Underestimation of energy intake by 3-d records compared with energy intake to maintain body weight in 269 nonobese adults[1-3]

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ABSTRACT We assessed how accurately participants in dietary trials reported their free-living energy intake. We compared self-reported energy intake, calculated from 3-d food records, with actual intakes needed to maintain body weight during controlled trials lasting 6–9 wk. In 269 free-living healthy male (n = 119) and female (n = 150) adults with mean body weights close to ideal values ($\bar{x} \pm$ SD body mass index in kg/m^2, 22.1 ± 2.4), energy intake reported in food records was 1.2 ± 1.6 MJ/d (277 ± 378 kcal/d) lower than actual energy requirements during the experiments. The relative bias was significantly smaller (P = 0.01) for men (−8.0 ± 13.4%) than for women (−12.2 ± 13.7%). Body mass index, daily energy intake, and age were not significantly related to the extent of underestimation. We conclude that food records systematically underestimate energy needs in young, nonobese well-educated adults. *Am J Clin Nutr* 1994;60:855–60.

KEY WORDS Diet records, energy needs, food intake, energy requirements, dietary intake, nutritional assessment

Introduction

Food-intake data are used in epidemiologic research and for assessing nutrient requirements. There are several methods to estimate dietary intake. However, the validity of most methods is uncertain. In general, recall and record methods result in much lower energy intakes than do doubly labeled water estimates of energy expenditure or supervised feeding to maintain body weight (1, 2).

Some characteristics of subjects who provide good records or of severe underreporters have been described. In literate and highly motivated subjects, self-report by dietary records yielded good agreement between mean energy intake and mean energy expenditure (1). It appears that self-reports are not representative of energy requirements in obese subjects (3–6). It has also been suggested that the degree of underreporting increases with the degree of energy intake (2, 7). An explanation for this could be that individuals tend to report intakes that are closer to perceived norms than to actual intake (7).

The aim of our study was to determine whether young, lean, highly educated adults would provide valid estimations of their energy intake. Therefore, we compared self-reported energy intakes from 3-d dietary records with the actual amount of energy required to maintain stable body weights in dietary experiments. In these studies the feeding of diets with known energy contents was supervised and this provided us an almost "gold standard" for determining energy intake.

Subjects and methods

Experiments and diets

Actual energy needs were defined as the amount needed to maintain weight during controlled trials. Data were obtained from six dietary trials, each with a duration of 6–9 wk, which were conducted between 1986 and 1993; key aspects are summarized in **Table 1.** We performed studies 2 and 3 in October and November, and the others between January and April. Approval for all studies was obtained from the Ethics Committee of the Department of Human Nutrition and Human Epidemiology.

The experimental diets varied in total fat content and fatty acid composition. Vitamin and mineral contents of the diets met the recommended dietary allowances of the Dutch Food and Nutrition Council (13). The diets were made available at 30 energy levels ranging from 5.5 to 20 MJ/d (1315 to 4782 kcal/d), in increments of 0.5 MJ (120 kcal). We supplied each individual with a diet that met his or her energy requirement, as judged by stable body weight during the trial. The diets consisted of conventional solid foods. On weekdays volunteers consumed their hot meals at the Department. All other food was supplied daily as a package and consumed at home. We provided ≈90% of total daily energy. Each day participants selected the remaining 5–13% of energy from a list of foodstuffs low in fat and cholesterol. These free-choice items provided an amount of energy fixed for each energy level. We allowed subjects unrestricted consumption of coffee and tea without milk and sugar, and of water, herbs,

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TABLE 1
Overview of the dietary trials

Study and year	Duration	Fat content of diets	Number of subjects: Total (n = 351)	Included in present analysis (n = 269)
	wk	*% of energy*		
1, 1986 (8)	8	22 or 39	57	45
2, 1987 (9)	7.5	37	60	48
3, 1988 (10)	9	39	59	48
4, 1990 (11)	9	41	56	48
5, 1992 (12)	9	39	59	45
6, 1993 (13)	6	40	60	35

and spices, lemon juice, vinegar, and nonenergy soft drinks. The subjects kept a diary in which they recorded their daily choice of free-choice items and any deviation from the guidelines.

During the experiments we contacted subjects on every weekday and advised them about the diets and the protocol if necessary. We urged subjects not to change their smoking habits and physical activity. They were asked to record any relevant change in their diaries. Other details were described previously (8–13).

Subjects

We recruited volunteers via local newspapers, via posters, and by approaching former participants. For the six trials combined, a total of 441 persons were screened. Because 48 of them participated more than once, these subjects generated 503 data points. The subjects lived in or around Wageningen, a small college town in the center of Netherlands.

