate of EE obtained from physical activity records or recalls. There were a few individuals who underestimated their physical activity when using the 7-d physical activity records and 7-d recall, as evidenced by EE Recall/BMR ratios as low as 1.42 and EE Recall /BMR ratios as low as 1.35 (Table 3).

More subjects underreported EE when using the 7-d physical activity record than when using the 7-d recall. Seven subjects underreported EE when using the physical activity records, whereas only 3 subjects underreported EE when using the 7-d recalls. These 3 subjects underestimated their physical activity when using both methods, suggesting an overall difficulty in reporting physical activity.

In this study, the 7-d recall was a less reliable instrument for estimating EE than when using the physical activity records. The large intraindividual variation may limit the usefulness of the 7-d recall in small populations. This serves as additional evidence for the difficulty in recalling physical activity from questionnaires and using those data to estimate the EE of human movement (28).

<table>
<thead>
<tr>
<th>TABLE 3</th>
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<tbody>
<tr>
<td>Ratios of energy expenditure (EE) as determined by the doubly labeled water method (EEDLW), by energy intake (EI), by physical activity records (EE_record), and by a physical activity recall (EE_recal) to basal metabolic rate (BMR)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE_DLW/BMR</td>
<td>1.81 ± 0.03 (1.58–2.05)</td>
</tr>
<tr>
<td>EI/BMR</td>
<td>1.80 ± 0.03 (1.58–2.07)</td>
</tr>
<tr>
<td>EE_record/BMR</td>
<td>1.94 ± 0.05 (1.42–2.37)</td>
</tr>
<tr>
<td>EE_recal/BMR</td>
<td>2.36 ± 0.19 (1.35–5.89)</td>
</tr>
</tbody>
</table>

\(^{1} \bar{x} \pm \text{SEM}; \text{range in parentheses. \( n = 24. \)} \)
Conclusions

Estimating the true energy cost of physical activity remains one of the unsolved problems of nutritionists, exercise physiologists, and epidemiologists. Although doubly labeled water is considered a criterion method for estimating EE in free-living persons, the cost of isotopes and analyses and the requirement for an isotope ratio mass spectrometer prohibits \( ^2H_2^{18}O \) from being widely used in studies of large populations (26). Therefore, it is of considerable importance that physical activity records can be used in individuals to predict free-living EE. Physical activity records have the unique advantage of providing additional information on the types of activity and time devoted by individuals to specific activities.

Our null hypothesis was that there would be no significant difference between EE estimated by 2 previously validated physical activity methods, ie, the 7-d physical activity recall and the 7-d physical activity record, and the doubly labeled water method. The present study indicates that 7-d physical activity records may estimate the mean EE of population, but that the 7-d recall method has limited application because it was both biased and imprecise. The use of these methods to predict individual EE depends largely on the compliance of the population being studied and the ability of the subjects to correctly estimate time spent in activities of differing intensities.

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