# Inaccuracies in self-reported intake identified by comparison with the doubly labelled water method[1,2]

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To test the accuracy of self-reported energy intake, reported intake was compared with measured energy expenditure. Results from nine studies were reviewed in which intake data were obtained by recall or weighed record for at least 7 days. Expenditure was measured for 7 days or more by the doubly labelled water method. Individual differences between reported intake and expenditure were large (range +25 to −76%). Group mean differences were smaller. Lean, nonathletic groups living in industrialized countries demonstrated the smallest mean difference between self-reported energy intakes and expenditure (0 to −20%). Obese populations demonstrated the largest mean differences (−35 and −50%), but women living in the Gambia and elite athletes also demonstrated large mean differences. Most of the difference appears to be due to underreporting, but some subjects lost weight during the reporting period indicating that some of the difference was due to undereating. Because the greatest bias was observed in obese subjects, current methods for self-reported energy intake are not recommended for use in obesity research.

*Key words*: dietary intake, doubly labelled water, nutritional assessment.

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Pour évaluer la précision d'auto-évaluations de l'apport énergétique, on a comparé les données rapportées aux mesures. On a révisé les résultats de neuf études portant sur des périodes d'au moins 7 jours. La dépense énergétique a été mesurée par la méthode de l'eau à double marquage. Les différences individuelles entre l'auto-évaluation de l'apport et la dépense d'énergie ont été importantes (+25 à −76%). Les différences moyennes des groupes ont été plus faibles. Les groupes non athlétiques, maigres, vivant en pays industrialisés, ont démontré la différence moyenne la plus faible entre l'auto-évaluation de l'apport et la dépense d'énergie (de 0 à −20%). Les populations obèses ont démontré les plus fortes différences moyennes (−35 à −50%); toutefois, les femmes vivant en Gambie et les athlètes d'élite ont aussi démontré de grandes différences moyennes. Les différences seraient dues en grande partie à une auto-évaluation trop faible, mais certains sujets ayant perdu du poids durant la période de contrôle, une partie de la différence a été attribuée à une sous-alimentation. Etant donné que l'écart le plus important a surtout été observé chez les sujets obèses, les méthodes actuelles d'auto-évaluation de l'apport énergétique ne sont pas recommandées dans la recherche sur l'obésité.

[Traduit par la revue]

Measurement of dietary intake in free-living individuals usually relies on self-reporting. Methods for measuring dietary intake include 24-h recall, in which subjects report the previous day's intake during an interview; multiday records, in which each food item is recorded throughout the day using either estimates, common household measures, or weighing of each serving; and semi-quantitative food frequency questionnaires, which involve an extensive interview in which subjects report frequency of intake and serving size for all food items in their habitual diets.

Methods for measuring dietary intake have been carefully developed and improved over the decades. With each new development, the method is evaluated. These evaluations, however, almost always refer to tests of precision, i.e., reproducibility of self-reported intakes. Alternatively, the new method may be validated against another self-reporting technique.

The vast majority of evaluations of self-report instruments have not included tests of accuracy or bias, because such tests are extremely difficult to perform. For example, if the validation is performed in the home environment, few objective methods exist for use as a reference method. Alternatively, if the self-report instrument is validated under controlled conditions in a research unit, the controlled conditions themselves may alter awareness of dietary intake as well as dietary intake itself. Thus, the accuracy of various self-reported dietary intake instruments remains largely unknown.

Despite the difficulty inherent in studies that address accuracy of self-reported intake, there have been several studies that raise concern about the accuracy of self-reported intake. These studies, while limited in number, compared self-reported energy intake with another measure of energy intake and have generally failed to validate the accuracy of self-reported intake.

Acheson et al. (1980) compared periodic self-reported 24-h recall with self-reported weighed dietary intake. When these subjects were given a blank sheet of paper on which to record their intake for the previous 24 h, subjects under-reported energy intake by 34%. Errors were reduced to 21% when a structured questionnaire was used to record the 24-h recall

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data. These 24-h recalls, however, were performed without active involvement of a trained interviewer, which is generally considered a more accurate method because the interviewer probes for items that the subject may have forgotten to record.

Using a different approach, Krantzler et al. (1982) compared telephone-based methods of self-reported intake with observed intake for students eating in a dormitory dining hall over 28 days. Seven-day records had a 13% food item disagreement with observation, while disagreement for 3-day records was 25%. Seven 24-h recalls had a 21% food item disagreement.

In a third study, Lissner et al. (1989) compared self-reported intake of women with measured intake fed these women during subsequent metabolic studies. These measured intakes were corrected for any change in body energy stores during the metabolic period. These authors found that the self-reported intakes tended to be underestimates of maintenance intakes. The degree of underestimation was related to the subject's fat-free mass, such that women with larger fat-free masses and thus larger energy requirements, under-report intake by the greatest margin.

Because of these studies and others (Bingham 1987), there is controversy about the accuracy of self-reported dietary intake. To date, much of the concern has been related to the rigors of methods used for determining intake (Durnin and Ferro-Luzzi 1982), and concerns that the act of measuring intake may induce a change in intake (Stockley 1985). The central obstacle to the resolution of the controversy is the absence of methods with which to validate the accuracy of self-reported intake, especially for free-living subjects in which the goal is to determine habitual intake. Recently, however, a noninvasive method to measure energy expenditure in humans has been validated. This method offers an opportunity to test the accuracy of self-reported energy intake.

