

Review article

The validity of self-reported energy intake as determined using the doubly labelled water technique

R. J. Hill* and P. S. W. Davies*†

School of Human Movement Studies, Faculty of Health, Queensland University of Technology, Brisbane, Queensland, Australia

(Received 7 December 1999 – Revised 20 October 2000 – Accepted 20 October 2000)

In the 1980s the development of the doubly labelled water (DLW) technique made it possible to determine the validity of dietary assessment methods using external, independent markers of intake in free-living populations. Since then, the accuracy of self-reported energy intake (EI) has been questioned on a number of occasions as under-reporting has been found to be prevalent in many different populations. This paper is a review of investigations using the DLW technique in conjunction with self-reported EI measures in groups including adults, children and adolescents, obese persons, athletes, military personnel and trekking explorers. In studies where a person other than the subject is responsible for recording dietary intake, such as parents of young children, EI generally corresponds to DLW determined energy expenditure. However, in instances where the subjects themselves report their intake, EI is generally under-reported when compared with energy expenditure. It was originally believed that this phenomenon of under-reporting was linked to increased adiposity and body size, however, it is now apparent that other factors, such as dietary restraint and socio-economic status, are also involved. This paper therefore aims to present a more comprehensive picture of under-reporting by tying in the findings of many DLW studies with other studies focusing particularly on the characteristics and mechanisms for under-reporting. Awareness of these characteristics and mechanisms will enable researchers to obtain more accurate self-reports of EI using all dietary recording techniques.

Self-reported energy intake: Doubly labelled water: Energy expenditure: Under-reporting

The ability to assess the energy intake of a person or group of subjects accurately is of vital importance in many areas of nutrition, clinical medicine, human biology and sports science. The importance lies within the fact that in many instances dietary intake data, collected from a representative sample of apparently normal, healthy individuals, is used as a guide to estimate the nutritional requirements of the general population (Committee on Dietary Allowances, Food and Nutrition Board, 1980). Thus, measurements of energy intake (EI) are often used to determine the minimum intake of energy or a specific nutrient that is

the requirement to maintain normal body function and health. The use of measures of EI is not restricted to the general population, however, with many studies using dietary assessment techniques to determine the energy requirements of special populations, for example, in disease states such as cystic fibrosis (Anthony *et al.* 1998; Collins *et al.* 1998; Reilly *et al.* 1999). A further use for dietary information is in nutrient balance investigations where measured nutritional status is expressed in relation to reported dietary intake. Previous investigations into the EI, and thus requirements, of certain groups have been based

Abbreviations: DLW, doubly labelled water; EE, energy expenditure; EI, energy intake.

* **Current address:** Children's Nutrition Research Centre, Department of Paediatrics and Child Health, Royal Children's Hospital, Herston, Brisbane, Queensland 4029, Australia.

† **Corresponding author:** Dr P. S. W. Davies, fax +61 7 3636 1981, email ps.davies@mailbox.uq.edu.au

on the assumption that the various dietary reporting techniques are valid and accurate (Morgan *et al.* 1978; Jain *et al.* 1980; Silman, 1980; Bingham *et al.* 1982).

The several methods available for obtaining information regarding dietary intake can be divided into three general categories, notably: (1) recall of foods eaten, (2) diet histories or retrospective questionnaires, and (3) diet records (Morgan *et al.* 1978; Barrett-Connor, 1991). Diet recalls are designed to quantitatively assess recent nutrient intake and usually involve the recollection of all foods consumed during the previous 24 h (Morgan *et al.* 1978). This method however, is not representative of habitual intake, which is often of interest in studies of diet and health (Barrett-Connor, 1991). In contrast, diet histories and food-frequency questionnaires provide better estimates of usual or habitual diet and dietary patterns at the group level, however, there are problems associated with recall, seasonality (Barrett-Connor, 1991) and their ability to identify individual differences in EI (Gibson, 1990). Diet records, involving the weighing or quantifying (usually in household measures) of all food and drink consumed over a period typically ranging from 3 to 7 d, has often been considered the most accurate and precise method of dietary assessment (Gibson, 1990; Barrett-Connor, 1991). However, the need to weigh and record intake over several days can be seen as tedious and time consuming and thus is often associated with poor compliance and/or an alteration of the diet during the recording period (Barrett-Connor, 1991; Black *et al.* 1993).

Until the 1980s it was not possible to determine the validity of dietary assessment methods using external, independent markers of intake in free-living populations. The development of the doubly labelled water (DLW) technique (Schoeller & van Santen, 1982; Coward *et al.* 1985), however, using the stable isotopes ^2H and ^{18}O to measure CO_2 production rate and hence energy expenditure (EE), has since made it possible to validate EI measures such as dietary records. This is based on the fundamental principal of energy metabolism that states EE and EI are equal under conditions of stable body weight and composition (Schoeller, 1990). Consequently, it has since been demonstrated that EI assessed via self-reported diet records are often underestimated by the reporter (Livingstone *et al.* 1992). This conclusion has been drawn from studies investigating many different groups of subjects including children and adolescents (Livingstone *et al.* 1992), adults (Livingstone *et al.* 1990), athletes (Westerterp *et al.* 1986) and obese individuals (Prentice *et al.* 1986).

The reasons behind the underestimation of dietary intake are not well known (Mertz *et al.* 1991), however, several studies have suggested a link between increased adiposity and under-reporting (Heitmann, 1993; Crawley & Summerbell, 1997; Lafay *et al.* 1997). It has further been suggested that poor body image and weight consciousness also play a significant role. Heitmann (1993), Crawley & Summerbell (1997) and Lafay *et al.* (1997) all conclude that inaccurate reports of EI appear to be an artifact of dieting and dietary restraint rather than adiposity alone.

As an underestimation of the diet consumed will lead to false conclusions when attempting to establish the nutritional requirements of a certain group, it is therefore

important that populations at risk of under-reporting be identified (Black *et al.* 1993; Hill & Davies, 1999). This present review will therefore discuss the findings of recent research regarding the underestimation of nutritional intake in various groups of subjects and the role of DLW in discovering the phenomenon. Although Black *et al.* published a similar review in 1993, the use of the DLW technique has increased and thus there is much new data that should be addressed, especially with respect to more active populations.

