British Journal of Nutrition (2009), **101**, Suppl. 2, S73–S85 doi:10.1017/S0007114509990602

Misreporting of energy and micronutrient intake estimated by food records and 24 hour recalls, control and adjustment methods in practice

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(Received 7 January 2009 – Revised 6 May 2009 – Accepted 1 June 2009)

In order to assess nutritional adequacy, valid estimates of nutrient intake are required. One of the main errors in dietary assessment is misreporting. The objective was to review the extent, nature and determinants of misreporting in dietary assessment, how this affects reported intakes of micronutrients and how this is identified and measured, and to identify the best ways of dealing with misreporting when interpreting results. A systematic literature search was conducted for studies of misreporting of dietary intake in adults by 24 hour recalls or by estimated or weighed food records, published up to March 2008. Thirty-seven relevant studies were identified. Possible causes of misreporting were identified. Methods most used to identify misreporting were the Goldberg cut-off (46 % studies) and the doubly labelled water technique (24 % studies). The magnitude of misreporting of energy intake was similar in all three dietary assessment methods. The percentage of under-reporters was about 30 % and energy intake was underestimated by approximately 15 %. Seven papers presented usable data for micronutrient intake. Absolute intakes of Fe, Ca and vitamin C (the three micronutrients addressed in all papers) were on average 30 % lower in low-energy reporters (LER) than that in non-LER and, although results were not consistent, there was a tendency for micronutrient density to be higher in LER. Excluding underreporters or using energy adjustment methods for micronutrient intakes is discussed. Residual method of energy adjustment seems to be a good tool for practice to decrease an influence of misreporting when interpreting results of studies based on food records and 24 hour recalls.

Dietary intake: 24 Hour recall: Food record: Misreporting

Assessment of dietary intake is difficult and the choice of type of assessment method may influence the results(1). Specifically, the EURRECA network of excellence needs clear guidelines for assessing the validity of reported micronutrient intakes among vulnerable population groups. One of the main sources of error in dietary assessment is misreporting, comprising both under- and overreporting. Misreporting introduces severe error not only in the estimation of energy intake (EI), but also in that of other nutrients.

Underreporting of usual EI includes both underrecording and undereating. Underrecording is a failure of respondents to record all the items consumed during the study period, or could be due to underestimating their amounts. It has been defined as a discrepancy between reported EI and measured energy expenditure (EE) without any change in body mass, with body mass (assumed to be) constant during the observation/reference period. Undereating occurs when respondents eat less than usual or less than required to maintain body weight, and is accompanied by a decline in body mass(2). It is difficult to establish misreporting, but even when it has been identified it is unclear whether or how these data may be interpreted and used. The concern is that this phenomenon produces erroneously low results for habitual food or nutrient intakes, but it is not yet clear whether to what extent different foods and nutrients are affected in all subjects. Relationships between dietary intakes and diet-related diseases could consequently be obscured or confounded. Before deciding whether to exclude data affected by misreporting, it is necessary to know more about whether low-energy reporting is a random event in the population, who it affects and any bias resulting from it(3). Although the name 'underreporters' is often given to those reporting implausibly low EI, several researchers use the name 'low-energy reporters' (LER) instead(3–5).

In the present paper, we aim to summarise and facilitate a better understanding of the problem of misreporting by describing measurement errors in dietary assessment resulting in under- or overreporting, to find out their determinants and methods used to identify misreporting, and to judge the

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Abbreviations: DLW, doubly labelled water; EE, energy expenditure; EI, energy intake; LER, low-energy reporters.

On behalf of EURRECA's RA.1.1 'Intake Methods' members: Serra-Majem L (Coordinator), Cavelaars A, Dhonukshe-Rutten R, Doreste JL, Frost-Andersen L, García-Álvarez A, Glibetic M, Gurinovic M, De Groot L, Henríquez-Sánchez P, Naska A, Ngo J, Novakovic R, Ortiz-Andrellucchi A, Øverby NC, Pijls L, Ranic M, Ribas-Barba L, Ristic-Medic D, Román-Viñas B, Ruprich J, Saavedra-Santana P, Sánchez-Villegas A, Tabacchi G, Tepsic J, Trichopoulou A, van't Veer P, Vucic V, Wijnhoven TMA.

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magnitude of these errors. We also provide information that may be used to minimise these errors, to highlight gaps in our knowledge, and to recommend future priorities for research. To reach the present objectives, we made an inventory about the errors described in the present papers, and the possibilities of coping with them. We focused on 24 hour recalls and food records used to assess average intakes of populations.

Materials and methods

Search strategy and study selection

We performed online searches of the published literature using databases Proquest 5000, CAB, FSTA and search programs PubMed (using MEDLINE database) and Science Direct (digital library of Elsevier publisher products) up to March 2008 to find studies addressing misreporting in nutritional assessment. Also an additional search in Google was made. The following medical subject headings (MeSH terms) and their combinations were used as search terms: ‘nutrition assessment’, ‘bias (epidemiology)’, ‘biological markers’, ‘reproducibility of results’ as well as following key words and their combination: ‘diet*’; ‘nutrition’; ‘misreporting’; ‘misreport*’; ‘underreport*’; ‘overreport*’; ‘micronutrient’; ‘intake’; ‘accuracy’; ‘survey’; ‘error’; ‘bias’. We also carried out a search of the references listed in the papers included in the final selection, applying the same inclusion/exclusion flow chart. The present search yielded 543 references that have been exported to EndNoteX1 reference manager. After exclusion of duplicates, we had 471 references in EndNote. We made an abstract review and studies that met any of the following exclusion criteria were excluded from the present review (279 references excluded):

i) studies that did not deal primarily with nutritional assessment methods and misreporting;
ii) studies in diseased or institutionalised persons exclusively;
iii) studies assessing only misreporting of weight/height, smoking or alcohol consumption;
iv) studies assessing nutritional status and not intake;
v) studies relating diseases or health outcomes to food consumption or nutrient intake; and
vi) studies without available abstract.