We supplied ample oral and written information about the aim of the study and the burden involved in participating. We measured blood pressure and urinary glucose and protein, obtained a written medical history, and asked subjects to record their food intake for 3 d. Eight (1.6%) subjects were excluded because of a history of atherosclerotic disease, hypertension, anemia, or other medical conditions as judged by an independent physician, or because their alcohol intake exceeded 10% of their daily energy intake. We excluded 25 (5.0%) applicants because they disliked foods that were essential parts of the study diets (eg, dairy products or olive oil). Another 25 (5.0%) withdrew for personal reasons before the trials started. Because men and older persons were underrepresented we admitted most of them, as well as their partners. Because only 60 subjects could be admitted to each trial, we excluded another 94 (18.7%) eligible persons by random lottery. A total of 351 (69.8%) subjects were enrolled in the six experiments. They gave their written informed consent for participation.

For the present analysis nine subjects (2.6% of the participants) were left out because their food records were missing or because they withdrew before the end of the trial. We omitted results of another 11 (3.1%) subjects because they had gained or lost > 2.0 kg body wt between day 14 and the last week of the study. Forty-eight subjects participated in more than one trial. We used the data from their first trial and dropped the 62 observations (17.7%) from their subsequent trials because of possible bias from multiple participation. This left 269 observations.

Characteristics of the subjects are presented in **Table 2.** The subjects were highly educated: in study 5 two subjects had completed primary school only, all others had completed secondary school, most of whom were attending college. In studies 5 and 6, 55–60% of the subjects were students, and 30–35% were employed; the remaining subjects were housewives or unemployed. It is likely that the characteristics of subjects in experiments 1–4 were similar.

Fifty-eight (21.6%) participants were lactoovovegetarians or disliked some kinds of meat. These subjects received diets without meat, which we compensated for by providing cheese, marmalade, oil, and eggs to achieve the same energy and macronutrient composition as the corresponding test diet with meat. The nutrient content of the diets met recommended dietary allowances for minerals and vitamins (15). Forty-seven women (31% of all women) used oral contraceptives. The participants received no financial reward except for the free food.

Food records

Two to three months before each trial the volunteers recorded their food intakes for two weekdays and one weekend day, using scales weighing to the nearest gram (studies 1–3) or estimating quantities in household measures (studies 4–6). Recording days were chosen at random and only changed if a serious deviation from habitual food intake could be expected (eg, major festivities). This occurred for only one or two subjects per experiment.

Dietitians employed for the assessment of dietary intake followed a course in food-consumption techniques developed at our Department (YH Blauw et al, unpublished observations, 1994) or were thoroughly instructed. During the first visit of the subjects to our Department the dietitian provided diaries for recording food intake plus oral and written instructions. The importance of keeping accurate records was explained; the subjects were told that the results would be used for determining their energy intake during the experiment and that they were not allowed to gain or lose weight. Additional instruction was given about the use of scales to participants of studies 1–3 and about recording the amounts of food in household measures to the participants of studies 4–6.

At the second visit of the subjects to our Department the dietitian checked whether the food records had been filled out properly, obtained additional information about poorly defined dishes and recipes and unclear items or amounts, and displayed examples of cups, glasses, and spoons to improve the estimation of household measures. The volunteers also spread a slice of bread

TABLE 2
Subject characteristics

	All (n = 269)	Men (n = 119)	Women (n = 187)
Age (y)	25.7 ± 9.6[1]	25.4 ± 9.3	25.9 ± 9.8
Age > 30 y (n)	43	17	26
Height (cm)	177.1 ± 9.4	184.5 ± 6.6	171.1 ± 6.6
Weight at start of trial (kg)	69.5 ± 9.6	75.4 ± 8.2	64.8 ± 7.8
BMI[2]	22.1 ± 2.4	22.2 ± 2.5	22.1 ± 2.4
BMI > 25.0 (n)	34	14	20

[1] $\bar{x}$ ± SD.
[2] In kg/m^2.

with their habitual amount of margarine, and the portion size for coding food records was corrected if necessary.

The dietitians estimated other portion sizes by using a table of common household units. One dietitian (JdV) checked and supervised the subsequent coding of the records and data-entry procedures. The energy content was calculated by using the Netherlands Nutrient Data Base 1985 (14). Additional data on food composition were obtained by chemical analysis or from the food industry.

Energy intake during the experiments

At the start of the trial each subject was assigned a 10% higher energy intake than the value from the food records at the start of the trial because an underestimation was expected from the literature and from previous experience.