The validation of energy intake using doubly labelled water

EI may be defined as the energy content of the food consumed in a daily diet that is subsequently available for metabolism (Seale & Rumpler, 1997). EE is the mechanical work performed by the body and the heat released to sustain life and lifestyle. The principle behind the validation of measures of EI using measures of EE is that of energy balance. Energy balance occurs when EI equals EE under conditions of stable body weight (McArdle *et al.* 1985). If EI is not matched by EE then energy balance no longer exists and change in body weight will result. Thus, if EI exceeds EE, a positive energy balance results and excess energy will be stored as body fat (adipose tissue). Alternatively, when EI is in deficit with respect to EE, that is, negative, body weight will be lost. Thus, due to this fundamental principle of energy metabolism the energy requirements of certain populations may be determined from either EI or EE. Basiotis *et al.* (1987) suggest a 'precise' estimate of EI is one that, 95 % of the time, is within 10 % of the true intake of a group. Due to the lack of a better alternative prior to the development of the DLW technique for human subjects and the low cost associated with dietary assessment methods in comparison with DLW, there has previously been greater usage of EI to determine dietary recommendations in large studies of nutrition and health. Unfortunately, as will be outlined later, the accuracy of these methods is doubtful in many populations.

Evidence of under-reporting

In recent years, numerous studies comparing self-reported EI with EE assessed via DLW have emerged in the literature. From this growing body of research it is now apparent that there is a generalized under-reporting of food intake in many subject groups ranging from children and teenagers to the elderly. This phenomenon is also prevalent in many special groups including obese individuals, athletes, military personnel and trekking explorers.

Tables accompany the section following as there are a large number of studies validating self-reports of EI using the DLW technique. Table 1 includes investigations of self-reported intake and DLW measured EE in adults and Tables 2–4 contain studies of children and adolescents, obese subjects, and athletes, respectively. Where possible, the EE reported in the tables are those adjusted for changes in body weight over the study period rather than the subjects actual EE.

Table 1. Previous research investigating the self-reported energy intake of adults compared with energy expenditure measured using doubly labelled water

Author	Subjects	EI method	EI (MJ/d)	EE (MJ/d)	% Difference*
Bathalon <i>et al.</i> (2000)	60 F classified as RE (mean age 60 years; <i>n</i> 26) and URE (mean age 59 years; <i>n</i> 34)	FFQ, three 24 h recalls and 7 d WR	URE 8.30 (WR) 7.60 (24 h) 7.40 (FFQ) RE 7.10 (WR) 6.60 (24 h) 6.50 (FFQ)	URE† 8.52 (WR) 8.44 (24 h) 8.64 (FFQ) RE† 8.12 (WR) 8.11 (24 h) 8.23 (FFQ)	URE +7 % (WR) −2 % (24 h) −8 % (FFQ) RE −6 % (WR) −13 % (24 h) −14 % (FFQ)
Black <i>et al.</i> (1997)	18 F aged 50–65 years; 27 M aged 55–87 years	4 d weighed record in each season (total 16 d)	8.30 F 10.06 M 9.34 total	9.50 F 11.67 M 10.78 total	−11 % F −12 % M −11 % total
Clark <i>et al.</i> (1994)	12 F divided into LG and SML eaters aged 27–51 years	5 d weighed record	10.49 (LG) 5.89 (SML)	8.48 (LG) 10.82 (SML)	+19 % (LG) −46 % (SML)
Goran & Poehlman (1992)	6 F and 7 M aged 56–78 years (mean 67 years)	3 d food record	5.99 (F) 9.73 (M) 8.00 (total)	8.75 (F) 11.19 (M) 10.07 (total)	−31 % (F) −12 % (M) −21 % (total)
Howat <i>et al.</i> (1994)	44 F divided into C (<i>n</i> 26) and EXP (<i>n</i> 18) groups aged 18–50 years	14 d food records; pre and post 24 h recalls‡. C, food model training; EXP, models and photographs	7.74 (C) 8.43 (EXP) 8.03 (total)	9.92 (C) 10.63 (EXP) 10.21 (total)	−22 % (C) −21 % (EXP) −21 % (total)
Johnson <i>et al.</i> (1994)	81 M aged 56–78 years; 56 F aged 56–81 years	3 d food record	9.84 (M) 7.13 (F)	11.14 (M) 9.33 (F)	−12 % (M) −24 % (F)
Johnson <i>et al.</i> (1998)	35 low-income females aged 19–46 years	Four multiple-pass 24 h recalls (two by phone and two in person)	9.19	11.23	−17 %
Jones <i>et al.</i> (1997)	29 women aged 49 years	7 d weighed record	7.08	9.56	−26 %
Kroke <i>et al.</i> (1999)	28 males and females aged 35–67 years	3 x 24 h recalls/season (total 12)‡; self-administered FFQ	9.05 (FFQ)	11.23 (FFQ)	−22 % (FFQ)
Livingstone <i>et al.</i> (1990)	16 M, 15 F aged 17–54 years (mean 32 years for M, 36 years for F)	7 d weighed record	11.21 M 8.00 F 9.66 total	14.23 M 9.93 F 12.15 total	−19 % M −18 % F −20 % total
Martin <i>et al.</i> (1996)	29 women aged 49 years	7 d weighed record	6.98	9.00	−20 %
Pannemans & Westerterp (1993)	17 M aged 72 years; 11 F aged 67 years assigned to DR or DQ groups	<i>n</i> 16 filled in a 4 d WR; <i>n</i> 12 DQ. Subjects re-fed self-reported EI during DLW measurement	10.09 WR 9.29 DQ	10.13 WR 9.25 DQ	0 % WR 0 % DQ
Prentice <i>et al.</i> (1986)	13 lean F aged 26–40 years (mean 29 years)	7 d weighed record	8.16	7.99	+2 %
Reilly <i>et al.</i> (1993)	11 F aged 68–79 years (mean 73 years)	3 d weighed record	6.71	9.21	−27 %
Riumallo <i>et al.</i> (1989)	6 M aged 20–32 years (mean 27 years) less than 90 % ideal weight for height	Consecutive 24 h recalls for 7 d over two periods (validated by written record)	11.21	11.36	−1 %
Rothenberg <i>et al.</i> (1998)	9 F and 3 M mean age 73 years	Diet history	8.62	9.90	−12 %