Studies also had to meet all of the following inclusion criteria to be included to the present review:

i) studies with 24 h recall or food record method;
ii) studies on adult populations at age 15 and more;
iii) studies addressing at least EI (but preferably also the intake of other nutrients, especially micronutrients); and
iv) studies with description of misreporting, identifying misreporters.

After the abstract review, sixty-nine references that seemed to be relevant were selected. Full texts of these candidate papers were obtained and reference lists from these papers and reviews dealing with the topic were reviewed to identify additional candidate references. We added fourteen references from bibliographies, resulting in eight-three papers identified for full text review. Finally, after full text review we found thirty-seven studies that met our inclusion criteria to be evaluated.

Data extraction

For each included study, data were extracted into an Excel file, with independent duplicate extraction of a random sample of 15 % by a second reviewer. Data extracted by both reviewers were compared to verify correctness. Data extracted included general identification of the paper (authors, year of publication, title, journal and name of study), characteristics of study (assessment method, reference method, number of days of assessment method, selected days), characteristics of subjects (number, sex, age, BMI, nationality, sampling method of the study population, subgroups), assessment of intake and activity parameters (including assessment of portion size/weight, energy and nutrients, physical activity and EE), misreporting evaluation (method of identifying misreporting, validation of the method, exclusion of misreporters) and results of misreporting evaluation (magnitude of misreporting, percentage of under- and overreporters). Studies were divided into three categories according to the assessment method used. We included sixteen studies using 24 hour recall(6–21), eleven studies with estimated food record(1,3,22–30) and eleven studies with weighed food record(4,30–39). One study used both estimated and weighed food records(30), leading to a total of thirty-eight studies. The overview of relevant studies is shown in Table 1.

Results

Determinants

The characteristics of energy-intake underreporters have been the subject of interest in several studies, reviewed in detail by Livingstone & Black(40).

BMI. This seems to be the most consistent factor related to underreporting. The probability that a subject will underreport generally increases with higher BMI. Twelve studies from the final selection found BMI as a significant predictor of underreporting(3,7,10,12,13,23–26,28,29,37), but four studies did not support this and found no statistically significant effect of BMI on reporting accuracy(18,27,30,32).

Age and sex. Both have been associated with energy underreporting. Studies studying this determinant found a higher proportion of LER among women and older subjects(10,25,30,39). However, some inconsistencies were found. Johnson *et al.* (39) found an association with female sex but none with age.

Socio-economic status and education. Five studies found lower socio-economic class and lower level of education as predictors of underreporting(4,12,24,25,31).

Health-related activities. These include smoking and dieting, and have often been linked with energy underreporting(4,7,10,24,41,42). From the final selection, three studies considered smoking as a determinant of misreporting(4,7,10). All of them found a higher prevalence of underreporters in smokers compared with non-smokers. A higher prevalence of dieters was found in the group of underreporters in both relevant studies looking at this(10,24).

Psychological factors. Psychological factors were discussed by several authors(43–45) and have been assessed with a variety of instruments to investigate their impact on energy underreporting(1,19,45) or even to exclude those participants who might tend to misreport due to psychological factors from

Table 1. Characteristics of studies evaluating magnitude of misreporting

									Magnitude of misreporting		
	Sex (*n*)	BMI	Number of days (d)	Portion size	Physical activity	Energy intake (MJ)	Energy expenditure (method)	Evaluation method	Under/over-estimation of EI	% of Under-reporters	% of Over-reporters
Studies using 24 hour recall method											
Harrison *et al.*(6)	4586 *v.* 3010 Women	Ranged (BMI >30/37 *v.* 20 subjects)	1 d *v.* 2 d	Measuring aids – not clear	No	Not mentioned	Calculated BMR (Schofield)	Goldberg cut-off 0·92	Not evaluated	W: 10 % Egyptians *v.* 35 % Americans	Not evaluated
Johansson *et al.*(7)	94 M, 99 W	Mean about 25	10 d in 1 year	Full size illustrations + household measures	Yes – PAQ	8·1 (M 9·2, W 6·9)	Estimated BMR	Goldberg cut-off 1·35	Not evaluated	67 % (M 61 %, W 72 %)	Not evaluated
Mirmiran *et al.*(8)	390 M, 511 W	Mean M 25, W 26	2 d	Household measures	No	10·0 (M 11·5, W 8·5)	Calculated BMR (Schofield)	Goldberg cut-off lower 1·35, higher 2·39	Not evaluated	31 % (W 40 %, M 19 %)	Not evaluated
McKenzie *et al.*(9)	88 W	25–39·9 (mean 32)	2 d	2D food models	Yes accelerometer	W 8·4	BMR measured	Goldberg cut-off (different cut-offs for different activity levels)	Not evaluated	29·5 % W	2·3 % W
Briefel *et al.*(10)	7769 M and W	Not mentioned	1 d	Not mentioned	No	9·1 (M 10·9, W 7·2)	Calculated BMR (Schofield)	Goldberg cut-off 0·9	Not evaluated	23 % (M 18 %, W 28 %)	Not evaluated
Olafsdottir *et al.*(11)	53 W	Mean 25·0	2 d	Measuring guides	No	W 9·5	Calculated BMR (Schofield)	Goldberg cut-off 1·35	Not evaluated	10 % W	Not evaluated
Klesges *et al.*(12)	11 663 M and W	Mean 25·65	1 d	Estimation	No	Not mentioned	BMR measured	Goldberg cut-off 1·16	Not evaluated	31 %	Not evaluated
Johnson *et al.*(14)	35 W	Mean 28·3	4 d in 14 d	Not mentioned	No	W 9·2	DLW	EI compared with EE (DLW), Goldberg cut-off: UR < 0·71, OR > 1·29	W under-estimated by 17 %	34 % W	3 % W
Subar *et al.*(13)/ Tooze *et al.*(45)	261 M, 223 W	Categories	2 d	Food models	Yes – PAQ	8·5 (M 9·2, W 7·8)	DLW	EI compared with EE (DLW), identif. of UR and OR based on 95 CI	EI under-estimated by 14 % (M 11 %, W 17 %)	21·5 % (W 22 % M 21 %)	W 1 % M 1·6 %
Lissner *et al.*(15)	211 M, 179 W	Not mentioned	2 d	Yes, but not clear	No	9·2 (M 10·4, W 7·9)	DLW	EI compared with EE (DLW)	EI under-estimated by 12·8 % (M 11·5 %, W 14 %)	Not evaluated	Not evaluated
Jonnalagada *et al.*(16)	45 M, 33 W	17·3–39·8 (mean 26·5)	2 × 3 d	2D visual aids + household measures	No	9·7 (M 11·2, W 8·1)	Estimated EE	Comparison with EI to weight maintenance	EI overesti-mated by 12 % (M 11 %, W 13 %)	Not evaluated	Not evaluated