## Energy expenditure as a measure of dietary intake

Energy is conserved, and therefore metabolizable energy intake must equal expenditure plus the change in body energy stores. Because of this equality, dietary intake has often been used to estimate energy expenditure. This relationship, however, can be reversed, i.e., energy expenditure and change in body energy stores can be used to measure metabolizable energy intake. Moreover, in individuals whose weight is stable to within several percentage points over a year, change in body energy stores is small and energy expenditure is essentially equal to energy intake. Even if one allows for normal growth, changes in body energy stores due to growth are small compared with energy expenditure. Only during the first year of life and during pregnancy does normal growth store more than 2% of average daily energy intake (Table 1). Average daily energy expenditure should therefore be virtually equal to habitual metabolizable energy intake in an individual, unless that individual is steadily increasing or decreasing body energy stores. However, even an individual who is laying down adipose tissue at a constant rate of 1 kg/month will have a habitual intake that is only 250 kcal/d greater than expenditure.

Until recently, daily energy expenditure has not been any easier to measure than dietary intake. During the last 5 years, however, the doubly labelled water method (Lifson and McClintock 1966) has been validated for measuring daily energy expenditure in free-living humans, and it is now possible to take advantage of the above equality to validate self-reported dietary intake with respect to metabolizable energy. The principle of this method is that after a loading dose of water labelled with deuterium and $^{18}O$, the deuterium is eliminated as water, while the $^{18}O$ is eliminated as water and carbon dioxide. As such, the elimination rate of deuterium is proportional to water flux and the $^{18}O$ elimination is proportional to the sum of water flux and carbon dioxide flux. The difference between the two elimination rates is therefore proportional to carbon dioxide production, and hence energy expenditure. The advantage of the method is that it only requires periodic sampling of physiologic fluids over a 7- to 21-day metabolic period while the subject is at home under normal living conditions.

The doubly labelled water method has been extensively validated in animals (Nagy 1980) and in humans (Schoeller 1988). The method has been validated by either comparison with respiratory gas exchange or measured dietary intake plus change in body energy stores (Table 2). These validations in humans have been performed by 3 independent research centers in 11 separate studies involving 56 subjects. The method has an accuracy of 1% and a precision (1 SD) of 6%. The accuracy of the method is not significantly affected by energy balance (Schoeller et al. 1989) or physical activity (Westerterp et al. 1988). Moreover, replicate measures in 3 subjects over a 2-year period and in 16 subjects in consecutive weeks have demonstrated a repeatability of 6% (Schoeller and Taylor 1987; DeLany et al. 1989). Thus, doubly labelled water is known to be accurate and precise enough to serve as a reference method for the validation of self-reported dietary intake.

## Review of comparisons of self-reported energy intake with expenditure

Energy expenditure, as measured by doubly labelled water, and self-reported dietary intake have been reported in nine recent publications. Although some of these studies have found that self-reported intake agrees with energy expenditure and hence provides an unbiased estimate of habitual intake, the majority of the studies have detected bias in self-reported intake. These studies are summarized below.

Riumallo et al. (1989) observed the highest level of accuracy for self-reported intake. They selected six chronically undernourished young, male subjects who were living in Santiago, Chile (Table 3). These six subjects were selected from about 80 applicants on the basis of their ability to keep complete dietary records. Dietary intake was determined by a combination of diary and 24-h recall for 7 consecutive days every other week for a total of 4 weeks. Subjects were required to record intake daily, then met daily with a dietitian, who tabulated intake by this log aided recall. The subjects were then fed in amounts needed to maintain constant weight for 12 weeks and energy expenditure was measured by doubly labelled water during the final week. Self-reported dietary intake ($\pm$SD) averaged 2689 $\pm$ 284 kcal/d versus a measured expenditure of 2724 $\pm$ 303 kcal/d (Fig. 1). When expressed as a percentage of expenditure, self-reported intake averaged 101 $\pm$ 13%. Thus, in these carefully selected, chronically underweight subjects, self-reported intake was accurate and reasonably precise.

The results of Riumallo et al. (1989), however, contrast sharply with those reported in an abstract by Singh et al. (1988). Because results have only appeared in an abstract, details are limited and results should be considered pre-

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TABLE 1. Energy intake stored during growth

| Subject | Growth rate ($g \cdot kg^{-1} \cdot d^{-1}$) | Energy stored (kcal/g) | Energy stored ($kcal \cdot kg^{-1} \cdot d^{-1}$) | Energy stored % of RDA[a] |
|---|---|---|---|---|
| 1-month-old infant | 5.8[b] | 4.1[a] | 25 | 23 |
| 6-month-old infant | 1.8[b] | 3.2[b] | 6 | 6 |
| 8-year-old child | 0.3 | 2.3 | 0.7 | 1 |
| 30-year-old adult | 0 | 0 | 0 | 0 |
| Pregnant adult | 0.8[c] | 4.5[c] | 4 | 10 |

[a]1989 Recommended dietary allowance for energy (10th ed., National Academy Press, 1989).
[b]Calculated from Fomon et al. (1982).
[c]Calculated from Forsum et al. (1988).

TABLE 2. Summary of validations of the doubly labelled water method in humans

| Subjects | *n* | % error ± SD | Ref. method | Citation |
|---|---|---|---|---|
| Adults | 4 | −0.4±5.6 | I/B | Schoeller and van Santen (1982) |
| Adult | 1 | −4.6 | RGE | Klein et al. (1984) |
| Adults | 5 | +1.5±7.6 | RGE | Schoeller and Webb (1984) |
| Adults | 4 | +1.9±2.0 | RGE | Coward and Prentice (1984) |
| Exercising adults | 2 | −2.5±4.9 | RGE | Westerterp et al. (1984) |
| Premature infants | 4 | −1.4±4.8 | RGE | Roberts et al. (1986) |
| Adults on TPN | 5 | +3.3±5.9 | I/B | Schoeller et al. (1986*a*) |
| Adults | 9 | +1.4±7.7 | RGE | Schoeller et al. (1986*b*) |
| Postsurgery infants | 9 | −0.9±6.2 | RGE | Jones et al. (1987) |
| Adults | 5 | +1.4±3.9 | RGE | Westerterp et al. (1988) |
| Exercising adults | 4 × 2 | −1.0±7.0 | RGE | Westerterp et al. (1988) |
| Weighted mean ± SD | 56 | 0.3±6.1 | | |

NOTE: I/B, intake plus change in body stores; RGE, respiratory gas exchange; TPN, total parenteral nutrition.