Table 1. *continued*

Author	Subjects	EI method	EI (MJ/d)		EE (MJ/d)		% Difference*	
			Y	O	Y	O	Y	O
Sawaya <i>et al.</i> (1996)	10 F aged 25 years (Y) and 10 F aged 74 years (O)	7 d WR; two 24 h recalls; and two FFQ (Willett, F1 and the Fred Hutchinson Cancer Research Centre (FHCRC), F2)	7.96 (WR) 8.51 (24 h) 7.89 (F1) 6.78 (F2)	5.85 (WR) 5.66 (24 h) 7.41 (F1) 5.66 (F2)	9.82	7.52	-19 % (WR) -13 % (24 h) -16 % (F1) -29 % (F2)	-22 % (WR) -16 % (24 h) +7 % (F1) -16 % (F2)
Schulz <i>et al.</i> (1989)	4 M and 2 F aged 20–30 years (mean 24 years)	14 d weighed record	13.28		13.28		+1 %	
Seale & Rumpler (1997)	11 F aged 52 years and 8 M aged 50 years	7 d weighed record	7.88 (F) 8.96 (M) 8.34 (total)		9.57 (F) 12.91 (M) 10.97 (total)		-18 % (F) -30 % (M) -23 % (total)	
Singh <i>et al.</i> (1989)	4 F aged 27 years (NPNL) and 9 lactating F aged 23 years (L)	11 d weighed record	6.05 (NPNL) 4.24 (L)		12.17 (NPNL) 10.40 (L)		-50 % (NPNL) -59 % (L)	
Taren <i>et al.</i> (1999)	37 F aged 44 years	3 d food records after 45 min training with food models	8.25		9.33		-12 %	
Tomoyasu <i>et al.</i> (1999)	39 M aged 70 years; 43 F aged 68 years	3 d weighed record	6.86 (F) 8.73 (M)		8.35 (F) 11.30 (M)		-18 % (F) -23 % (M)	
Velthuis-te Wierik <i>et al.</i> (1995)	Subgroup of 8 M aged 35–50 years (mean 43 years) in an intervention study	7 d food record	11.80 (before intervention)		14.30 (before intervention)		-17 % (before intervention)	
Westerterp <i>et al.</i> (1996)	9 F, 10 M assigned FF diet group; 8 F, 10 M assigned to RF diet group, aged 20–35 years	Four 3 d food records over 6 months	FF: 6 month report 11.00 (M) 9.20 (F) 10.10 (total) RF: 6 month report 10.40 (M) 9.10 (F) 9.80 (total)		FF: 6 month report 14.30 (M) 10.80 (F) 12.70 (total) RF: 6 month report 13.00 (M) 11.50 (F) 12.20 (total)		FF: 6 month report -21 % (M) -15 % (F) -20 % (total) RF: 6 month report -20 % (M) -16 % (F) -21 % (total)	

EI, energy intake; EE, energy expenditure; RE, restrained eater; URE, unrestrained eater; FFQ, food-frequency questionnaire; WR, weighed record; M, male; F, female; LG, large; SML, small; C, control; EXP, experimental; DQ, dietary questionnaire; DLW, doubly labelled water; Y, young; O, Old; NPNL, non-pregnant non-lactating; L, lactating; FF, full fat; RF, reduced fat.

* Values correspond to EI as a function of EE. Thus, a negative value indicates under-reporting.

† A different total EE is given for each EI method due to the use of the corresponding EI method's RER in the EE calculation.

‡ Indicates results not given.

|| EE determined from prediction equation developed using DLW.

Adults

Using a subsample of the Northern Ireland Diet and Health Study, Livingstone *et al.* (1990) found under-reporting in both adult men (*n* 16) and women (*n* 15). The authors assessed EI via a 7 d weighed record during the 14 d measurement of EE using DLW and found a significant difference between intake and expenditure in both sexes, with a mean bias to under-reporting of -19 % and -18 % EI in men and women respectively. However, when the subjects were divided into tertiles of the reported EI, that is, low, middle and high EI groups, it was found that the bias toward under-reporting was not uniform across tertiles. Both male and female subjects in the lowest and middle thirds of EI were found to under-report, however, those comprising the top third of the group showed good

agreement with expenditure. This suggests there is differential reporting within populations.

Further studies investigating the nutritional habits of adults have also detected the underestimation of habitual intake. Martin *et al.* (1996), in a study of women participating in a long-term dietary-intervention trial to determine the incidence of breast cancer, found a bias of over 20 % towards the under-reporting of food intake. Similarly, Seale & Rumpler (1997) found nineteen adult male and female subjects under-recorded their intake by 23 %. These values are also in accordance with other studies of adults using various methods to assess dietary intake (Sawaya *et al.* 1996; Jones *et al.* 1997; Johnson *et al.* 1998; Kroke *et al.* 1999).

In an attempt to determine whether training would improve the accuracy of dietary recording, Howat *et al.*

Table 2. Previous research investigating the self-reported energy intake of children and adolescents compared with energy expenditure measured using doubly labelled water