Table 1. *Continued*

									Magnitude of misreporting		
	Sex (*n*)	BMI	Number of days (d)	Portion size	Physical activity	Energy intake (MJ)	Energy expenditure (method)	Evaluation method	Under/over-estimation of EI	% of Under-reporters	% of Over-reporters
Conway *et al.*(17)	49 W	20–45 (mean 29·7)	1 d	USDA food model booklet + ruler, measuring cups and spoons	No	W 10·0	No	Comparison with actual intake	Not evaluated	4 % W	6 % W
Poppitt *et al.*(18)	33 W	Mean 32·9	1 d	Household measures	Yes – PAQ	W 13·3	Calculated BMR (Schofield)	Comparison with actual intake	W underreported EI by 12·5 %	Not evaluated	Not evaluated
Ard *et al.*(19)	79 M, 71 W	Mean 28·9	1 d	Measuring guides	No	13·1 (M 15·5, W 10·7)	No	Comparison with actual intake	Range of over-reporting: M 6·7 % to 8·7 % W 9·3 % to 1·7 %	Not evaluated	Not evaluated
Conway *et al.*(20)	42 M	Mean 27·6	1 d	Measuring guides	No	M 14·9	Calculated BMR (Schofield)	Comparison with actual intake	M overestimated by 8 %	Not evaluated	Not evaluated
Kahn *et al.*(21)	139 M, 105 W	≧ 30–25 subj.	1 d	Not mentioned	No	Not mentioned	No	Protein intake compared with urine nitrogen	Protein intake: M over-reported by 12–19 %	Not evaluated	Not evaluated
Studies using estimated food record method											
Lafay *et al.*(22)	529 M, 504 W	Mean M 24·8 W 23·5	3 d	Household measures	No	8·1 (M 9·3, W 6·9)	Calculated BMR (Schofield)	Goldberg cut-off 1·05	Not evaluated	16 %	Not evaluated
Samaras *et al.*(23)	436 W	17–41·9 (mean 24·3)	7 d	Not mentioned	Yes – PAQ	W 7·8	BEE from Garby formula (Danish)	Goldberg cut-off 1·35	Not evaluated	W 32 % (18 % in healthy weight, 39 % overweight, 44 % obese)	Not evaluated
Luhrman *et al.*(24)	105 M, 238 W	Mean 26·8	3 d	Household measures	No	9·0	RMR by indirect calorimetry	Goldberg cut-off 1·07	Not evaluated	11·9 % (M 16·2 %, W 7·6 %)	Not evaluated
Hirvonen *et al.*(25)	1523 M, 1686 W	Not mentioned	3 d	Picture booklet	No	1982: 10·1, 1992: 9·1	Calculated BMR (Schofield)	Goldberg cut-off 1·27	Not evaluated	1982: 30 % (M 27 %, W 33 %) 1992: 44 % (M 42 %, W 46 %)	Not evaluated
Price *et al.*(3)	960 M, 938 W	Not mentioned	7 d	Household measures	Yes – PAQ	8·0 (M 9·0, W 7·0)	Calculated BMR (Schofield)	Goldberg cut-off 1·10	Not evaluated	20·6 % (M 18·5 %, W 22·7 %	4·10 %
Mahabir *et al.*(26)	65 W	Mean 27·7	7 d	Estimation	No	W 6·8	DLW	EI compared with EE (DLW)	W underestimated by 37 %	Not evaluated	Not evaluated