TABLE 3. Subject characteristics

| Study | *n* | Gender (M:F) | Age (years) | Weight (kg) | Height (cm) | BMI ($kg/m^2$) | % fat |
|---|---|---|---|---|---|---|---|
| Riumallo et al. (1989) | 6 | 6:0 | 27±4 | 55.0±3.9 | 168±7 | 20±1 | 9±2 |
| Delany et al. (1989) | 8 | 8:0 | 25±5 | 72.2±6.8 | 176±8 | 24±2 | 18±8 |
| Bandini et al. (1990) | 28[a] | 14:14 | 14.4±1.3 | 56.0±9.6 | 164.4±8.5 | — | 21.2±7.5 |
| | 27[b] | 14:13 | 14.7±2.0 | 95.0±25.1 | 163.9±7.6 | — | 42.7±7.0 |
| Prentice et al. (1986) | 13[a] | 0:13 | 29±5 | 57.5±6.3 | 161±8 | 22±2 | 28±6 |
| | 9[b] | 0:9 | 35±5 | 87.9±14.3 | 163±3 | 33±5 | 43±3 |
| Bronstein and King (1988) | 15 | 0:15 | — | — | — | — | — |
| Schulz et al. (1989) | 6 | 4:2 | 24 | 70.4±10.3 | 179 | — | 12±4 |
| Singh et al (1988) | 13 | 0:13 | — | — | — | — | — |
| Livingstone et al. (1989) | 31 | 16:15 | — | — | — | — | — |
| Westerterp et al. (1986) | 4 | 4:0 | — | 69.2±5.8 | — | — | 12±1 |
| Haggarty et al. (1988) | 4 | 0:4 | — | 50.6±3.2 | — | — | 14±1 |

NOTE: BMI, body mass index.
[a]Nonobese.
[b]Obese.

liminary. Singh measured intake and expenditure in thirteen Gambian women (Table 3) who were engaged in farming activities during the height of the agriculture season. Food intake was assessed by direct weighing for about 13 days and expenditure by doubly labelled water for the same period. Reported intake averaged 1300 ± 150 kcal/d less than measured energy expenditure, a discrepancy of over 50%. Estimates of energy contributed from body fat stores could only account for 440 ± 120 kcal/d, suggesting a considerable degree of unreported food intake.

A second study in which self-reported intake was found to be accurate was that of DeLany et al. (1989). Nine Special Forces soldiers (Table 2) reported their intake during a 4-week field exercise. Energy expenditure was measured by doubly labelled water over these same 4 weeks. This study therefore differs from most others summarized here because it does not represent habitual dietary intake. The soldiers were living under field conditions, were probably more physically active than normal, were consuming prepackaged meal-ready-to-eat field rations in place of their typical diet, and lacked access to

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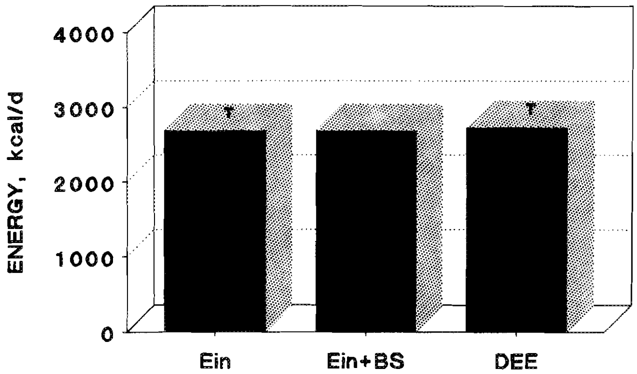


FIG. 1. Comparison (±SE) of self-reported habitual energy intake (Ein) and daily energy expenditure (DEE) in six undernourished adult males living in Chile (Riumallo et al. 1989). BS, body energy stores.

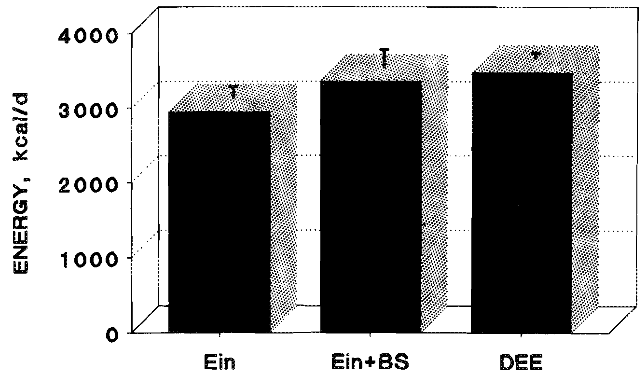


FIG. 2. Comparison (±SE) of self-reported energy intake (Ein), change in body energy stores (Ein + BS), and energy expenditure (DEE) in nine soldiers under field training conditions (DeLany et al. 1989).

any other food. Prepackaging of the diet probably facilitated the estimation of portion sizes, because each package contained a known amount of the food item. Dietary intake averaged 2960 ± 487 kcal/d versus an expenditure of 3400 ± 260 kcal/d (Fig. 2). The subjects, however, tended to lose weight presumably owing to these nonhabitual conditions. When intake was corrected for loss of body energy stores estimated from total body water, intake plus change in body energy stores averaged 3230 ± 520 kcal/d or 95 ± 16% of measured energy expenditure. Thus, while self-reported energy intake underestimated the intake necessary to maintain energy balance, self-reported intake was an accurate measure of energy intake during the reporting period.