Author	Subjects	EI method	EI (MJ/d)	EE (MJ/d)	% Difference*	
Bandini <i>et al.</i> (1990)	14 M and 14 F aged 12–18 years	2 week food record	9.00	11.53	–20 %	
Bandini <i>et al.</i> (1997)	109 F aged 8–12 years	7 d food record	7.00	8.03	–12 %	
Bandini <i>et al.</i> (1999)	10 M and 12 F aged 12–18 years (mean 15 years)	14 d food record	9.00	11.71	–22 %	
Barden <i>et al.</i> (2000)	29 children with SCD and 23 Con (mean age 11 years)	3 d weighed record by subjects and caretakers	7.62 (SCD) 7.95 (Con)	7.21 (SCD) 8.10 (Con)	+6 % –2 %	
Bratteby <i>et al.</i> (1998)	25 M and 25 F mean age 15 years	7 d weighed record	11.40 (M) 8.28 (F)	13.82 (M) 10.70 (F)	–18 % (M) –22 % (F)	
Champagne <i>et al.</i> (1996)	11 AA, F (<i>n</i> 5) and M (<i>n</i> 6); 12 C, F (<i>n</i> 6) and M (<i>n</i> 6) of mean age 11.4 years	8 d food record (lunch recorded by nutritionist)	6.40 (AA;F) 6.95 (AA;M) 8.49 (C;F) 8.82 (C;M)	9.54 (AA;F) 11.59 (AA;M) 9.67 (C;F) 10.33 (C;M)	–33 % (AA;F) –40 % (AA;M) –12 % (C;F) –15 % (C;M)	
Champagne <i>et al.</i> (1998)	56 AA, F (<i>n</i> 27) and M (<i>n</i> 29); 62 C, F (<i>n</i> 31) and M (<i>n</i> 31) of mean age 10 years	8 d food record (lunch recorded by nutritionist and parental assistance for other meals and snacks)	6.50 (AA;F) 7.54 (AA;M) 7.16 (C;F) 8.81 (C;M)	9.02 (AA;F) 10.62 (AA;M) 9.66 (C;F) 10.77 (C;M)	–26 % (AA;F) –28 % (AA;M) –24 % (C;F) –17 % (C;M)	
Davies <i>et al.</i> (1994)	81 children aged 1.5–4.5 years	4 d weighed record completed by parent	4.77	4.93	–3 %	
Johnson <i>et al.</i> (1996)	12 M and 12 F aged 4–7 years	Three multiple-pass 24 h recalls	6.31 (M) 6.68 (F) 6.50 (total)	7.02 (M) 6.43 (F) 6.72 (total)	–10 % (M) +4 % (F) –3 % (total)	
Kaskoun <i>et al.</i> (1994)	22 M and 23 F aged 4.2–6.9 years	Willett FFQ completed by parent	9.13 (M) 9.11 (F) 9.12 (total)	5.84 (M) 5.63 (F) 5.74 (total)	+56 % (M) +62 % (F) +59 % (total)	
Livingstone <i>et al.</i> (1992)	41 M and 37 F aged 3–18 years divided into age groups	Diet histories (DH) in all age groups; 7 d WR aged 7–18 years	DH 5.91 6.55 8.48 9.28 11.95 11.62 12.83	WR N/A 5.26 (3 years) 6.09 (5 years) 7.62 (7 years) 8.45 8.78 (9 years) 10.54 (12 years) 9.08 11.71 (15 years) 9.28 13.50 (18 years)	DH WR +12 % N/A +8 % N/A +11 % +7 % +6 % –3 % +13 % –11 % +1 % –22 % –2 % –27 %	
Stallings <i>et al.</i> (1996)	61 SQCP and 37 Con aged 2–18 years (mean 9 years SQCP and 6 years Con)	3 d weighed record	5.83 (SQCP) 6.63 (Con)	4.03 (SQCP) 6.93 (Con)	+45 % (SQCP) –2 % (Con)	

EI, energy intake; EE, energy expenditure; M, male; F, female; SCD, sickle cell disease; Con, control; AA, African-American; C, Caucasian; FFQ, food-frequency questionnaire; DH, diet history; WR, weighed record; N/A, not available; SQCP, spastic quadriplegic cerebral palsy.

* Values correspond to EI as a function of EE. Thus, a negative value indicates under-reporting.

(1994) studied forty-four women, previously identified as being restrained eaters or disinhibitors, aged between 18 and 50 years. The eighteen subjects allocated to the experimental group were trained with a combination of food models and life-size food photographs, however, the twenty-six in the control group were trained with food models only. The ability of the subject groups to estimate food portions was tested both before training and 3 and 11 d after training. Although the percentage errors of estimation decreased across the three tests, both groups

overestimated portion sizes. In effect, this would result in a greater self-reported EI when compared with EE. However, over the same period, subjects' EI was assessed by two unannounced 24 h recalls (one before and one after training) and 14 d food records. Both groups still under-reported their EI as compared with their DLW measured EE by 22 % and 21 % for the control and experimental subjects, respectively. The authors speculated that in contrast to the food recording period, as the subjects did not consume the foods during the portion tests, other

Table 3. Previous research investigating the self-reported energy intake of obese persons compared with energy expenditure measured using doubly labelled water

Author	Subjects	EI method	EI (MJ/d)	EE (MJ/d)	% Difference*
Bandini <i>et al.</i> (1990)	14 M and 13 F obese adolescents aged 12–18 years	2-week food record	7.26	14.18	–46 %
Bandini <i>et al.</i> (1999)	10 M and 11 F obese adolescents aged 12–18 years (mean 14 years)	14 d food record	7.39	13.87	–45 %
Black <i>et al.</i> (1995)	1 M and 10 F post-obese adults aged 21–51 years	21 d weighed record (half traditional method and half PETRA cassette system)	7.16	9.73	–27 %
Buhl <i>et al.</i> (1995)†	10 obese adults of mean age 39 years	14 d food record	4.26†	10.34†	–59 % Total group –7 %
Goris <i>et al.</i> (2000)‡	30 obese M, mean age 44 years	7 d food record	10.40‡	16.70	–37 % (26 % under-eating; 12 % under-recording)
Lichtman <i>et al.</i> (1992)	16 obese diet resistant adults aged 48 years Group 1 (<i>n</i> 10) experimental; Group 2 (<i>n</i> 6) control	14 d weighed record	4.30(Group 1) 7.09 (Group 2)	8.71 (Group 1) 9.98 (Group 2)	–47 % (Group 1) –19 % (Group 2)
Prentice <i>et al.</i> (1986)	9 obese F aged 23–38 years (mean age 29 years)	Two 7 d weighed records	8.28	10.22	–19 %

EI, energy intake; EE, energy expenditure; M, male; F, female.

* Values correspond to EI as a function of EE. Thus, a negative value indicates under-reporting.

† Values (MJ/d) not given for entire study population (one subject excluded due to overestimation of EI compared with EE).

‡ EI adjusted for changes in body weight not reported (authors state 12 % under-reporting after adjustment).

Table 4. Previous research investigating the self-reported energy intake of athletes compared with energy expenditure measured using doubly labelled water

Author	Subjects	EI method	EI (MJ/d)	EE (MJ/d)	% Difference*
Branth <i>et al.</i> (1996)	6 M offshore racing sailors	No individual data. Food inventory averaged for crew members	17.10	19.30	–11 %
Davies <i>et al.</i> (1997)†	6 M and 6 F young Chinese gymnasts	4 d weighed record	7.30	8.39	–13 %
Edwards <i>et al.</i> (1993)	9 F endurance runners	7 d food diary	8.53	12.51	–32 %
Haggarty <i>et al.</i> (1988)	4 elite F runners	21 d weighed diet record	9.70	14.61	–34 %
Hill & Davies (1999)	11 F classical ballet dancers	4 d weighed record	10.19	12.98	–21 %
Schulz <i>et al.</i> (1992)	9 F elite distance runners	6 d diet record	10.28	11.82	–13 %
Sjödin <i>et al.</i> (1994)	4 F and 4 M cross-country skiers	5 d weighed record (F), 4 d weighed record (M)	18.20 (F) 30.20 (M)	18.30 (F) 30.20 (M)	–1 % (F) 0 % (M)
Trappe <i>et al.</i> (1997)	5 elite F swimmers	2 d diet record	13.10	23.4	–43 %
Westerterp <i>et al.</i> (1986)	5 M cyclists during the Tour de France	Food diary kept over 3 weeks	24.50 (week 1) 26.30 (week 2) 23.20 (week 3)	29.40 (week 1) 36.00 (week 2) 35.70 (week 3)	–13 % (week 1) –21 % (week 2) –35 % (week 3)

EI, energy intake; EE, energy expenditure; M, male; F, female.