Table 1. *Continued*

									Magnitude of misreporting		
	Sex (*n*)	BMI	Number of days (d)	Portion size	Physical activity	Energy intake (MJ)	Energy expenditure (method)	Evaluation method	Under/over-estimation of EI	% of Under-reporters	% of Over-reporters
Koebnick *et al.*[27]	13 M, 16 W	Mean 23·4	4 d	Photographs, household measures and portion sizes	No	9·7	DLW	EI compared with EE (DLW), >20 % deviation = misreporters	EI under-estimated by 14 % (W 14 %, M 15 %	31 %	7 %
De Vries *et al.*[30]	119 M, 150 W	Mean 22·1	3 d	Study 1–3: scales, study 4–6: household measures	No	10·6 (M 12·8, W 8·8)	Required intake	Comparison with EI to weight maintenance	EI under-estimated by 10·4 % (W 12·2 %, M 8·0 %)	Not evaluated	Not evaluated
Kretsch *et al.*[28]	22 W	Mean 27·8	7 d	Household measures	Yes – physical activity record	W 8·6	No	Comparison with EI to weight maintenance	W under-estimated by 14·6 %: normal weight by 9·7 %, obese by 19·4 %	Not evaluated	Not evaluated
Asbeck *et al.*[1]	28 M, 55 W	Mean M 23·9 W 22	7 d	Household measures + attributes large/medium/small	Yes – physical activity record	8·6 (M 12·6, W 8·3)	REE by indirect calorimetry, TEE = REE × 1·55	EI - TEE >20 % defined as significant misreporters	EI under-estimated by 7·2 % (W 11·2 %, M 3·1 %)	37 % (M 14·3 %, W 49 %)	3·5 % (M 8·3 %, W 1 %)
Hoidrup *et al.*[29]	175 M, 173 W	Mean M 25·2 W 23·5	7 d in 3 week	Household measures, photo series	Yes – PAQ	9·0 (M 10·5, W 7·4)	TEE = BMR + PAL	EI compared with estimated TEE	EI under-estimated by 20 %	Not evaluated	Not evaluated
Studies using weighed food record method											
Cook *et al.*[31]	558 M, 539 W	Mean 26·6	4 d	Dietary scales	No	Not mentioned	Calculated BMR (Schofield)	Goldberg cut-off 1·1	Not evaluated	38·5 (M 29 %, W 48 %)	Not evaluated
Barnard *et al.*[32]	7 M, 9 W	19–33 (mean 24·9)	7 d	Measuring cups, spoons, dietary scales	Yes – PAQ	10·7 (M 12·8, W 8·2)	DLW, EE determined from PAQ	Goldberg cut-off accurate reporters 0·79 ≧ EI/EE ≤ 1·21	Not evaluated	Inaccurate reporters: 20 % M, 33·3 % W	See under-reporting
Bingham *et al.*[33]	160 W	Not mentioned	4 d	PETRA scales	No	W 7·8	Calculated BMR (Schofield)	Goldberg cut-off 1·2	Not evaluated	W 23 %	Not evaluated
Livingstone *et al.*[40]	28 M, 22 W	Mean 24·6 (adults)	7 d	Dietary scales	No	Not mentioned	DLW, BMR by indirect calorimetry	Goldberg cut-off accurate reporters 0·55 ≧ EI/EE ≤ 1·25	Not evaluated	14·3 % adults	0 % Adults
Martin *et al.*[35]	29 W	Mean 23·1	7 d	Dietary scales, household measures	Physical activity recall	W 6·8	DLW	EI compared with EE (DLW)	W under-estimated by 20 %	Not evaluated	Not evaluated
Tomoyasu *et al.*[36]	28 M, 36 W	20·5–45·1	3 d	Dietary scales, measuring instruments	Yes – PAQ	8·8 (M 9·7, W 7·9)	RMR by indirect calorimetry, peak VO2	EI compared with EE (DLW)	Underestimation by 11·7 % (M 13·6 %, W 9·8 %)	Not evaluated	Not evaluated

Table 1. *Continued*

									Magnitude of misreporting		
	Sex (*n*)	BMI	Number of days (d)	Portion size	Physical activity	Energy intake (MJ)	Energy expenditure (method)	Evaluation method	Under/over-estimation of EI	% of Under-reporters	% of Over-reporters
Tomoyasu *et al.*(37)	39 M, 43 W	Mean 24·9	3 d	Dietary scales, measuring instruments	No	7·8 (M 8·7, W 6·9)	RMR measured + calculated from Weir's equation	EI compared with EE (DLW)	Underestimation by 20·2 % (M 22·7, W 17·8)	Not evaluated	Not evaluated
Livingstone *et al.*(38)	16 M, 15 W	Mean 25·5	7 d	Dietary scales	Yes – method not mentioned	8·9 (M 10·6, W 7·1)	DLW, BMR by indirect calorimetry	EI compared with EE (DLW) and with BMR (cut-off 1·35)	Underestimation by 20 % (M 21 %, W 19 %)	29 %	Not evaluated
Pryer *et al.*(4)	1087 M, 1110 W	Mean 24·75 (M 25·2, W 24·3)	7 d	Calibrated dietary scales	No	Not mentioned	Calculated BMR (Schofield)	EI < 1·2 BMR… LER	Not evaluated	37·5 % (W 46 %, M 29 %)	Not evaluated
De Vries *et al.*(30)	119 M, 150 W	Mean 22·1	3 d	Study 1–3: scales, study 4–6: household measures	No	10·6 (M 12·8, W 8·8)	Required intake	Comparison with EI to weight maintenance	Underestimation by 10·4 % (M 8·0 %, W 12·2 %)	Not evaluated	Not evaluated
Johnson *et al.*(39)	81 M, 56 W	Mean 24·8 (M 25·3, W 24·3)	3 d	Dietary scales, measuring cups and spoons	Yes – PAQ	8·5 (M 9·8, W 7·1)	RMR measured, EE calculated (Weir's equation)	EI compared with TEE	Overestimation by 18 % (M 12 %, W 24 %)	Not evaluated	Not evaluated

W, women; M, men; PAQ, physical activity questionnaire; DLW, doubly labelled water; EI, energy intake; EE, energy expenditure; BEE, basal energy expenditure; REE, resting energy expenditure; TEE, total energy expenditure; LER, low-energy reporters, PAL, physical activity level.

the study sample(46). The instruments used were: Fear of Negative Evaluation Scale that measures a level of concern a person has about the opinion another person has of her or him; Stunkard–Sorensen body silhouettes measuring person's deviation of body image from healthy or ideal; Marlowe–Crowne Social Desirability Scale that measures social desirability, what the tendency is of some persons to respond with what is perceived to be a socially appropriate response rather than an objective response(45), or Stunkard–Menssick's Three-Factor Eating Questionnaire. Depression, which can influence reporting accuracy by impairing cognitive processes, is often evaluated in research settings using the Beck depression inventory, which screens the presence and severity of depression(44).

Eating habits. Eating habits of respondents also influence misreporting. For example, in the OPEN study(13,45), underreporting tended to increase with higher intakes. It appears that the more respondents consume, the more difficult it is to report consumption accurately, perhaps because remembering more foods or larger portion sizes is challenging or because of societal pressure to consume less. Higher percentage of energy from fat and variability in number of meals per day were among the best predictors of underreporting in women and eating frequency was the best predictor of underreporting in men.

Other sources of misreporting

Respondent memory lapses. Respondent memory lapses may affect recall methods in two ways: the respondent may fail to recall foods actually consumed (errors of omission) or may report foods that were not consumed during the recalled day (errors of commission)(47).

Misrepresentation of portion size consumed. Misrepresentation of portion size consumed can arise from respondents failing to quantify accurately the amount of food consumed, or from misconceptions of an 'average' portion size. It is a problem in both 24 hour recalls and estimated food records. Respondents differ in their ability to accurately estimate portion sizes visually. Such discrepancies vary with the type and size of food(47). Large errors may occur, for example, when estimating foods high in volume but low in weight(48). The estimation then needs a correction.