Most other studies have noted much larger biases in self-reported intake. The largest discrepancy was reported by Bandini et al. (1990), in a comparison of self-reported intake with expenditure in obese and nonobese adolescents (Table 3). Subjects recorded their intake in common household units for 14 days. Each subject received individual instruction on measuring intake and was telephoned every 2 to 5 days by a dietitian, who inquired about the status of intake records to improve adherence. Energy expenditure was measured over the same 14 days by the doubly labelled water method. In the nonobese subjects, self-reported intake averaged only 81 ± 19% of measured expenditure (2190 ± 620 kcal/d versus an expenditure of 2760 ± 600 kcal/d (Fig. 3)). In the obese, self-reported intake averaged only 59 ± 24% of expenditure (1940 ± 720 kcal/d versus an expenditure of 3390 ± 610 kcal/d (Fig. 3)). Unlike the study of DeLany et al. (1989), this low reported intake could not be traced to undereating during the reporting period, because both the obese and nonobese gained weight during the reporting period (0.1 ± 0.7 and 0.4 ± 1.0 kg, respectively). Therefore, the low self-reported intake in both groups probably reflects under-reporting.

In a similar study, Prentice et al. (1986) compared self-reported intake with expenditure in lean and obese women (Table 3). Self-reported intake involved a 7- or 14-day weighed dietary record in the middle of a 14- to 21-day measurement of energy expenditure by the doubly labelled water method. Self-reported dietary intake (1880 ± 350 kcal/d) compared quite well with measured energy expenditure (1910 ± 240 kcal/d) in the lean groups, but poorly (1610 ± 430 kcal/d versus 2440 ± 310 kcal/d, respectively) in the obese group (Fig. 4). Expressed as a percentage of measured expenditure, self-reported weighed intake averaged 98 ± 15

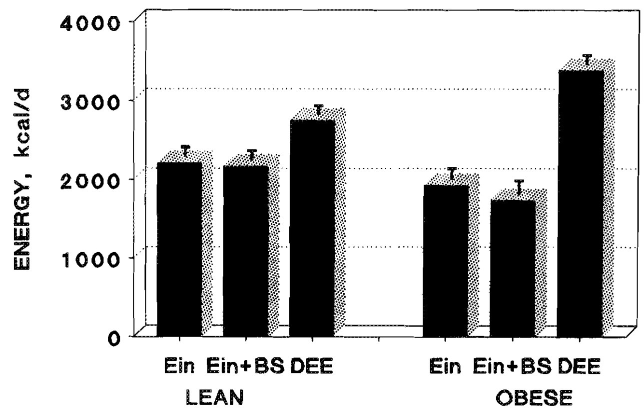


FIG. 3. Comparison (±SE) of self-reported habitual energy intake (Ein), change in body energy stores (BS), and energy expenditure (DEE) in nonobese ($n$ = 28) and obese ($n$ = 27) adolescents (Bandini et al. 1990).

and 67 ± 15% of the presumed habitual intake in the lean and obese groups, respectively. Like the data reported by Bandini et al. (1990), bias was greater among the obese subjects. However, in contrast to the observations by Bandini et al. (1990), the lean control group reported intake quite accurately, and the obese group tended to lose weight during the dietary reporting period. The sum of self-reported intake and change in body energy stores averaged 83 ± 17% of measured expenditure. Thus, on average about half of the low self-reported intake was due to under-reporting and half due to undereating.

A third study also grouped subjects as either normal or overweight. This study by Bronstein and King (1988) involved pregnant women (Table 3). Qualitatively, the results are similar to those of Prentice et al. (1986); normal and overweight groups reported very similar intakes, whereas energy expenditure was 550 kcal/d greater in the obese group than in the lean group. Unfortunately, quantitative details are unavailable because the report has only been published in abstract form.

The first full report in which self-reporting can be compared with expenditure for adult men living in an industrialized country has recently been published (Schulz et al. 1989). Six young, nonobese men (Table 2) weighed and recorded food intake for 2 weeks while energy expenditure was measured

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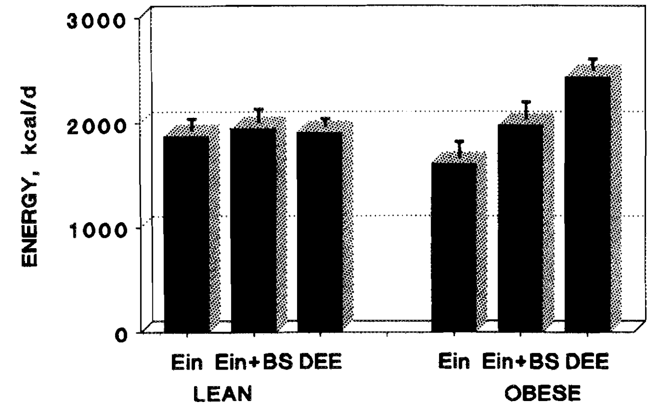


FIG. 4. Comparison (±SE) of self-reported habitual energy intake (Ein), change in body energy stores (BS), and energy expenditure (DEE) in nonobese ($n$ = 13) and obese ($n$ = 9) British women (Prentice et al. 1986).

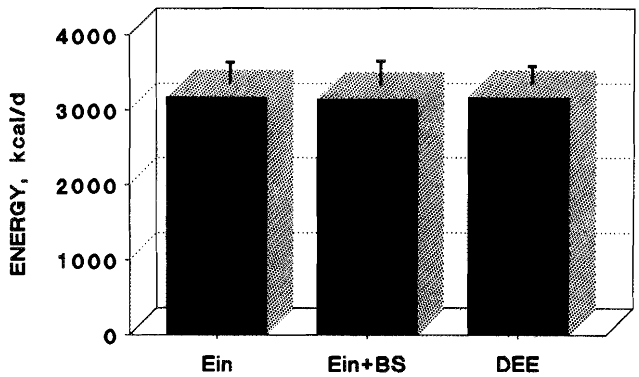


FIG. 5. Comparison (±SE) of self-reported habitual energy intake (Ein), change in body energy stores (BS), and energy expenditure (DEE) in six young adult males (Schulz et al. 1989).

using the doubly labelled water method. The self-reported intake was unbiased. Reported intake averaged 3180 ± 690 vs. an expenditure of 3170 ± 690 kcal/d (Fig. 5), however, individual variation was moderately large. Reported intake expressed as a percentage of expenditure averaged 101 ± 16%.