* Values correspond to EI as a function of EE. Thus, a negative value indicates under-reporting.

† Diet recording assisted by dietitians.

factors, such as what they thought the size of the portion should be, did not bias their perception of portion size. This phenomenon of persistent under-reporting even with training was also documented by Taren *et al.* (1999). These authors used three-dimensional food models, serving utensils, plates, bowls and other commonly used measures for estimating portion sizes during a 45 min training session. However, EI was still underestimated by 12 % in their female subject group.

To date, there have been several investigations dealing with the energy metabolism of people who consider themselves 'small-eaters' or 'large-eaters' but are of normal and static weight (Morgan *et al.* 1982; McNeill *et al.* 1989; Clark *et al.* 1992, 1993). These studies reported that compared with weight matched 'small-eaters', 'large-eaters' consumed on average nearly twice as much energy per d. As a result of this finding it was suggested that the 'small-eaters' were more metabolically efficient than the 'larger eaters'. By using DLW to measure EE it was, however, shown that this was not in fact the case but that under-reporting was prevalent in the 'small-eaters' group. In a study by Clark *et al.* (1994), in comparison with the 'large-eaters' who overestimated their intake by 19 %, the 'small-eaters' under-reported their EI by 46 %.

The theory of 'metabolic efficiency' has also been used to explain the low self-reported intakes of persons in developing nations. Previous reports of EI in non-pregnant, non-lactating Gambian women suggested that these individuals had a reduced energy requirement (Prentice, 1984), however, DLW studies have since shown that this is not the case (Singh *et al.* 1988, 1989). It was found that EE expressed either as a multiple of resting metabolic rate or as a function of fat-free mass, did not give evidence of reduced energy needs, as it was slightly elevated compared with similar women in developed countries. In addition, these studies found the persistence of low reported food intakes in these women but only minimal changes in body weight, indicating the significant under-reporting of EI.

The misrepresentation of the food consumed also occurs in older adults and elderly people. Pannemans & Westerterp (1993) conducted a study in the elderly where subjects reported their dietary intake via either a 4 d diet record or diet questionnaire and were then subsequently fed their reported intake for 3 weeks. Energy requirements, assessed using DLW, were found to be greater in both groups and consequently weight loss occurred during the re-feeding period due to the subjects being in negative energy balance.

Reilly *et al.* (1993) used a 3 d diet record to obtain data regarding the EI of ten healthy elderly women aged 68–79 years. Self-reported EI was found to be 27 % lower than EE, measured over 14 d, and there was no change in body weight over the study period. When the authors expressed their subjects' reported EI as a ratio to BMR, six out of the ten subjects had values < 1.27. According to the Food and Agriculture Organization/World Health Organization/United Nations University (1985) a value of 1.27 is merely a survival requirement and as such, does not take into account activities of daily life such as food preparation, personal hygiene routines or the energy required to earn a living. Hence, values < 1.27 are physiologically

implausible with respect to long-term health and thus, cannot be representative of habitual intake.

Although to a smaller extent than other studies, under-reporting was also encountered by Black *et al.* (1997) in their validation of energy and nitrogen intake of older adults against 24 h urinary nitrogen excretion and DLW assessed EE. As a group, the subjects, aged 50–87 years, misrepresented their food intake by 11 %, with males and females not differing substantially in their degree of under-reporting. Correspondingly, Rothenberg *et al.* (1998) found under-reporting of EI of 12 % in their combined gender subject pool. Their aim was to investigate the validity of a diet history when compared with EE measured using DLW.

In contrast, Johnson *et al.* (1994) found differential reporting between sexes in their study participants. Their subjects were of similar age to Black *et al.* (1997) (56–81 years), however, while males under-reported by 12 %, women participants showed greater misrepresentation and underestimated their intake by 24 %. However, Johnson *et al.* (1994) did not use DLW to measure the EE of their subjects but rather, a prediction equation developed using DLW by Goran & Poehlman (1992). The Goran & Poehlman study was conducted on six women and seven men (56–78 years) and resulted in the derivation of prediction equations for energy requirements based on maximal O₂ uptake and the energy cost of leisure time activity. It is questionable however, whether an equation developed using such a small sample size is representative of the larger population. Goran & Poehlman indicate that this is a limitation of their equations and state the purpose of the equations is to allow the comparison of data from future studies. Johnson *et al.* (1994) argue the use of the aforementioned prediction equation was appropriate as their sample was physiologically and geographically similar to the original sample from which the equation was generated.

Sawaya *et al.* (1996), interested in determining if different groups exhibited a similar bias to under-reporting, studied the self-reported intakes of healthy older and younger women using four commonly employed intake methods while simultaneously measuring EE via DLW. The subjects, of mean age 25.2 years for the younger group and 74.0 years for the older group, completed a 7 d weighed record during which their EE was also measured over 7 d. Once at the commencement, and again at the end of this period, subjects were administered a 24 h recall, two different food-frequency questionnaires and a questionnaire that assessed the extent of dietary restraint. In both groups, self-reported EI was less than EE for all methods except measurement one of the Willett food-frequency questionnaire in older women. There was no significant difference between the two age groups for any of the methods used to obtain EI information. The authors however, do state that the effects of age may have not been apparent due to their small subject pool and that further studies are needed to determine if a real bias exists.

A further finding of the Sawaya *et al.* (1996) study was that the second assessments of EI, taken after the 7 d weighed intake period, were lower than the first, suggesting that the process of recording food consumption was associated with a subsequent decrease in reported dietary

intake. The authors propose that this was probably the result of under-eating due to the subjects' small loss of body weight over the study interval. However, as the mean weight loss was less than would be expected if a change in diet was the sole source of the difference between the measurements, the authors postulate that it is more likely to be due to a combination of both under-eating and under-reporting. Increased self-consciousness about the foods consumed over the weighing period may have manifested itself in under-reporting.

