# Use of a triaxial accelerometer to validate reported food intakes[1,2]

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**ABSTRACT**

**Background:** An easy and cheap method for validating reported energy intake (EI) is needed.

**Objective:** Reported EI was compared with calculated energy expenditure ($EE_{calc}$) and with energy expenditure measured by the doubly labeled water method ($EE_{DLW}$).

**Design:** EE was calculated on the basis of basal metabolic rate (BMR) measured with the ventilated-hood technique and physical activity (PA) measured with a triaxial accelerometer ($EE_{VH+PA}$) and on the basis of BMR estimated by using World Health Organization equations and PA ($EE_{WHO+PA}$): $EE_{calc} = -1.259 + 1.55 \times BMR + 0.076 \times$ counts/min ($r^2 = 0.90$, $P = 0.0001$). Subjects [$n = 12$ men and 12 women aged 60 ± 3 y; body mass index (in kg/m$^2$): 26 ± 4] reported their food intakes for 7 d and $EE_{DLW}$, $EE_{VH+PA}$, and $EE_{WHO+PA}$ were assessed over the same 7 d.

**Results:** Reported EI (9.0 ± 2.1 MJ/d) was lower ($P < 0.0001$) than were $EE_{DLW}$ (11.3 ± 2.3 MJ/d), $EE_{VH+PA}$ (10.8 ± 1.7 MJ/d), and $EE_{WHO+PA}$ (10.8 ± 1.8 MJ/d). Underreporting was 19.4 ± 14.0%, 16.7 ± 13.6%, and 16.4 ± 15.5% on the basis of $EE_{DLW}$, $EE_{VH+PA}$, and $EE_{WHO+PA}$, respectively. The difference of 2.7 ± 8.0% between $EE_{DLW}$ and $EE_{VH+PA}$ was not related to the average of both percentages and was not significantly different from zero. The percentage of underreporting calculated with $EE_{WHO+PA}$ was not significantly different from that calculated with $EE_{DLW}$.

**Conclusions:** The use of a combination of BMR (measured or estimated) and PA is a good method for validating reported EI. There was no significant difference between the percentage of underreporting calculated with $EE_{VH+PA}$, $EE_{WHO+PA}$, or $EE_{DLW}$. *Am J Clin Nutr* 2001;73:549–53.

**KEY WORDS** Energy intake, energy expenditure, triaxial accelerometer, doubly labeled water, basal metabolic rate, physical activity, elderly, underreporting, underrecording

## INTRODUCTION

Food intake by humans is often related to health or disease indexes in epidemiologic studies and is used as a measure (outcome) in intervention studies. Measurements of food intake with use of dietary records, food-frequency questionnaires, dietary histories, or 24-h recalls are mostly unreliable because of underrecording, undereating, or both (1, 2). A reporting bias in measured food intake can attenuate or exaggerate associations with nutrition and obesity-related disease or disturb the outcome of intervention studies (3, 4). Underreporting of habitual food intake was measured in both obese and lean subjects (2, 5, 6–8). Thus, measured food intake in nutrition research needs to be validated to ensure that the right conclusions are drawn.

The reporting of total food intake can be checked by validating reported energy intake (EI). Several methods for validating reported EI have been used with varying degrees of success. The doubly labeled water method, which measures the total energy expenditure (EE) of subjects in free-living situations, is the most reliable method for validating reported EI. However, it is very expensive ($H_2{}^{18}O$ is not readily available) and is thus not practical in large studies. Total EE is the sum of basal metabolic rate (BMR), physical activity (PA), and diet-induced EE (a constant fraction of ≈10% of EI and, when subjects are in energy balance, of total EE) and can serve to validate reported EI. BMR can be measured with a ventilated hood or calculated with formulas that use age, sex, height, and weight or with formulas that use body composition. The most variable part is the PA, which can be measured with activity diaries, questionnaires, heart rate monitors, or accelerometers. The triaxial accelerometer seems to give the most objective measure of individual PA in free-living situations (9, 10).

The ratio of EE to BMR is known as the PA level (PAL); if there is no underreporting, EE:BMR equals EI:BMR. Goldberg et al (11) set cutoff limits for EI:BMR to recognize underreporting at the group level. However, the proposed cutoff limits for EI:BMR have failed to identify underreporters of food intake at the individual level (2, 12). The cutoff limits are based on minimum PALs for subjects and do not take variation in individual PALs into account.

An easy and cheap method for validating individual reported EIs in large surveys is needed. Estimated or measured BMR in combination with PA assessed with a triaxial accelerometer might be such a method. We present the results of a validation study in which the reported EI of elderly subjects was compared with calculated EE ($EE_{calc}$) and with EE measured by the doubly labeled water method ($EE_{DLW}$).