Body weights were measured twice weekly before lunch with subjects wearing no shoes or heavy clothing such as jackets and sweaters. If body weight tended to change by > 0.2 kg, we adjusted the energy intake by raising or lowering it in steps of 0.5 MJ/d so as to maintain a stable body weight, ie, < 2.0 kg between day 14 and the end of the experiment.

We calculated the energy content of the experimental diets using the same database as for the food records (14) and used this for the comparisons with self-reported energy intake. In addition, each day we collected duplicate portions of each experimental diet for an imaginary participant with an energy intake of 10 MJ/d (2391 kcal, studies 1–3) or 11 MJ/d (2630 kcal, studies 4–6). Duplicates were stored at −20 °C, pooled, and chemically analyzed for protein (16), total fat (17), fatty acid composition (18), dietary fiber (19), and cholesterol (20). Available carbohydrate was calculated by the difference between total energy content and the amount of energy derived from protein and fat. The energy content calculated from these analyses plus the determined contribution of the energy intake from the consumed free-choice items yielded a check of the energy content of the diets as calculated from the food table.

The mean decrease in body weight of all subjects was 0.32 ± 0.65 kg between days 1 and 7, 0.15 ± 0.53 kg between days 8 and 14, and 0.05 ± 0.91 kg between day 14 and the last week of the experiments. Seventy-five (28%) subjects lost or gained > 1.0 kg but < 2.0 kg between day 14 and the end of the experiment. We defined actual individual energy intakes as the mean energy level between day 14 and the end of the trial.

Dietary adherence was confirmed by the individual changes in the fatty acid composition of serum cholesteryl esters or erythrocytes, which were consistent with the differences in the dietary fatty acid composition in experiments 2, 3, 4, and 5 (9–12). Anonymous questionnaires on compliance were filled out in studies 5 and 6. Inspection of these questionnaires and the diaries did not reveal deviations from the protocol that might have affected the results. It was estimated that illegal foods supplied at most 0.02 MJ/d, or 5 kcal/d (studies 5 and 6).

Statistical analysis

The null hypothesis was that the energy intake estimated from the 3-d food records before the study would not differ from the average energy need from day 14 until the end of the study. This was analyzed by a paired *t* test with use of the *Statistical Analysis System* (21). Differences between subgroups were tested by unpaired *t* tests (21).

Results

Self-reported energy intakes vs calculated energy needs

Pretrial energy intake as reported in the 3-d records was on average 10.6 ± 3.0 MJ/d (2533 ± 717 kcal/d). There was no difference between the three recording days; mean reported energy intake was 10.7 ± 3.4 on the first day, 10.6 ± 3.5 on the second day, and 10.4 ± 3.6 MJ on the third day. Actual intakes between day 14 and the end of the trial—when body weights were stable—averaged 11.7 ± 2.6 MJ/d (2796 ± 621 kcal/d). Mean self-reported energy intake was 10.4% lower than the energy need during the experiments (**Table 3**). The Pearson correlation coefficient between the recorded amount of energy and actual energy requirement was 0.85 for all subjects, 0.70 for the men, and 0.73 for the women ($P < 0.0001$).

The absolute differences were similar for men (−1.1 MJ/d; 95% CI −1.4, −0.8 MJ/d) and women (−1.2 MJ/d; 95% CI −1.4, −1.0 MJ/d), but when expressed as a percentage of energy intake during the experiments the food records underestimated energy needs more in women (−12.2%; 95% CI −14.4, −10.0%) than in men (−8.0%; 95% CI −10.4, −5.6%, P for difference between men and women = 0.01).

The underestimation in the 43 subjects aged 31–67 y was 10.7% vs 8.5% for the younger adults ($P = 0.33$). The 34 participants with a body mass index (BMI, in kg/m^2) > 25 underestimated their energy intake by −12.0% as compared with −10.1% for the 235 subjects with a BMI ≤ 25 ($P = 0.53$). Men with a BMI > 25 ($n = 14$) underestimated their energy intake by 15.0%, and men with lower BMIs ($n = 105$) by 7.1% ($P = 0.06$). In women the underestimation was 12.6% for the higher-BMI group (BMI > 25, $n = 20$) and 9.9% for the lower-BMI group (BMI ≤ 25.0, $n = 130$; $P = 0.54$).

The degree of underestimation was not correlated with absolute energy intake in both sexes combined ($r = 0.00$, $P = 0.92$) or in men ($r = 0.00$, $P = 0.93$), and weakly correlated in women ($r = 0.15$, $P = 0.07$). We found no association between misestimation and the change in body weight between day 14 and the end of the trial ($r = -0.06$, $P = 0.33$).