The measurement aids commonly used to assist in the estimation of portion size in the present review were household measures (fifteen studies), drawings and photographs (six studies), and food models (two studies). In some studies, a clear description of the portion-size measurement aids was not provided(6,14,21).

Methods used to identify misreporting

Biomarkers – doubly labelled water. The doubly labelled water (DLW) technique is the gold standard for measuring EE under free-living conditions. This method was used in nine studies (24 %) included in the present review. The subjects are given a dose of water enriched with the stable isotopes ^{2}H and ^{18}O. Urine samples are collected at baseline before administration of the dose and subsequently either daily or at the beginning and end of the measurement period. It is recommended to verify the completeness of urine collection by the *para*-aminobenzoic acid check: participants take a known amount of *para*-aminobenzoic acid as tablets and urinary recovery is assessed(13). The urine samples are analysed to determine the rate of disappearance of each isotope from the body. The measurement period is most usually 14 d in adults(14,26,27,32). EE calculated is then compared with the reported EI and the deviation is expressed as magnitude of misreporting (as a percentage of EE or as an absolute deviation in kJ or kcal). In most of the DLW studies in the present review, the validity of the group mean EI was measured.

Urinary biomarkers. Nitrogen excretion levels in 24 h urine samples are used to validate 24 h protein intake. It was used in two studies in the present review(21,33). Completeness of urine collection is verified by the *para*-aminobenzoic acid check, as described above. Within-subject variation in daily nitrogen excretion of individuals may be large, and repeat collections of consecutive 24 h urine samples are necessary if the method is to be used to validate the protein intakes of individuals(47).

The urinary excretion of certain other nutrients for which urine is the major excretory route has also been used as a biomarker of dietary intake. Na excretion can be used as a measure of dietary Na intake. Day-to-day fluctuations in Na excretion are larger than those for nitrogen. Hence, even more collections are required to correctly characterise Na excretion in an individual. For K, the situation is similar.

Goldberg cut-off. Currently it is becoming a convention to express reported EI as a multiple of BMR and to use this index (EI/BMR) in relation to expected EE as a validity check for negative bias in EI(49,50). The so-called Goldberg cut-off method was the most commonly used method for identifying misreporters in the present review – seventeen relevant studies (46 %). The principles of the Goldberg cut-off and the statistical derivation of the equation to calculate it were described originally by Goldberg *et al.* (50). More recently, the principles have been restated and the factors to be used are in the equation revised by Black(51). The present paper provides guidance for its application and comments on its usefulness and limitations. It points out that the technique has not always been fully understood or correctly applied. The Goldberg equation calculates the confidence limits (cut-offs) that determine whether the mean reported EI is plausible as a valid measure of food intake even if chance has produced a dataset with a high proportion of genuinely low (or high) intake(51).

Physical activity. The sensitivity of the Goldberg cut-off was improved when subjects were assigned to low, medium and high activity levels and different physical activity levels and cut-off values were applied to each level(52). This strategy depends on being able to choose suitable physical activity levels values, which is not always easy. It also depends on being able to measure activity or total EE in individuals. The 'gold standard' for measuring EE is the DLW technique. Other techniques include heart rate monitors, accelerometers, activity diaries and simple questionnaires. Each has its own associated errors and limitations. Five studies using the Goldberg cut-off measured physical activity. Four studies used physical activity questionnaires and one study used an accelerometer(9).

BMR. BMR for the calculation of the Goldberg cut-off can be either measured or estimated from predictive equations. Some studies measure a classical BMR using indirect calorimetry where subjects spend the previous night in the place of measurement and BMR is measured immediately upon waking with minimal physical disturbance. It should be measured lying at rest, in a thermo neutral environment and in a fasting state. Indirect calorimetry was used in three studies in the present review(9,12,38). Other studies measured RMR, when subjects are brought to the place of measurement early in the morning and RMR is measured after a period of quiet rest (four studies). Alternatively, BMR can be predicted from standard age- and sex-specific equations derived by Schofield(53) and recommended by FAO/WHO/UNU (1985). Fourteen relevant studies estimated BMR (eleven of them used it for the Goldberg cut-off calculation), almost all of them, except two, used the Schofield equation. One study used the Garby formula that was developed and validated for Danish populations using the direct accurate measures of body composition from dual energy X-ray absorptiometry scanning(23) and in one study it was not specified what equation was used(7).

Other methods. Another method to validate reported dietary intake is to compare it with the actual intake of subjects. Actual intake is obtained by direct observation of people eating during the study period. This method attempts to measure absolute validity, but it is very time consuming and presents some practical difficulties. It was used in four studies in the present review. All of them were on a relatively small sample and the period of intake assessment was just 1 d(17–20).

Three studies compared reported EI with EI needed for weight maintenance(16,28,30). They supplied each individual with a diet that met his or her energy requirements, as judged by stable body weight during the trial.

Three studies directly compared reported EI with calculated total EE(1,29,39).

Energy-intake misreporting

The magnitude of misreporting depends on the nutritional assessment method used, thus it will be described separately for the 24 hour recalls and the food records. Data from relevant studies are shown in Table 1. The magnitude of misreporting can be expressed as the prevalence of misreporting or as the extent of under- or overestimation of intake. The prevalence of misreporting is expressed as a percentage of misreporters in the study sample. It is best assessed by using the Goldberg cut-off. The under- or overestimation of intake is calculated by subtracting mean EE (or observed EI) from mean reported EI. A positive number represents underreporting and a negative number means overreporting. It is usually expressed as a percentage of EE.

24 Hour recall. The available data of mean percentage of underreporters in studies using the 24 hour recall method ranged from 21·5 to 67 % (median 31). For men, it was 18–61 % (median 20) and for women 4–72 % (median 28·8). When we exclude the highest number, which comes from a study in older subjects having a BMI about 25 and that may be considered as an outlier(7), the ranges change to 21·5–31 % (median 27) in both sexes, 18–21 % (median 19) in men and 4–40 % in women (median 28).