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## SUBJECTS AND METHODS

### Subjects

Thirty subjects (14 women and 16 men) with a mean (±SD) age of 60 ± 4 y (range: 55–74 y) and a mean body mass index (BMI; in kg/$m^2$) of 26.3 ± 3.6 (range: 19.4–34.1) participated in the study. They were recruited for an exercise intervention by advertisements in local newspapers. Results presented here are baseline measurements, which were made before the intervention began. The protocol was approved by the Medical Ethical Committee of the University of Maastricht, Maastricht, Netherlands.

### Food and water intakes

Food and water intakes were measured with a 7-d dietary record. Subjects received instructions from a dietitian on how to keep a food record and were asked not to change their habitual food intakes. The data on the food records were used to calculate intakes of total energy, protein, fat, carbohydrate, and water with a computer program based on food tables (BECEL NUTRITION PROGRAM, 1988; Nederlandse Unilever Bedrijven BV, Rotterdam, Netherlands). Total water intake was calculated from reported food and water intakes and the calculated amount of metabolic water. The amount of metabolic water was calculated by multiplying EE by the fraction of energy from protein, fat, and carbohydrate (from the 7-d food record). The oxidation of protein, fat, and carbohydrate gives 0.41, 1.07, and 0.6 mL water/g, respectively (13).

### Energy expenditure and water loss

$EE_{DLW}$ was measured according to Westerterp and Bouten (14). Water balance was assessed to measure the percentage of underrecording (ie, the failure to record in a food diary everything that is consumed; 2).

The estimated CV for $EE_{DLW}$ was 6% (15). Water loss was calculated by using the deuterium elimination method, which has an estimated CV of 7% (15). In the evening on day 0, subjects were given a weighed dose of a mixture of 99.84 atom% $^2H_2O$ in 10.05 atom% $H_2{}^{18}O$, such that $^2H$ and $^{18}O$ increased from baseline by ≥150 and ≥300 ppm, respectively. A background urine sample was collected in the evening of day 0. Additional urine samples were collected on day 1 (from the second void of the day and during the evening) and in the morning and evening of days 8 and 15. $EE_{DLW}$ was calculated over the second week, during which subjects recorded their food intakes.

BMR was measured with an open-circuit, ventilated-hood system ($BMR_{VH}$) in the morning while subjects lay for 30 min in a supine position. Subjects had slept at the university the night before this measurement was made and were in a fasting state. The estimated CV for $BMR_{VH}$ is 4% (16). Gas analyses were made with a paramagnetic oxygen analyzer (Servomex type 500A; Crowborough, United Kingdom) and with an infrared carbon dioxide analyzer (Servomex type 500A) similar to the system described by Schoffelen et al (17). Weir's (18) equations were used to calculate BMR. BMR was also estimated by using equations from the World Health Organization ($BMR_{WHO}$), in which age, sex, body mass, and height are incorporated (19).

PA was assessed with a triaxial accelerometer for movement registration (Tracmor; Philips Research, Eindhoven, Netherlands). The triaxial accelerometer was an improved version (smaller, 7 × 2 × 0.8 cm; weight: 30 g) of the triaxial accelerometer used in previous studies (14, 20). Subjects wore the triaxial accelerometer on a belt at the back of their waist during waking hours and recorded the times at which they awoke in the morning, put the triaxial accelerometer on and off, and went to bed. Total counts per day were divided by the amount of time the subjects wore the triaxial accelerometer to get an average number of counts/min. The triaxial accelerometer measures accelerations in the anteroposterior, mediolateral, and vertical directions of the trunk and was validated against the doubly labeled water method in another study (K Westerterp, U Ekelund, unpublished observations, 2000) in 16 men and women with a mean (±SD) body mass of 92.2 ± 25.2 kg, PAL of 1.76 ± 0.14, and age of 20 y. This validation resulted in the following equation in which triaxial accelerometer counts and BMR were used for total $EE_{calc}$:

$$EE = -1.259 + 1.55 \times BMR + 0.076 \times counts/min \quad (1)$$

(regression analysis: $r^2 = 0.90$, $P = 0.0001$; residual SD: 0.809 MJ/d). Other validations of the triaxial accelerometer output with the doubly labeled water method showed similar correlations (14, 20). EE calculated on the basis of $BMR_{VH}$ and PA is referred to as $EE_{VH+PA}$ and EE calculated on the basis of $BMR_{WHO}$ and PA is referred to as $EE_{WHO+PA}$.