Children and adolescents

There is increasing evidence to show that dietary habits formed early in life have a considerable impact on long-term health status (Blair *et al.* 1996; O'Neil *et al.* 1997; Buttriss 1999; Power *et al.* 1999). Thus, the adequacy of the diets of children and adolescents and accuracy in their assessment is of vital importance. Research has previously shown that in studies involving younger children where dietary records are completed by a parent or guardian, good agreement can be found between reported intake and DLW measured EE (Livingstone *et al.* 1992; Davies *et al.* 1994; Johnson *et al.* 1996), and in some instances, EI may even be overestimated (Kaskoun *et al.* 1994). Studies investigating older children and adolescents however, where the onus is on the child or adolescent to record intake, have again shown a potential bias to under-reporting.

Livingstone *et al.* (1992) studied the dietary habits of seventy-eight children and adolescents aged between 3 and 18 years using both weighed records and diet histories. With respect to the 7 d weighed record, under-recording was apparent in the age groups 12, 15 and 18 years with differences of -11 %, -22 % and -27 %, respectively. In these older age groups the responsibility for recording was placed on the subjects rather than the parents, as for the younger age groups. In contrast to the weighed record, the diet history method showed good agreement, with a slight tendency for overestimation, across all age groups whether the subject or the parent completed the assessment. This led the authors to the conclusion that diet histories overcame the age-related reporting bias of weighed records at the group level, however, with respect to the individual, precision was still lacking.

In a group of twenty-three African-American and white sixth-grade students of both sexes (mean age 11.4 years) under-reporting was also found to be prevalent (Champagne *et al.* 1996). In this case, under-recording was found to be higher in boys as a group and African-Americans as a group. EI was 12 % and 15 % less than EE in white girls and boys respectively, and 33 % and 40 % less in African-American girls and boys respectively. An interesting feature of this study was that the children's lunch intake was recorded by a nutritionist. A further study by Champagne *et al.* (1998) of 118 children (mean age 10 years) found similar results. Their subjects were divided into categories according to ethnicity, sex, age and body fat (i.e. lean, obese and distribution of fat), and their EI was assessed using an 8 d diet record with parental assistance. Again, compared with DLW measured EE, under-reporting increased with increasing age in all groups and African-

American children under-reported their intake to a greater extent than white children, with African-American boys showing the largest degree of under-recording. The authors state, however, that their findings were surprising as efforts had been made to increase the accuracy of the dietary intake data since their previous study.

Consistent with the bulk of the literature are findings by Bandini *et al.* (1990). In twenty-eight lean adolescents of mean age 14.4 years, self-reported EI was approximately 20 % less than DLW-measured EE. Even when reported food intake was adjusted for changes in body weight it was still significantly different from EE. In a further study by Bandini *et al.* (1997), 109 preadolescent girls self-reported EI 12 % lower than EE. As with the authors' previous study (Bandini *et al.* 1990), the difference between EI and EE increased with increasing age and total EE. Bandini *et al.* (1997) suggest that cases of under-reporting by adolescents may in part be due to the subject not wanting their parents to know all the foods they have eaten and concern over their parents having access to their diet records.

Bratteby *et al.* (1998) studied a similar age group to Bandini *et al.* (1990) (mean age 15 years) in response to suggestions that sedentary lifestyles with low EI and EE are prevalent amongst Swedish children and adolescents. Comparing EI assessed via a 7 d weighed record against EE determined using DLW, the authors found the adolescents' EI were not low but rather that they were underestimated. EI was under-reported by 18 % for boys and 22 % for girls. Under-reporting was additionally found to be particularly apparent in subjects with increased body fat content. Their results contradicted the previously held beliefs of low EI, EE and physical activity in adolescents in Sweden.

Obese populations

There is a vast body of literature addressing the energy requirements of obese individuals. Within this literature dietary intake records frequently indicate that obese subjects generally consume less or the same amount of energy than non-obese controls (Johnson *et al.* 1956; Hampton *et al.* 1967; Baecke *et al.* 1983; Kromhout, 1983; Braitman *et al.* 1985). This has perplexed many researchers and led to the development of several explanations for the persistence of a subject's obesity including the reduction of one or more components of total EE (Ravussin *et al.* 1988; Griffiths *et al.* 1990). DLW has, however, shone light on the issue and linked the so-called low intake to under-reporting.

One of the earliest papers to validate EI against EE assessed the self-reported energy intake of obese persons aged 29 years and compared it with EE measured via DLW (Prentice *et al.* 1986). The authors matched obese subjects with lean individuals of similar height, social class and occupation and found that in contrast to the accurate reporting of dietary intake in the lean individuals, obese persons, on average, underestimated their food records by 19 %.

More recent research has shown similar results. Buhl *et al.* (1995) and Lichtman *et al.* (1992) found a mean underestimation of nutritional intake of 59 % and 47 %

respectively, in adult obese subjects. It must be noted, however, that the findings of Buhl *et al.* (1995) are reported at both the group level (n 10) and without the inclusion of one subject's data (shown earlier). In fact, the 10th subject overestimated their EI by 12 %, and if all results are included, the degree of under-reporting is reduced to 7 %.

Under-reporting has also been detected in obese adolescents (Bandini *et al.* 1990). Comparison of EI from a 2-week food diary with EE measured by DLW showed that the obese teenagers studied were in negative energy balance by 45 %. Further research by Bandini *et al.* (1999) involved additional analysis of the data from the aforementioned 1990 study to determine whether the consumption of high-energy low-nutrient-dense foods was higher in obese adolescents compared with non-obese. The results indicated that the percentage of energy, after adjustment for under-reporting, from high-energy foods did not differ between the obese and non-obese adolescents studied and thus, excess energy in the diet may come from a variety of food sources, not only high-energy snacks.

It may therefore be assumed that the failure of most obese subjects, both adults and adolescents included, to lose weight despite a self-reported low dietary intake is explained by the significant under-reporting of usual food consumption.

The underestimation of habitual intake is also evident in post-obese persons. Black *et al.* (1995) have reported misrepresented EI compared with DLW assessed energy requirements in these individuals. The authors used a 10 d weighed record, the PETRA system of recording weight and food description on cassette, and two diet histories administered before and after the study. The results were reported as a combination of all diet analysis methods and it was found the post-obese subjects under-reported food intake by a mean 27 %.