Overreporting was found in 40 % of studies evaluating the prevalence of misreporting. Four studies (9,13,14,17) evaluated overreporting in women and it ranged from 1 to 6 % (median 2·6 %). The only study evaluating the prevalence of overreporting in men showed 1·6 % of overreporters(13).

EI was underestimated by 12·8 % in one study(15) and by 14 % in a second study(13) (median 13·4) – only two studies were available with data for both sexes together. The rest of the studies stratified for sex and underestimation of EI appeared to be higher in women than men. Three studies found overestimation of EI(16,19,20). In one of them(19), men overestimated by 6·7–8·7 % and women from 9·3 % to 11·7 %, one found men to overestimate by 11 % and women by 13 %(16), and in the last one, the reported intake of men was 8 % higher than the actual intake, but the difference was not found to be significant(20).

Estimated food records. The percentage of underreporters in studies using estimated food records ranged from 11·9 to 44 % (median 30): for men it was 14·3–42 % (median 18·5) and for women 7·6–49 % (median 32·5).

Overreporting was evaluated in 43 % of studies with data on prevalence of misreporting. The range was 3·5–7 % (median 4·1).

EI underestimation ranged from 7·2 to 20 % (median 12·2) and it was higher in women than men. There was no case of overestimation of EI.

Weighed food records. The percentage of underreporters in studies using weighed food records ranged from 14·3 to 38·5 % (median 33·3). The percentage of underreporters could not be evaluated separately in men and women, because only two studies reported this(4,31). Only one study evaluated overreporting but did not find any overreporter(40).

EI was underestimated on average from 10·4 to 20·2 % (median 18) and was not different between men and women. One study found overestimation of EI and it was higher in women than men(39).

Comparison of the percentage of underreporters and the extent of underestimation in studies using 24 hour recalls and food records is given in Table 2. There was no significant difference between the medians of percentage of misreporters for all three methods (24 hour recall, estimated and weighed food record; $P > 0·05$), the median was approximately 30 %.

Table 2. Underestimation of energy intake (EI) and percentage of underreporters (UR) in studies using 24 hour recalls and food records (Ranges and medians of data from each study) $P > 0·05$, differences between medians of each method

	Underestimation of EI (%)			Prevalence of UR (%)		
Type of study	Number of studies	Median	Range	Number of studies	Median	Range
24 Hour recall	2	13·4	12·8–14·0	5	31·0	21·5–67·0
Estimated food record	4	12·2	7·2–20·0	7	30·0	11·9–44·0
Weighed food record	5	18·0	10·4–20·2	4	33·3	14·3–38·5

Misreporting of macro- and micronutrients

We looked at studies assessing intake of macro- or micronutrients besides intake of energy and compared the intake between groups of LER and non-LER and separately for men and women. Usable data of macronutrient intake were found in eight papers(1,3,4,8,10,22,24,31) and for micronutrient intake in seven papers(3,4,8,10,24,25,31).

Four studies compared absolute intakes of macronutrients and results were consistent for all macronutrients(3,8,22,54). LER had significantly lower absolute intakes of the energy-yielding macronutrients – protein, carbohydrates, and fat than non-LER (data not shown). Seven studies expressed the intake of macronutrients as a percentage of energy(1,3,4,10,22,24,31). The results of these studies are quite inconsistent for carbohydrates and fat. There was one study with significantly higher and another with significantly lower percentage of energy from carbohydrates in non-LER compared with LER(4,10). The rest of the studies did not show statistically significant differences. The percentage energy from fat was more often higher in non-LER than LER, significantly so in three studies(3,10,31). However, studies also showed the opposite result, although not being statistically significant(1,4). For protein intake, results were more consistent. Higher percentage of energy from protein was found in LER than non-LER. In four studies, the difference was significant for both sexes(3,4,10,31).

The list of micronutrients assessed in each study differed, but Fe, Ca and vitamin C were assessed in all of them, so we focused on these three micronutrients. Results are shown in Table 3. Five studies compared absolute amount of intake(3,8,10,24,25) and five compared micronutrient densities

Table 3. Daily intake of Fe, Ca and vitamin C in low-energy reporters (LER) and non-LER as absolute numbers and energy densities

		Absolute numbers			Energy densities		
Study	Energy reporters	Fe (mg)	Ca (mg)	Vitamin C (mg)	Fe (mg/E)	Ca (mg/E)	Vitamin C (mg/E)
24 Hour recall							
	Men						
Mirmiran *et al.*(8)	LER	21·0	598	100			
	Non-LER	28·0	716**	130**			
	Women						
	LER	15·0	512	98			
	Non-LER	22·0**	636*	130**			
	Men						
Briefel *et al.*(10)	LER	10·3	513	79			
	Non-LER	19·5**	1043**	124**			
	Women						
	LER	8·1	437	71			
	Non-LER	14·0**	803**	104**			
Estimated food record							
Luhrman *et al.*(24) (density mg/MJ)	Men						
	LER	10·8	739	83·8	1·63	111	12·6
	Non-LER	15·2***	997**	120·5**	1·48	98	11·7
	Women						
	LER	7·8	674	77·5	1·55	138	16·1
	Non-LER	12·6***	1010***	117·2***	1·48	120	13·7
Hirvonen *et al.*(25) (density mg/MJ)	Men						
	LER	13·5	914	117·0	1·74	116	15·2
	Non-LER	20·4***	1420***	148·0***	1·66*	115	12·3***
	Women						
	LER	11·0	802	132·0	1·18	136	22·0
	Non-LER	15·6***	1170***	159·0***	1·67***	125**	17·3***
Price *et al.*(3) (density mg/MJ)	Men						
	LER	10·0	715	60·0	1·50	100	8·6
	Non-LER	14·0***	1031***	69·0***	1·30***	95*	6·4***
	Women						
	LER	9·0	624	58·0	1·40	114	10·7
	Non-LER	12·0***	887***	69·0***	1·60***	106**	8·3***
Weighed food record							
Pryer *et al.*(4) (density mg/1000 kcal)	Men						
	LER				5·7	382·2	29·3
	Non-LER				5·6	382·0	26·5
	Women						
	LER				6·3	430·4	37·1
	Non-LER				6·0**	422·3	34·4
Cook *et al.*(31) (density mg/1000 kcal)	Men						
	LER				6·1	443·7	36·4
	Non-LER				5·8*	443·2	34·2
	Women						
	LER				6·6	499·7	47·1
	Non-LER				5·8***	466·1**	38·6***