### Body mass

Energy balance was checked by measuring changes in body weight over each of the 2 wk separately. Thus, possible weight changes resulting from a change in diet while reporting food intakes could be compared with normal weight fluctuations. Subjects were weighed (in underwear) in the morning on day 1, before consuming any food or beverages and after voiding, with a digital balance accurate to 0.01 kg (Sauter, Ebingen, Germany) and on days 8 and 15 with a digital balance accurate to 0.1 kg (Seca, Almere, Netherlands). Both balances were calibrated with four 20-kg weights.

### Statistics

Means and SDs were calculated for subjects who had 7 d of PA data and who recorded their food intake for 7 d. Reported EI was compared with $EE_{DLW}$, $EE_{VH+PA}$, and $EE_{WHO+PA}$ by using paired *t* tests with Bonferroni correction. Prediction margins for reported EI versus $EE_{VH+PA}$ were calculated as ±2 times the residual SD of the value obtained in a previous validation study (K Westerterp, U Ekelund, unpublished observations, 2000). The percentage underreporting of food intake was calculated by using $EE_{DLW}$, $EE_{VH+PA}$, and $EE_{WHO+PA}$ (%underreporting$_{DLW}$, %underreporting$_{VH+PA}$, and %underreporting$_{WHO+PA}$) as follows:

$$Underreporting = [(EI - EE)/EE] \times 100\% \quad (2)$$

The calculated %underreporting values were compared by using Bland-Altman analysis and *t* tests (21).

Changes in body mass over the recording week were compared with changes over the nonrecording week by using a paired *t* test with Bonferroni correction and were compared with zero by using a one-sample group *t* test. Total water intake was compared with water loss by using a paired *t* test with Bonferroni correction. The percentage underrecording (%underrecording) and undereating were calculated if a significant difference was found between water intake and water loss and if a significant change was found in body mass over the recording week:

**TABLE 1**
Energy intake (EI), energy expenditure (EE), basal metabolic rate (BMR), physical activity (PA), water intake, water loss, and metabolic water values of the total group of subjects[1]

| | Value |
|---|---|
| EI (MJ/d) | 9.0 ± 2.1 (5.3–14.5) |
| $EE_{DLW}$ (MJ/d) | 11.3 ± 2.3[2] (7.5–14.6) |
| $BMR_{VH}$ (MJ/d) | 6.6 ± 1.1 (4.7–8.8) |
| $BMR_{WHO}$ (MJ/d)[3] | 6.6 ± 1.2 (5.0–9.2) |
| PA (counts/min) | 24.2 ± 10.0 (10.7–48.6) |
| $EE_{VH+PA}$ (MJ/d)[4] | 10.8 ± 1.7[2] (8.2–14.0) |
| $EE_{WHO+PA}$ (MJ/d)[5] | 10.8 ± 1.8[2] (8.3–14.6) |
| Water intake (L/d) | 2.2 ± 0.6 (1.0–3.6) |
| Metabolic water (L/d) | 0.3 ± 0.06 (0.2–0.4) |
| Water loss (L/d) | 3.2 ± 0.7[6] (1.8–4.1) |

[1] $\bar{x}$ ± SD; range in parentheses. DLW, doubly labeled water method; VH, ventilated-hood technique; WHO, World Health Organization equations; PA, triaxial accelerometer–assessed physical activity.
[2] Significantly different from EI, $P = 0.0007$.
[3] Estimated with an equation including age, sex, body mass, and height (19).
[4] $EE_{VH+PA} = -1.259 + 1.55 \times BMR_{VH} + 0.076$ counts/min (PA).
[5] $EE_{WHO+PA} = -1.259 + 1.55 \times BMR_{WHO} + 0.076$ counts/min (PA).
[6] Significantly different from the sum of water intake and metabolic water, $P = 0.0007$.

$$\text{Underrecording} = [(\text{water intake} - \text{water loss})/\text{water loss}] \times 100\% \quad (3)$$

$$\text{Undereating} = [(\text{body mass change} \times 30\ \text{MJ}/7\ \text{d})/\text{EE}] \times 100\% \quad (4)$$

Significance was set at $P < 0.05$. The STATVIEW program (1992–1998; SAS Institute Inc, Cary, NC) was used for the statistical analysis.