In contrast, Livingstone et al. (1989) reported a significant bias in a recent abstract. Weighed dietary intake was compared with measured expenditure in 16 males and 15 females living in Northern Ireland. Weighed dietary intake in men averaged 2680 ± 590 kcal/d versus a measured expenditure of 3400 ± 710 kcal/d (Fig. 6). Women, reported intakes of 1910 ± 450 kcal/d versus an expenditure of 2360 ± 360 kcal/d (Fig. 6). Expressed as a percentage, weighed intakes were 81 ± 22 and 82 ± 21% of expenditure and hence of the presumed habitual intake in men and women, respectively. Overweight subjects (130% of ideal body weight) tended to report an intake that was in greater error when expressed as a percentage of expenditure (34 ± 20%), but only three overweight subjects were studied. Information on weight change was unavailable in this report and thus it could not be determined if the bias was due to under-reporting or undereating.

Two investigators have compared self-reported intake with measured expenditure in elite, lean athletes. Westerterp et al.

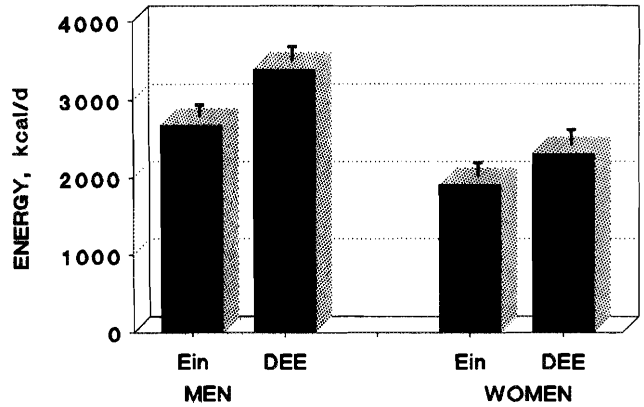


FIG. 6. Comparison (±SE) of self-reported habitual energy intake (Ein) and energy expenditure (DEE) in adult men ($n$ = 16) and women ($n$ = 15) (Livingstone et al. 1989).

(1986) studied four elite male cyclists during the Tour de France, a 3-week bicycle race. Energy intake was reported in a daily diary for 3 weeks while energy expenditure was measured during each week by the doubly labelled water method. Energy intake averaged 5900 ± 290 kcal/d compared with an expenditure of 8060 ± 130 kcal/d. Expressed as a percentage of expenditure, intake averaged 74 ± 3% (Fig. 7). The discrepancy between intake and expenditure increased in each succeeding week, beginning at −13 ± 8% and increasing to −35 ± 4%. This discrepancy was not simply due to undereating because body weight only decreased by 1.4 ± 0.6 kg during the race. Body composition data suggested this was all fat loss and thus could supply about 600 kcal/d. It should also be noted that the discrepancy cannot be traced to a bias in doubly labelled water in these very physically active subjects, as the accuracy of the method has been validated under exercise conditions (Westerterp et al. 1988).

In the second study, Haggarty et al. (1988) compared self-reported intake with measured expenditure in elite female runners. This report has only appeared as an abstract; therefore methodological details are limited and results should be considered preliminary. Similar to the male cyclists self-reported intake was considerably less than measured expenditure (2320 ± 600 vs. 3500 ± 300 kcal/d), (Fig. 7), averaging only 66% of the presumed habitual intake. Surprisingly, these lean, active subjects under-reported in amounts comparable to obese, sedentary subjects, rather than lean subjects indicating that errors in reported intake are not restricted to overweight individuals.

## Interpretation

The findings presented above indicate great variation in the accuracy of self-reported intake. The grouped comparisons presented above demonstrate the absence of bias in some groups, but very large biases in others. In several of the groups in which bias exists, a portion can be assigned to undereating, whereas in others, almost all of the difference appears to be due to under-reporting. For example, in the obese women studied by Prentice et al. (1986), close to half the mean difference could be accounted for by weight loss; but in the study reported by Bandini et al. (1990), the obese adolescents actually gained weight.

The issue of undereating versus under-reporting cannot be

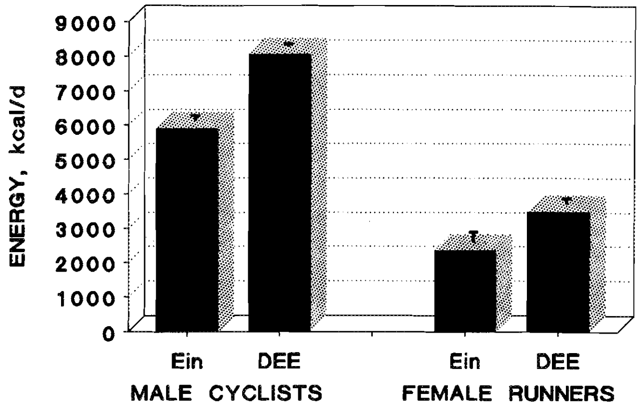


FIG. 7. Comparison (±SE) of self-reported energy intake (Ein) and expenditures in four elite cyclists during the Tour de France (Westerterp et al. 1986) and four elite female runners (Haggarty et al. 1988).

addressed on an individual basis using the currently available data. This issue requires a better estimate of the energy contributed by a decrease in body energy stores. However, because both sources of error introduce bias in the estimate of habitual intake, it is possible to pool current data and evaluate the accuracy of self-reported energy intake for estimating habitual energy intake using energy expenditure as the reference measure.