Athletes

For groups of individuals who regularly expend high amounts of energy on a daily basis, adequate nutrition is a primary concern. One such group of individuals are endurance trained athletes. In the event of the under-reporting of nutritional intakes in this group it is difficult to accurately recommend energy requirements and thus both health and performance may consequently suffer. Unfortunately, the underestimation of EI is also widespread in this population and thus is a pressing issue for sports scientists working in this field.

Many investigations into the EI of athletes began as a result of anecdotal and scientific reports that athletes were able to take in small amounts of food in the face of high EE because they were 'metabolically efficient' (Mulligan & Butterfield, 1990; Edwards *et al.* 1993). This concept has already been mentioned previously and was, until the advent of studies using DLW, a commonly held belief in sports science. The theory has subsequently been dispelled however, and the cause of the low EI linked to under-reporting. Table 4 displays the results of frequently cited papers outlining the underestimation of habitual intake in athletes.

An extension to athletes under-reporting EI is that

exercise training itself has been shown to influence the accuracy of dietary recording in healthy non-obese adults and adolescents. Westerterp *et al.* (1992b) studied thirteen men and women both at the beginning and end of a 40-week endurance training intervention programme. All subjects were previously not exercising and the initial difference between the subjects' EI from a food record and EE from DLW, both assessed over 7 d, was only -5 %. However, by the end of the intervention period the discrepancy between the measurements had risen to -19 %. Only 10 % of this difference could be accounted for by under-eating as determined by changes in body weight and thus, the remainder was associated with under-reporting. Similarly, van Etten *et al.* (1997) found under-reporting increased over the duration of an 18 week weight-training programme. Their previously sedentary male subjects initially under-reported EI by 21 %, but over the course of the exercise programme this increased to 28 % and 34 % mid-programme and programme completion respectively.

In their study of adolescent males and females (15-17 years old), Ambler *et al.* (1998) allocated subjects to a control or training group. The protocol for the training group consisted of 90 % aerobic or endurance type activities and ran over a 5-week period. The control subjects participated in a computer workshop that was running concurrently with the training sessions. Total EE was measured over a 10 d period beginning in the fourth week of training and a diet record was kept over the last 3 d of measurement. In the control group no significant difference was reported between EI and EE, however, for the training groups EI was found to be less than their EE (11 % for males and 27 % for females). This finding was the same across genders and there was no weight loss during the study for any of the groups. These aforementioned studies therefore suggest that under-reporting is also associated with subjects making a transition from one EE to another.

Military and trekking expeditions

Although the two subject groups, military personnel and trekking explorers, are not identical, studies using these subjects will be addressed together in this section. This is due to the fact that the nature of these undertakings place certain limitations on the subjects' food consumption in most of these investigations. With respect to the military studies, food ration packs of known energy content are supplied to the subjects, and in most cases little or no external food can be or is consumed. For the expedition groups, and in some instances the military groups, a subject's food consumption is often limited to what they can carry. So although subjects may be allowed to consume food *ad libitum* in some of these studies, there are logistical restrictions on the type and amount of foods available. It may therefore be argued that although the subjects participating in these activities are free-living with respect to EE, they are not necessarily under free-living conditions with respect to EI.

DeLany *et al.* (1989) measured the EI and EE of sixteen special forces soldiers randomly allocated to a lightweight

ration group (containing a maximum of 8.28 MJ/d) or a ready-to-eat meal group (containing a maximum 16.82 MJ/d) over a 4-week period. All food rations were supplied for both groups, however, the ready-to-eat meal group was limited by the amount they could carry into the field due to space and weight considerations. Hence, they were free to choose which individual food items were taken and carried 1 weeks supply at a time. Both groups' missions included reconnaissance, surveillance and electronic warfare for 25 d over hilly terrain. Over the 28 d period subjects were dosed with DLW twice. After adjustment for changes in body energy stores the combined EI of the two groups was only 5 % less than DLW measured EE (14.06 MJ/d EI v. 14.56 MJ/d EE for the ready-to-eat group; 12.97 MJ/d EI v. 13.89 MJ/d EE for the lightweight ration group). The similarity between the two measures seen in this study was probably due to the supplying of pre-weighed rations of known energy content and thus taking away the need for food weighing or recall. Other studies involving the supply of rations to their subjects have also reported good agreement between EI and EE after adjusting for changes in body energy stores (Forbes-Ewan *et al.* 1989; Hoyt *et al.* 1991, 1994). The findings of Forbes-Ewan *et al.* (1989) actually indicated an overestimated EI of 17.5 % compared with their DLW measured EE result, however, the food intake in this study involved the supply of rations and was not subject reported. In addition, body energy reserves were assessed using measurement of skinfold thickness, which can be an imprecise measure of body composition (Fogelholm *et al.* 1996; Kuczmarski, 1996; Hildreth *et al.* 1997; Reilly, 1998).

In contrast to the aforementioned findings, when food rations are not supplied and soldiers are allowed to eat *ad libitum*, under-reporting is prevalent. Burstein *et al.* (1996) assessed the ability to self-report EI in soldiers performing military activities under both cold and hot conditions. Fourteen male infantry soldiers, aged between 19–20 years, participated in the winter study and ten in the summer study. Both groups were exposed to similar activities over the 12 d study period. The self-reported EI was 33 % and 23 % less than EE in the winter and summer groups, respectively, and changes in body weight did not explain the difference between the two measures. Thus, although the winter and summer phases differed in temperature by over 30°C, under-reporting occurred in both groups and was, therefore, not influenced by seasonality.

Under-reporting by soldiers in cold climates has also been documented by other authors (King *et al.* 1992; Jones *et al.* 1993). Jones *et al.* (1993), investigating the effectiveness of food rations to meet energy needs in cold environments, measured the EE and EI of ten soldiers during a 10 d field exercise in the Canadian Arctic. In this study, subjects were provided with field rations but also had unlimited access to supplemental foods. As determined by the DLW method, the EE of the infantrymen was 18.06 MJ/d over the testing period. In contrast, the self-reported EI assessed by food records was 11.02 MJ/d. Hence, EI was misreported by –39 %. Although body weight was lost over the study period the authors state that even if all weight lost was assumed to be fat mass, the degree of mismatch of EE and EI could not be explained by

this alone, and thus, it was probable that the discrepancy was influenced by under-reporting.