## RESULTS

Thirty subjects participated in the baseline measurements; 6 subjects were excluded from the statistical analysis because of missing PA data during the recording week. The 24 subjects with complete data had a mean (±SD) age of 60 ± 3 y (range: 55–65 y) and a BMI of 26.1 ± 3.5 (range: 19.4–32.7). Values for EI, EE, BMR, PA, water loss, and water intake are presented in **Table 1**. $BMR_{WHO}$ was not significantly different from $BMR_{VH}$. The mean differences of 0.45 MJ/d between $EE_{DLW}$ and $EE_{VH+PA}$ and of 0.47 MJ/d between $EE_{DLW}$ and $EE_{WHO+PA}$ were not significant. The reported EI of 9.0 MJ/d was significantly lower than $EE_{DLW}$, $EE_{VH+PA}$, and $EE_{WHO+PA}$. The correlation between reported EI and $EE_{VH+PA}$ is shown in **Figure 1**; the line of identity and ≈95% prediction margins are also shown. Twelve of the 24 subjects were identified as underreporters; ie, they reported an EI below the prediction margin.

Values for $\%underreporting_{DLW}$, $\%underreporting_{VH+PA}$, and $\%underreporting_{WHO+PA}$ were 19.4 ± 14%, 16.7 ± 13.6%, and 16.4 ± 15.5%, respectively. A Bland-Altman plot of the difference between $\%underreporting_{DLW}$ and $\%underreporting_{VH+PA}$ against the mean %underreporting is shown in **Figure 2**. The difference was not related to the mean in a simple regression analysis ($r = 0.06$, $P = 0.78$). The relative bias was 2.7% (NS) and the SD of the mean difference was 8.0%. The 4 subjects clustered in the bottom left of Figure 2 were men with a relatively high PAL (2.0 compared with 1.6 for the other 20 subjects). The difference between $\%underreporting_{DLW}$ and $\%underreporting_{WHO+PA}$ was also not related to the mean of both percentages (simple regression analysis: $r = 0.15$, $P = 0.49$). The relative bias was 3.0% (NS) and the SD of the mean difference was 11%.

The means of the 3 body mass measurements were 76.5 ± 11.4 kg on day 1, 77.1 ± 11.7 kg on day 8, and 76.8 ± 11.7 kg on day 15. The change in body mass over the nonrecording week was 0.62 ± 0.74 kg and that over the recording week was −0.24 ± 0.66 kg ($P = 0.01$). The change in body mass over the recording week was not significantly different from zero and indicated no undereating. The energy equivalent of the change in body mass over the recording week was −0.8 ± 2.6 MJ/d (1 kg body mass was assumed to be 30 MJ; 22). The reported water intake plus calculated metabolic water was 2.6 ± 0.7 L/d and was significantly different from the measured water loss of 3.2 ± 0.7 L/d ($P = 0.0007$). The calculated %underrecording was 19.5 ± 11.2%.

## DISCUSSION

The use of a combination of PA and $BMR_{WHO}$ or $BMR_{VH}$ values was found to be a good validation method for reported EI given that no significant difference was found between $\%underreporting_{VH+PA}$, $\%underreporting_{WHO+PA}$, and $\%underreporting_{DLW}$. The relative bias between $\%underreporting_{DLW}$ and $\%underreporting_{VH+PA}$ might be higher for subjects with PALs > 2.0 than for subjects with PALs < 2.0. However, because only 4 subjects in this study had a PAL of ≈2.0, no conclusions can be drawn from this.

The triaxial accelerometer used in this study is a miniaturized version (based on same principle) of the triaxial accelerometer used in previous studies (14, 20). Thus, the smaller triaxial

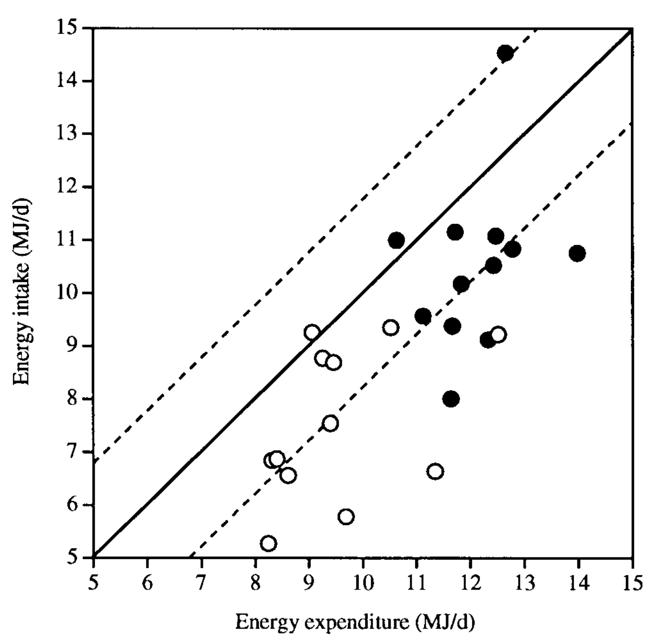


**FIGURE 1.** Correlation between reported energy intakes and energy expenditure (calculated by using measured basal metabolic rate and triaxial accelerometer–assessed physical activity) in elderly men (●) and women (○). The line of identity and 95% prediction margins are shown.