This evaluation is first limited to nonathletic individuals from developed nations in an effort to remove some of variance due to culture, education, and heavy exercise. With this limitation, individual data on self-reported energy intake and energy expenditure are available from 79 subjects. These include the studies of Prentice et al. (1986), Bandini et al. (1990), and Schulz et al. (1989). It should be noted, however, that this is not a random population, because it is heavily weighted toward adolescent (55/79) and obese subjects (34/79).

The results from these 79 subjects demonstrate a negative bias in self-reported intake. When the difference between intake and expenditure is compared with the mean of the two measures, the bias is significant and the results quite variable between subjects (Fig. 8A and 8B). Among males, self-reported intake averaged 2510 ± 780 kcal/d versus an expenditure of 3300 ± 580 kcal/d ($p < 0.01$, paired $t$-test). Among females, self-reported intake averaged 1780 ± 410 kcal/d versus an expenditure of 2520 ± 650 kcal/d ($p < 0.01$, paired $t$-test).

In males, the bias is largest for small mean values of reported intake and expenditure, while just the opposite is observed in females. This divergence, however, appears to be an artifact arising from the large differences between the two variables, which often exceed 50%. When energy intake is plotted against energy expenditure, the deviation from the line of identity increases with increasing expenditure in females, while little trend is observed in males (Fig. 9A and 9B). When energy intake and energy expenditure are plotted independently against body weight (Fig. 10A–10D), self-reported intake demonstrates a flat slope, i.e., no increase with weight, while expenditure in these free-living subjects increases with weight, as expected from previous studies performed in respiration chambers in which both resting metabolic rate and total energy expenditure were observed to increase with weight (Ravussin et al. 1986).

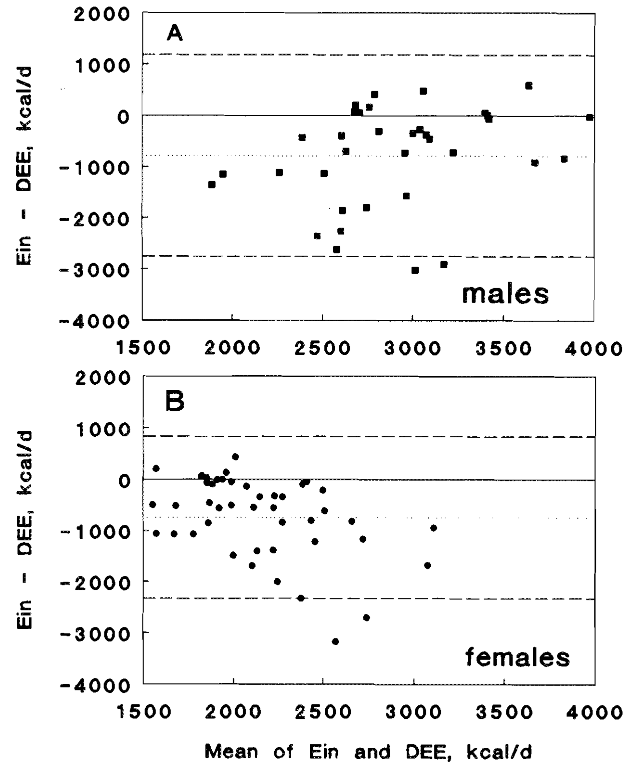


FIG. 8. Self-reported energy intake (Ein) and measured energy expenditure (DEE) do not agree. Differences average nearly −800 kcal/d and not infrequently exceed −2000 kcal/d. Means ± 2SD are indicated by dashed lines. Data adapted from Prentice et al. (1986), Schulz et al. (1989), and Bandini et al. (1990).

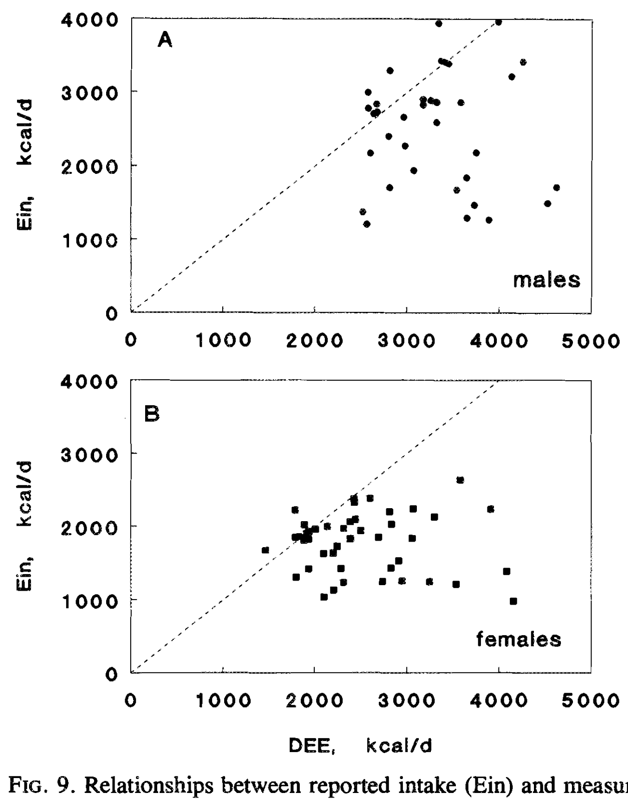


FIG. 9. Relationships between reported intake (Ein) and measured energy expenditure (DEE) in males (A) and females (B). Data adapted from Prentice et al. (1986), Schulz et al. (1989), and Bandini et al. (1990).