Mean values were significantly different for non-LER *v.* LER: $^*P<0·05$, $^{**}P<0·01$, $^{***}P<0·001$.

per 1 MJ or 1000 kcal$^{(3,4,24,25,31)}$. When comparing absolute numbers of micronutrient intake, the results were consistent for all three micronutrients: LER of both sexes had lower intakes of Fe, Ca and vitamin C than non-LER. The differences were significant in all studies except one, where it was not significant for Fe in men. Male LER reported on average 32 % and female LER 33 % lower intakes of Fe than non-LER. For Ca, the differences were similar, 33 *v.* 32 %. In addition, for vitamin C men LER reported on average 26 % and women LER 25 % lower intakes than non-LER. When intakes of micronutrients were energy adjusted by the density method, the results were not that consistent, but energy densities of micronutrients tended to be slightly higher in LER than non-LER. For Fe, the difference was significant in four of five studies$^{(3,4,25,31)}$, for Ca it was significant only in three studies and more often for women$^{(3,25,31)}$. For vitamin C, the difference was significant in three studies, in two cases for both sexes and in one case only for women$^{(3,25,31)}$.

Discussion

The selected studies showed several determinants of misreporting although the evidence was not always consistent. BMI was found to be a strong determinant of misreporting in many studies, although it has to be taken into account that not all obese persons underreport, and not all normal-weight persons provide valid reports. Martin$^{(35)}$ found that underreporting of EI appears to occur across a broad spectrum of body weight and BMI. Although many studies found higher proportion of underreporters among women, it remains unclear whether men underreport to a lesser degree than women, or whether they underreport to the same degree but from a higher energy requirement and therefore fewer fall below a single cut-off applied across all subjects$^{(52)}$. Relevant studies from the present review identified socio-economic status and education as a determinant of underreporting. But other studies besides the final selection found LER to be from higher socio-professional class and having higher education levels$^{(45,54)}$. Poor literacy skills in the less educated might be expected to result in underreporting; however, health or diet consciousness in the better educated or those of higher socio-economic status might prompt the same response. Besides the determinants mentioned earlier, there are additional possible determinants of misreporting, such as a behavioural effect. It is described as a change in eating behaviour during the study period. Subjects often change their dietary habits in order to make reporting easier, leading to reporting that is not based on their normal diets$^{(44)}$. This error is specific for the food record method or announced 24 hour recalls.

Identifying the presence of misreporting and its magnitude provides the foundation for handling it. However, it is not clear what method is the best to use. Although DLW provides an independent and objective measure of EE and is easy to use in the field because it places minimal burden on the subjects' activities, it has some limitations. It is unfortunately extremely expensive, because it requires sophisticated laboratory and analytical back-up; therefore, it cannot be used as a routine tool for validating EI data$^{(40)}$. The various measures used to estimate the plausibility of self-reported intake (DLW, urinary markers, cut-off equations and comparison with estimated or measured EE) makes comparison among studies difficult. The same method is not even always used in a standardised way. For example, in using the EI: BMR ratio, different equations for BMR and different cut-off points are applied to identify underreporters. Very little difference was found in sensitivities of Goldberg cut-off using measured and calculated BMR$^{(52)}$. No advantage of using measured BMR in large epidemiological studies was found. However, it was shown that using measured BMR can avoid some misclassifications that might be important in small studies where individual data have greater influence on results and conclusions. Black$^{(52)}$ recommended to use a physical activity level value appropriate to the study population based on information about physical activity or lifestyle$^{(49)}$. This information is most often gained from physical activity questionnaires. When such questionnaires are used in large-scale studies, they are required to be simple, easy to administer and easy to analyse. Most physical activity questionnaires have been primarily designed to document high-intensity exercise. However, much of the variation between subjects comes from differences in time spent sitting, standing and moving about – activities that are difficult to quantify. A questionnaire that elicits the pattern of the general lifestyle, occupational activity and leisure activity is required$^{(51)}$. If the measurement of EE is obtained, EI may be compared directly with it and the Goldberg cut-off is irrelevant. In small studies where it is desirable to obtain a measure of EE, detailed activity diaries or the use of accelerometers or heart rate monitoring are possible instruments to apply$^{(49)}$.

The magnitude of EI misreporting was expected to be the lowest in studies using weighed food records, because the error caused by incorrect estimation of portion sizes is minimised when using this assessment method. However, the analysis of available data did not support this presumption. There was no significant difference between the medians of percentage of misreporters for all three methods (24 hour recall, estimated and weighed food record), the median was approximately 30 % and medians of percentage underestimation of EI was even slightly higher for weighed food record (18 %) than for the other two methods (13·4 % in 24 hour recall and 12·2 % in estimated food record), although the difference was again not significant (Table 2). The result that the magnitude of misreporting was not lower for weighed record studies could be caused by a smaller number of weighed food record studies providing data on the percentage of underreporters (four studies), but it is possible that subjects in weighed food record studies did not underreport, but underate as a result of the previously described behavioural effect. To avoid this bias, it should be a routine to monitor a change in body weight between the beginning and the end of the study.

Many studies evaluate the magnitude of underreporting, determinants of underreporting and characteristics of underreporters, but less emphasis is given to studying overreporting. Although the prevalence of overreporting seems to be lower, concentrating only on underreporting might lead to other bias in dietary surveys.