TABLE 3
Preexperimental daily energy intake reported in 3-d records vs actual energy intake required to maintain weight during controlled trials in nonobese adults

	All subjects ($n = 269$)	Men ($n = 119$)	Women ($n = 150$)
Reported intake			
(MJ)	10.6 ± 3.0[1]	12.8 ± 2.6	8.8 ± 2.0
(kcal)	2533	3070	2089
Required intake			
(MJ)	11.7 ± 2.6	14.0 ± 1.9	9.9 ± 1.4
(kcal)	2796	3338	2373
Difference[2]			
(MJ)	−1.2 ± 1.58	−1.1 ± 1.84	−1.2 ± 1.34
(kcal)	−277	−268	−283
Percent difference			
(%)	−10.4 ± 13.7	−8.0 ± 13.4	−12.2 ± 13.7

[1] $\bar{x}$ ± SD.
[2] All differences are significantly different from zero, $P < 0.05$.

The average underestimation was −8.8 ± 14.9% in studies 1–3 when foodstuffs were weighed, and −12.1 ± 12.0 in studies 4–6 when the amounts of food were estimated (P = 0.05).

When all data of the 48 participants who participated twice or more were included (adding 62 observations, n = 331) the underestimation was −8.6% ± 13.3 for men and −12.9% ± 14.1 for women vs −8.0% for men and −12.2% for women in the initial data set (n = 269).

The chemical analysis of duplicate portions showed that the energy content of the provided diets was on average 0.2 MJ, or 48 kcal/d (range −0.1 to 0.5 MJ), lower than we calculated using the food table. Duplicate portions collected for a lower (8.0 MJ, or 1913 kcal) and a higher (14.0 MJ, or 3348 kcal) energy level in study 3 yielded similar results.

Table 4 shows that the mean underestimations differed between experiments. The average underestimation of 10.8% in studies 2 and 3, which took place in autumn, was not significantly different from the 10.1% in studies 1, 4, 5, and 6, which were performed in the spring.

TABLE 4
Recorded minus actual energy intake per study[1]

Study	Percent difference
1 (n = 45)	−4.6 ± 7.1
2 (n = 48)	−14.3 ± 9.6
3 (n = 48)	−7.2 ± 21.8
4 (n = 48)	−13.0 ± 12.1
5 (n = 45)	−13.1 ± 11.4
6 (n = 35)	−9.4 ± 12.8

[1] $\bar{x}$ ± SD. Preexperimental energy intake in studies 1–3 was recorded by weighed portions and in studies 4–6 by estimated portions. Studies 2 and 3 were executed in autumn and studies 1, 4, 5, and 6 in spring.

Discussion

The subjects in our study undoubtedly underestimated their energy requirements when they recorded their food intake for 3 d. Although a self-reported energy intake of 10% less than actual energy intake seems small, the consequences for the interpretation of nutrition survey data are substantial.

The precision of the method proved to be high, as indicated by the strong association between reported and actual energy intake. Note that this association might be slightly inflated because the dietary records were used to calculate the energy needs during the trials. However misestimation was not associated with the change in body weight, which suggests that energy need as determined during the trials was independent of the over- or underestimation of energy reported in the dietary records. Thus, inflation—if any—could not have been substantial.

The degree of underestimation was weakly associated with BMI in men but not with BMI in women, age, or absolute level of energy intake. However, the relative underestimations were higher for women than for men.

It is conceivable that subjects intentionally underreported their food intake because they wanted to lose weight during the experiments. However, this is not likely because they knew that weight loss was not allowed during the trials and that their energy intake would be adjusted. Also, they were not obese. The participants were well-educated and the applicants with excessive alcohol intakes were excluded. For these reasons the subjects in our study would be expected to provide accurate records (1).

The reported energy intakes of our subjects agreed with the results of the Dutch National Food Consumption Survey (22) for which a 2-d record was used. For women (n = 1611) in the same age range, the reported energy intake was 9.0 MJ (2151 kcal) vs 8.7 MJ (2080 kcal) in our study and for men (n = 1608), aged 16–49 y, 12.3 MJ (3940 kcal) vs 12.8 MJ (3059 kcal) observed here.