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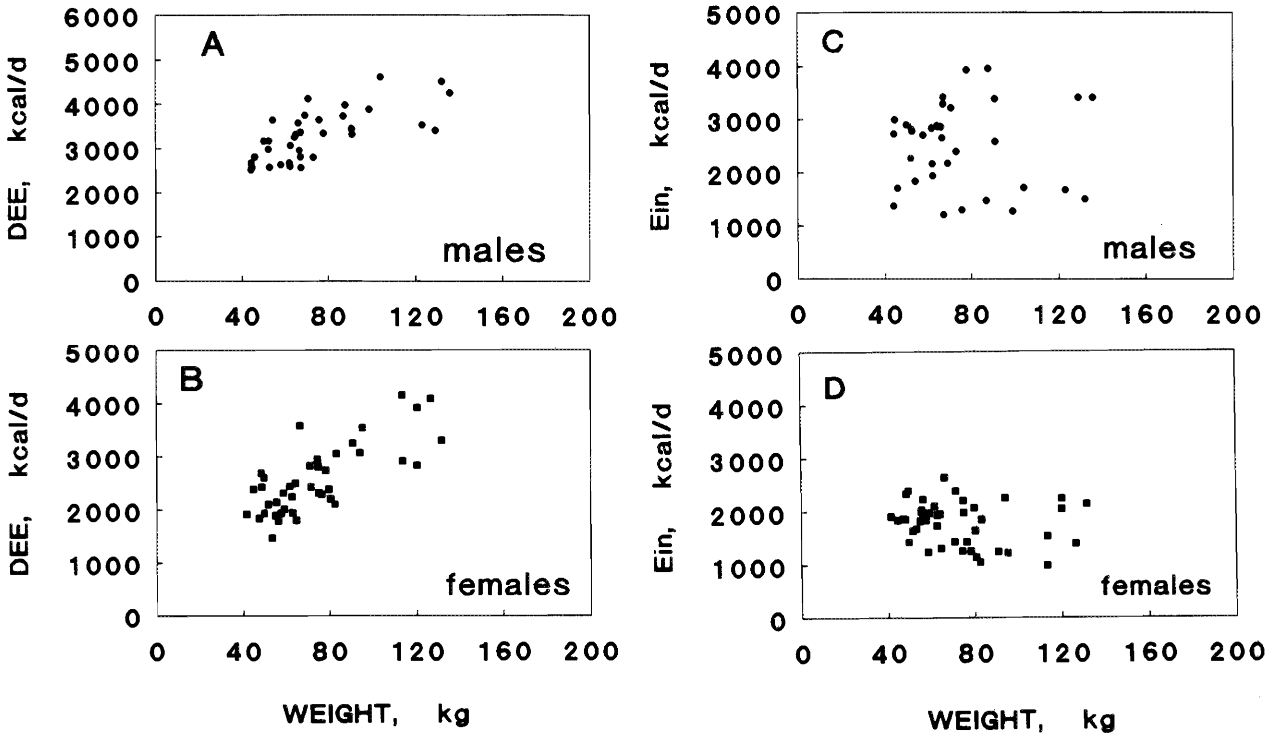


FIG. 10. Measured energy expenditure (DEE) increases with increasing weight in males (A) ($r = 0.70$, $p < 0.01$) and females (B) ($r = 0.75$, $p < 0.01$), whereas self-reported intake (Ein, C and D) demonstrates a flat slope with increasing weight ($r = 0.00$ and 0.19, $p > 0.05$, in males and females, respectively). Data adapted from Prentice et al. (1986), Schulz et al. (1989), and Bandini et al. (1990).

The correlation matrix for the difference between reported energy intake and measured expenditure and subject characteristics is shown in Table 4. The bias in self-reported energy intake expressed as kilocalories per day is correlated with weight, and percent body fat. The bias also correlates with fat-free mass in females, but not in males. Because weight, percent body fat, and fat-free mass are usually intercorrelated, it is not possible to determine if any of these parameters is an independent predictor of bias.

The biases observed in elite athletes (Haggerty et al. 1988; Westerterp et al. 1986) and Gambian women (Singh et al. 1988), however, do not fit the same pattern. Although most of these results have only appeared in abstracts, the descriptions indicate that these subjects have neither large body weights nor increased body fat, yet the difference between self-reported intake and measured expenditure is as large or larger than that reported in heavy, obese subjects. This observation may indicate that there are numerous factors that influence the bias in self-reported intake. We speculate, however, that the bias is related to the degree with which the energy intake deviates from the expectations for the population norm rather than body size or composition. For example, heavy, obese individuals may report an intake closer to an idealized population norm; athletes may report an intake closer to the values reported by less physically active individuals; and Gambian women may report lower intakes because of possible cultural expectations that their intakes should be small to provide more food for husbands and children.

No single mechanism explains all the individual variation in the bias. If the self-reported energy intake expressed as a percentage of measured energy expenditure is plotted against body weight for the more homogenous subpopulation of 79 subjects discussed above (Fig. 11), the correlation with weight only accounts for 23% of the variance about the regression ($r = 0.43$). The remaining variance is partially due to uncertainty (one SD) in the measurement of daily energy expenditure ($s_{\mathrm{DEE}}$), day-to-day variation in intake ($s_{\mathrm{Ein}}$), and as yet unassigned factors that bias self-reported intake ($s_{\mathrm{other}}$). Stated mathematically,

$$s_{\mathrm{total}}^2 - s_{\mathrm{wt}}^2 = s_{\mathrm{DEE}}^2 + s_{\mathrm{Ein}}^2 + s_{\mathrm{other}}^2$$

From the repression line shown in Fig. 11, $s_{\mathrm{total}} = 0.182$ and $s_{\mathrm{wt}} = 0.087$. From the data in Table 1, the relative uncertainty in energy expenditure by the doubly labelled water method is estimated to be 5.4% ($s_{\mathrm{DEE}} = 0.06$), and within subject day-to-day variability in energy intake is estimated to

TABLE 4. Correlation matrix for the difference between reported energy intake (Ein) and daily energy expenditure (DEE) and body size and composition

| | Ein − DEE (kcal/d) | Weight (kg) | % fat | FFM (kg) |
|---|---|---|---|---|
| Females | | | | |
| Ein − DEE (kcal/d) | — | | | |
| Weight (kg) | 0.71 | — | | |
| % fat | 0.62 | 0.88 | — | |
| FFM (kg) | 0.69 | 0.94 | 0.70 | — |
| Males | | | | |
| Ein − DEE (kcal/d) | — | | | |
| Weight (kg) | 0.41 | — | | |
| % fat | 0.49 | 0.77 | — | |
| FFM (kg) | 0.14 | 0.76 | 0.17 | — |

NOTE: FFM, fat-free mass. Data adapted from Prentice et al. (1986), Schulz et al. (1989), and Bandini et al. (1990).