Conducting the present systematic review, we have recognised that most of the information about misreporting and its magnitude is limited to EI misreporting. Only a few studies aimed at validating reported intake of micronutrients and studying which micronutrients were misreported and to what degree. Some of the studies evaluating EI misreporting assessed intake of macro- and micronutrients as well and thus made it possible to compare intake of macro- and micronutrients between groups of LER and non-LER. The studies did not always use the same definition of non-LER and LER, and we did not make general comparisons as we were not able to redefine it. Absolute intakes of all macronutrients were lower in underreporters, as could be expected. However, it is more important to observe how the percentage of energy from each macronutrient differs between underreporters and adequate reporters. The results identified were only for protein and were quite consistent, showing that LER had a higher percentage of energy from protein than non-LER. For fat and carbohydrates, the results were not clear.

We made the comparisons between LER and non-LER only for three micronutrients – Fe, Ca and vitamin C – because the intake data of these micronutrients were available from all studies. Based on the results of these three micronutrients, the conclusion would be that misreporting of micronutrients goes hand in hand with misreporting of energy. However, it was not always found to be the rule for all the micronutrients(4,8). Unfortunately, there is a lack of data to provide conclusions for all micronutrients. At least we know that when assessing the intake of Fe, Ca or vitamin C, it has to be taken into account that with underreporting of energy, there could be about 30 % underreporting of these nutrients as well.

We cannot avoid misreporting, but we can try to lower its prevalence by taking misreporting and its determinants into account when designing the study and choosing appropriate methodology and standardised procedures. Because one of the main factors influencing misreporting in the recall method is respondents' memory lapses, we could try to minimise this by several ways.

Multiple-pass dietary interviews, automated by the use of a microcomputer, are now used in many national surveys. It minimises the omission of possible forgotten foods and standardises the level of detail for describing foods and the method to elicit specific details for certain food items(47).

Memory aids like plastic food, coloured paintings, photographs can also help reduce memory lapses. Additionally, when they are available as a range of graduated portions, they have the advantage of reducing portion-size measurement error. Minimising the time period between the actual food intake and its recall will reduce respondent memory lapses in recall methods(47). In one study, financial incentive was used to motivate subjects and to improve accuracy in dietary recall in a sample of overweight females, but no change was found in reported EI or the number of underreporters between groups with and without the financial incentive(55).

Interpersonal communication between the subject and the interviewer is also important. To minimise the influence of psychological determinants of misreporting it is necessary to use the right language, to promote understanding between the researcher and the subject, and to motivate the subject.

The existence of measurement error in dietary assessment can have serious consequences when interpreting dietary data. Underreporting of EI results in serious overestimates of nutrient inadequacies(47). Smith *et al.* (56) have shown that the proportion of subjects with intakes less than recommended daily allowance for Fe, Zn, Ca and K decreases significantly when EI underreporters are excluded. The existence of measurement error attenuates correlations between nutrient intake and the outcome parameters, so that important associations between diet and disease may be attenuated. There are some studies that investigated selective underreporting of specific foods and beverages, but this analysis was beyond the scope of the present review. However, selective underreporting of certain foods may hamper the usefulness of dietary data for developing food-based dietary guidelines. Efforts to overcome this problem have led some investigators to exclude underreporters from the dataset. However, such an approach introduces a source of unknown bias into the dataset and is not recommended(47). Moreover, excluding only underreporters, but not overreporters, introduces another source of bias. A possible way to solve this, when assessing intake of several nutrients, could be to identify misreporters and to assess the intake of the group with and without misreporters. The difference between these amounts could be then used as a part of uncertainty evaluation.

Another approach is to include all the respondents, but to control for EI by the use of statistical methods. Several methods for *energy adjustment* exist, and their choice and justification for their use is debated. The selection of the appropriate model depends on the particular research question of interest and should be consulted with a statistician(47). Four models have been proposed for accounting for total EI when one is examining the effect of nutrients on disease outcomes: the standard multivariate model; the energy-partition model; the nutrient density model; the residual model(40). The most commonly used methods of energy adjustment are the nutrient density method and the residual method(4,8). The nutrient density method is used as an absolute amount of nutrients divided by total EI. This method of adjustment is dependent on the changes in EI, such that energy-adjusted amounts of nutrients obtained by using this method are still correlated with EI. Therefore, using the nutrient density method is not appropriate in studies looking for the diet–disease relationship. When using the residual method, amounts of nutrients are independent from total EI(8). The residual method is done through the use of linear regression with total EI as the independent variable and intake of the nutrient of interest as the dependent variable. In the cases where the nutrient variables are skewed, they should be transformed to improve normality before their use in the regression. The energy-adjusted nutrient intake of each subject is determined by adding the residual – that is, the difference between the observed nutrient values for each subject and the values predicted from the regression equation – to the nutrient intake corresponding to mean EI of the study population(47). A cross-sectional study in Iran(8) determined the effect of underreporting of EI on the estimates of nutrient intakes. It was found that the absolute intakes of macro- and micronutrients (except for B_{12} in females and B_6 and Zn in both sexes) were lower in underreporters, but following the residual method of energy adjustment, no significant differences were seen. Because underreporting of EI was found to affect the estimates of nutrient intake, they suggest making energy adjustment in studies aimed at determining the association between a certain chronic disease and nutrient intake. In the OPEN study, when protein was adjusted for EI by using either the nutrient density or nutrient residual, the attenuation in estimated disease relative risk was less severe. However, micronutrients were not studied(57). Possible ways of how to handle misreporting when assessing the intake of several nutrients could then be: (i) to compare intakes of the group with and without misreporters and then use the difference as a part of uncertainty evaluation; or (ii) to use energy adjustment methods (nutrient density or residual method with usage of linear regression analysis).

Acknowledgements

The studies reported herein have been carried out within the EURRECA Network of Excellence (www.eurreca.org), financially supported by the Commission of the European Communities, specific Research, Technology and Development Programme Quality of Life and Management of Living Resources, within the Sixth Framework Programme, contract no. 036196. The present report does not necessarily reflect the Commission's views or its future policy in this area. K. P. wrote the first manuscript, J. R., J. V., M. J. and P. V. draft discussed, rearranged and finally revised. There has been no conflict of interest. The authors of the present paper would like to thank Dr Margaret Ashwell, Dr Janet Lambert, Dr Adriënne Cavelaars, Dr Olga Souverein and Mrs Sandra Crispim for their technical contribution to the present publication.

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