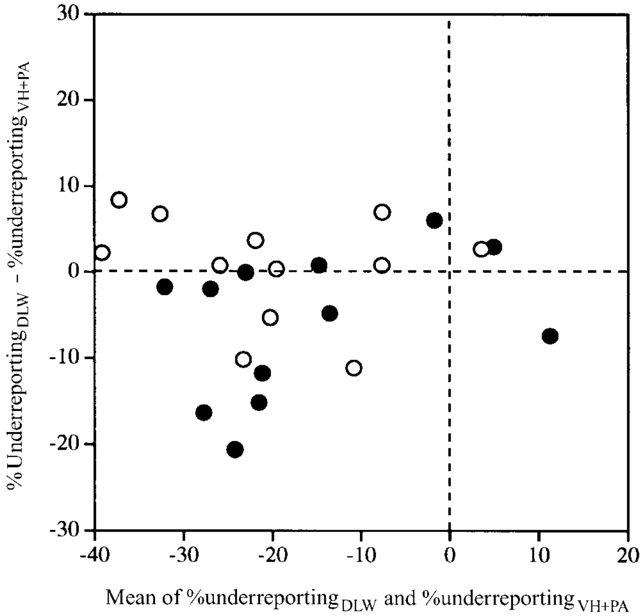


**FIGURE 2.** Difference between the percentage underreporting by elderly men (●) and women (○) calculated on the basis of energy intake and energy expenditure measured with the doubly labeled water method (%underreporting$_{DLW}$) and the percentage underreporting calculated on the basis of energy intake and energy expenditure measured by using triaxial accelerometer–assessed physical activity (PA) and basal metabolic rate measured with a ventilated-hood (VH) technique (%underreporting$_{VH+PA}$) plotted against the mean of %underreporting$_{DLW}$ and %underreporting$_{VH+PA}$ values.

accelerometer required a new EE equation, which was developed in a previous, unpublished study. The equation was derived from a younger population than that in the present study but, as shown in the present study, is also valid for older populations. A few of the accelerometers used in the present study did not register any activity because of problems with battery contact; the data of 6 subjects had to be excluded from the statistical analysis.

In previous studies, the output of the triaxial accelerometer for movement registration was found to be a good discriminator between PALs (14). However, additional studies with groups of subjects with a wider range of PALs than in the subjects of the present study is advised to assess the use of a combination of BMR and PA to validate reported EI.

The triaxial accelerometer gives an objective measurement of the PA of subjects in their natural environment, which is not true of diaries or questionnaires (10). Subjects completing activity diaries may alter their normal activity patterns or overreport their activity. In a group of obese subjects who failed to lose weight under a physician's care, overreporting of up to 51% of PA, assessed with activity diaries, was found (23).

In the present study, %underreporting (≈18%) was comparable with values found in other studies (2, 5, 6–8). In these other studies, the %underreporting was explained on a group level by underrecording (ie, the compliance with food recording) and not by undereating as in our 2 previous studies (2, 8). In the present study, %underrecording was calculated by using the water balance method, but water balance was not corrected for eventual water input from atmospheric exchange. The water input from atmospheric exchange can account for 3–10% of water turnover, depending on the inspired air volume and absolute humidity, which would result in an increase in total water intake (15). A higher total water intake would mean a smaller difference between water intake and water loss and the %underrecording would be reduced to 17% or 10%.

A reported EI outside the prediction interval of the calculated EE (Figure 1) indicated underreporting. A simple adjustment of food intake for these underreporters is no solution because of selective underreporting (3). Recent studies showed selective underreporting of fat intake by both obese and lean subjects (8, 24, 25). The reported protein intake can be validated with urine nitrogen analysis (26), but there is no validation method for reported carbohydrate and fat intakes (27). A possible method to solve the problem of underreporting is to confront subjects with the accuracy of their recordings: whether they ate less during the recording period (undereating) or whether they did not write down everything they consumed (underrecording). The subjects would then be asked to rerecord their food intake. In a previous study of lean women, this method resulted in improved food recording by 16 of 18 subjects (28). More studies in other populations are necessary to validate this method for improving the accuracy of food records.

This study and other studies of underreporting of food intake make it clear that the design of a nutrition study should include a validation method for reported food intakes as well as a strategy for dealing with possible underreporting of food intake (2, 5, 6–8). The triaxial accelerometer for the assessment of physical activity proved to be an easy and valid method for the determination of underreporting of food intake at the individual level.

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