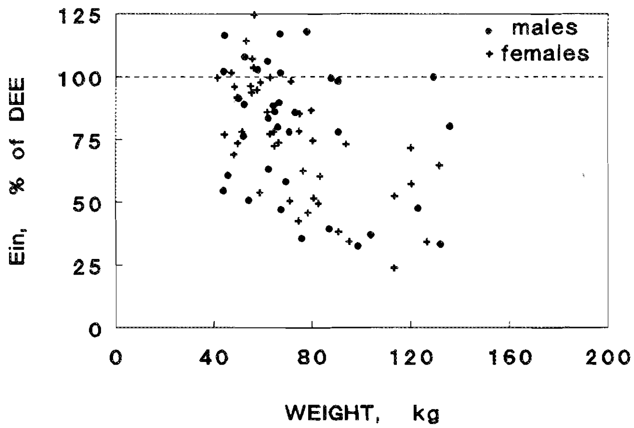


FIG. 11. The relative bias in reported energy intake (Ein) expressed as the ratio of intake to measured expenditure correlates with body weight ($r = -0.48$, $p < 0.01$). Data adapted from Prentice et al. (1986), Schulz et al. (1989), and Bandini et al. (1990).

be 23% (Bingham 1987). Because intakes were recorded for 7–14 days, this uncertainty is reduced. Assuming an average record length of 11 days, the variation in the mean daily reported intake is reduced to 7% ($s_{Ein} = 0.07$). By difference the interindividual uncertainty in self-reported intake that cannot be assigned is 13%.

## Discussion

Direct comparisons of self-reported energy intake with energy expenditure by the doubly labelled water method have begun to appear in literature. Although several of these reports are only in abstract form and thus preliminary, a pattern has begun to emerge. Using energy expenditure as a measure of habitual energy intake because habitual energy intake must equal energy expenditure for an individual to maintain weight, these comparisons indicate that the bias in self-reported energy intake can be appreciable. The bias is largest in obese adolescents and smallest in lean adults living in industrialized countries.

The differences between reported intake and measured expenditure have been assigned to bias in self-reporting intake because the differences cannot be explained by bias in the measurement of energy expenditure by the doubly labelled water method or random error in either the intake or expenditure methods. Doubly labelled water has been validated against respiratory gas exchange and measured dietary intake without any detectable bias (Table 2). It should be noted, however, that the doubly labelled water method measures $CO_2$ production and not energy expenditure. Because of this, knowledge of the respiratory ratio ($R$) is needed to calculate energy expenditure. In the outpatient studies reviewed above, $R$ was not measured, but was estimated from the macronutrient composition of diet (Black et al. 1986). Thus, any difference between the assumed macronutrient composition of the diet and the diet as consumed would introduce an error into the energy expenditure measurement. The error in energy expenditure, however, is only 1% for each 0.01 $R$ unit which roughly corresponds to a change of 3% of total energy contributed by carbohydrate. It is therefore unlikely that the error will exceed 5% unless the diet contains a very unusual amount of fat or carbohydrate. Dietary studies (Black et al. 1986) suggest that this error will be less than a few percentage points, unless the subject obtains more than 5–10% of their energy from alcohol. With this one exception, it is unlikely that the uncertainty in $R$ would account for more than a 3% difference between intake and expenditure. This of course requires that the estimated $R$ value be appropriate for study population. For example, the average diet in developing countries contains much more carbohydrate than fat in developed countries. Appropriate $R$ values appear to have been chosen for the studies reviewed here.

It is also unlikely that errors in the use of food tables to calculate the energy content of the diet can explain the failure of intake and expenditure to coincide. While large variations in energy content of single food items exist (Acheson et al. 1980), differences between actual metabolizable energy for a whole diet and that calculated from food tables are typically less than 7% (Acheson et al. 1980; Woo et al. 1982; Schoeller and van Santen 1982). Moreover, it would be very hard to explain how errors in self-reported intake are 20–30% larger in obese individuals than they are in lean individuals on the basis of errors in the tabulated energy content.

Although the bias in self-reported energy intake raises concern, these findings should not be interpreted as evidence that dietary records are useless. These findings, however, help identify the limitations of dietary records. Perhaps the greatest limitation occurs in the use of dietary records for studies of energy balance and obesity because there are systematic errors associated with obesity. Indeed, it is now possible to explain the apparent contradictions in studies such as the Zetphen study (Kromhout et al. 1988) in which it was found that obesity as defined by body mass index (BMI) was negatively correlated with energy balance as calculated from the difference between self-reported intake and physical activity, i.e., excessive body weight was associated with consuming less energy than was being expended. This seeming contradiction of the laws of physics can now be explained by the tendency of heavy persons to under-report their intake. Self-reporting of dietary energy intake is therefore not recommended for quantitative studies of energy balance in obese individuals.

The development of the doubly labelled water method has finally made it possible to assess the accuracy of self-reported energy intake. Unfortunately, self-reported intake was found to be biased in individuals with large energy expenditures and to have greater interindividual variation than previously believed. The doubly labelled water method represents a unique, but potentially expensive opportunity, to refine and improve techniques for assessing dietary intake.

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