The differences between energy content of the diets as assessed by chemical analysis and the calculated value would imply an average energy intake during the experiments of 11.5 MJ/d instead of 11.7 MJ/d. The difference between analyzed and calculated values was probably due to a slight overestimation of the energy content of foods in the nutrient database. In that case a correction should also be applied to the database used for evaluating the food records, and the degree of underreporting would remain unchanged. If the difference between calculated and analyzed energy contents of the experimental diets was due to smaller amounts of food being provided than planned for them, the degree of underreporting would become 7.8% instead of 10.4%. However, this is less likely to have happened because all foods were weighed out on high-quality scales, which were periodically recalibrated. The average weight loss between day 14 and the final week of the experiment was 50 g, or 1.2 g/d. This implies that as a group our subjects were very close to energy balance and that the subjects' actual energy requirements were even slightly higher than calculated here. The deviations from the protocol recorded in the diaries and filled out in the anonymous questionnaires would indicate that the subjects' energy intake was only 0.02 MJ/d (5 kcal/d) higher than determined. If subjects did underreport their extra consumption, then the discrepancy between reported and actual energy intake would increase and the conclusions of this study would be reinforced. Although 2 or 3 mo elapsed between the recording of food intake and the start of the trial, there is no plausible reason why subjects should have increased their energy expenditure. The degree of underreporting was the same for experiments performed in autumn, with food records obtained in July and August, as for experiments performed between January and April, with food records obtained in November and December. Thus, seasonal fluctuations in activity do not explain our findings. The differences in underestimation between experiments as shown in Table 4 could be due to the use of different recording methods, because dietary records by estimated portions provide in general less accurate estimations than by weighed amounts of foods (23).

The mean energy needs of our subjects were approximately the same as those in many other studies (1, 2). The men in our study consumed on average 14 MJ/d (3346 kcal) and the women 9.9 MJ (2379 kcal), whereas others (1, 2, 24, 25) found on average 13.5 MJ/d (3260 kcal) for men and 9.5 MJ/d (2400 kcal) for women.

The subjects in our trials underestimated their energy intake by ≈10%. Mertz et al (2) found an underreporting of 18% in a group of free-living volunteers when comparing energy intake recorded during ≥ 7 d with energy intake needed to maintain body weight. Livingstone et al (25) calculated the difference between self-reported energy intake and energy requirements as measured by the doubly labeled water method for 31 free-living men and women. They found an underestimation of 19% for men and of 18% for women (25). Hallfrisch et al (26) compared energy intake needed to maintain body weight in metabolic studies and found underestimations of 19% for the men and 37% for the women. Lissner et al (27) found that women underestimated their energy intake by 24% when comparing self-reported energy intake by 3–5-d records with measured energy intake in a metabolic unit.

Perhaps the high education level of the subjects in our study could be an explanation for the smaller underestimation observed here. Schoeller et al (28) reviewed three studies (3, 6, 29) representing 79 nonathletic individuals from developed countries. These studies applied the doubly labeled water technique to determine actual energy requirements. Self-reported energy intake was on average 24% lower than determined energy need for men and 29% for women. However, obese subjects and adolescents were overrepresented in these studies, which could explain part of the large differences between reported and actual energy intakes (29). In some other studies, reviewed by Black et al (1); the reported energy intake agreed with the energy requirements assessed by the doubly labeled water method, but the number of subjects was small.

The women in our studies showed a larger relative degree of underreporting than the men. A sex-specific difference between reported and actual energy intake was also described by Schoeller et al (28). They found the largest bias in men with low energy needs and in women with relatively high energy needs. At most we could confirm this for women, in whom we found a weak, nonsignificant positive association between the level of energy intake and the degree of underestimation.

Underestimation is generally smaller in lean people than in obese people (28). We could confirm this for the men but not for the women. However, few of our participants were obese. In our study the bias between reported and determined energy intake was similar for subjects older than 30 y and subjects 18–30 y of age. Still, age might affect the accuracy of food records. In adolescents differences between age groups have been reported (1). Also, Jørgensen (30) reported that older age groups provided more complete 7-d food records than did younger age groups.

Our study adds to the growing body of evidence that dietary records or surveys underestimate food intake. However, the precision of the method is high, as indicated by the high correlation between self-reported energy intake and actual energy need. Therefore, records appear suitable for ranking well-educated, lean subjects by energy intake. However, for epidemiologic studies and for assessing nutritional requirements of individuals one has to reckon with underestimation not only in obese but also in nonobese subjects.

One way to improve the results of food records is an upward adjustment of the individual energy intakes with the mean expected underestimation of the group. The number of subjects classified within 5% of their actual energy need increased from 43 (or 16%) to 95 (or 35%) when self-reported energy intakes were raised by 11%. However, one has to be cautious when adjusting individual food records because underreporting is not consistent among individuals. Although many suggestions have been made as to the causes of underestimation, the characteristics of severe underreporters are still not clear.

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