Research has shown that weight loss is a well documented phenomenon that occurs during high-altitude expeditions (Boyer & Blume, 1984; Guillard & Klepping, 1985; Rose *et al.* 1988). It is, however, not known to what extent this weight loss is due to a deficit in EI as studies have detailed that the under-reporting of EI also occurs under these conditions.

Three base-camp personnel and seven climbers participated in an energy balance study during exposure to high altitudes of between 5300 and 8848 m above sea level (Reynolds *et al.* 1999). EI was assessed using daily food records over a 9-week period and EE was measured using DLW on two separate occasions of 3-weeks duration during this time period. Of the ten subjects, two were dosed with DLW at both the beginning 3-week period and before the final 3-week period. After adjustment for changes in body weight the EI value reported by the base-camp personnel (10.50 MJ/d) and the climbers (20.63/d) respectively, was 23 % and 8.6 % less than their measured EE (13.70 MJ/d; 22.57 MJ/d). Thus, as with other studies previously mentioned, the loss of body weight could not solely explain the apparent negative energy balance and hence, under-reporting was a factor.

Stager *et al.* (1992) have reported similar results in their abstract detailing a climb on Mount McKinley, AK, USA. Although data from this study has also been presented elsewhere (Stager *et al.* 1995), information regarding the investigation's methodology is limited. However, from the results presented it is still possible to detect the presence of under-reporting with respect to the EI data. Assuming the loss of body weight that occurred in the group of six climbers had an energy density equivalent to that of mixed tissue (30 KJ/g) (Food and Agriculture Organization/World Health Organization/United Nations University, 1985), the difference between the subjects' adjusted EI and measured EE was 6.34 MJ/d. Thus, as a group the climbers underestimated their EI by 23 %.

Minor errors, however, in the assessment of changes in body energy stores may substantially effect energy balance equations (Jones *et al.* 1993) and thus in turn effect the detection of under-reporting. A case study by Stroud *et al.* (1993) of two men attempting to walk to the North Pole reported a mismatch between EI and EE of –9 % and –23 % for each subject, respectively. A confounding factor in this study was that the accurate measurement of body weight change may have been compromised by fluid retention, as both subjects had peripheral pitting oedema at the conclusion of the investigation. Even a small amount of fluid retention of 1 litre/d may lead to a potential error of 0.83 MJ/d in the overall estimation of EE (Stroud *et al.* 1993). Burstein *et al.* (1996) suggest that a temporary disturbance of fluid balance may also have affected their results as their subjects' final body weight was not measured until 36 h upon return to base camp. These papers illustrate the importance of accurately assessing changes in body energy stores when attempting to isolate under-reporting.

Westerterp *et al.* (1992a) suggest that after adjustment for changes in body weight and composition, their subjects

did not under-report EI during a climb on Mount Everest. The authors state that the subjects having to carry their own food in conjunction with close supervision was responsible for the prevention of under-reporting in this group. However, the fact that several methods were used for the assessment of alterations in energy stores, in particular isotope dilution, may have also played a role. Many of the aforementioned studies in this present section showing a good agreement between EI and EE report using isotope dilution to assess energy store change. This may therefore be important for these populations as it was previously mentioned that fluid homeostasis may be disturbed during trekking and the isotope-dilution technique is more sensitive to changes in body fluid status.

A further study by Westerterp *et al.* (1994) indicated that malnutrition rather than under-reporting was responsible for the difference between EI and EE in six men and women during a stay at the summit of Mount Sajama, Bolivia (6542 m). Changes in body composition over the testing period were however estimated using skinfold thickness measurements and as previously mentioned, these can be an imprecise (Fogelholm *et al.* 1996; Kuczmarski, 1996; Hildreth *et al.* 1997; Reilly, 1998). In addition, it has been suggested that the use of skinfold thickness measurements is not appropriate in high altitude conditions due to altitude oedema (Fulco *et al.* 1992). Westerterp *et al.* (1994) also examined protein balance to estimate changes in body composition (i.e. fat-free mass), however, the authors state that this method may also be problematic due to decreased hydration of fat-free mass at altitude.

Under-reporting and diet assessment methods

It must be noted that all of the papers mentioned earlier have used many different commonly employed forms of dietary assessment. This therefore indicates the under-reporting of food intake is not confined to only one method of obtaining dietary information but occurs across all techniques (Black *et al.* 1995).

Reasons for under-reporting

Although many of the DLW studies cited earlier have elucidated reasons for under-reporting, additional insight on the phenomenon can be gained by examining non-DLW research as well. Thus, the following sections on the characteristics of under-reporters and mechanisms for under-reporting are not restricted to investigations using DLW alone, but also includes studies using psychological inventories, diet assessment techniques and cut-off values for the EI:BMR ratio.

Characteristics of under-reporters

As some studies have found accurate reports of energy requirements in lean individuals but not in the obese (Prentice *et al.* 1986), it was originally believed under-reporting was associated with increased adiposity. This belief is supported by many studies which show that under-reporting becomes more dramatic as body weight increases

(Prentice *et al.* 1986; Bandini *et al.* 1990; Schoeller, 1990; Lichtman *et al.* 1992; Heitmann, 1993; Briefel *et al.* 1997; Lafay *et al.* 1997; Price *et al.* 1997; Johnson *et al.* 1998; Taren *et al.* 1999). Similarly, other studies have shown an association between increased body size and under-reporting, as prevalence increases with higher BMI (Kretsch *et al.* 1999; Kroke *et al.* 1999; Tomoyasu *et al.* 1999). However, it has since been discovered that the underestimation of dietary intake is not confined to obese people and that other factors are involved.

Black *et al.* (1995) suggested under-reporting in post-obese subjects was related to dieting and dietary restraint. Lafay *et al.* (1997) also reported a similar association in lean individuals with weight stability who misrepresent food intake and other studies have found repeated food restriction is a characteristic of obese subjects as well (Briefel *et al.* 1997; Kretsch *et al.* 1999). It was found by Bathalon *et al.* (2000) that restrained eaters under-reported food intake to a greater degree than unrestrained eaters. Restrained eating or dietary restraint may be defined as the tendency to consciously control food intake in order to assist weight loss or prevent weight gain (Lafay *et al.* 1997). All the aforementioned groups may perceive the need to diet due to increased concerns about their body weight and poor body image.

The underestimation of food intake has been found more prevalent in women than men and thus is also related to gender (Johnson *et al.* 1994; Briefel *et al.* 1997; Price *et al.* 1997). This finding has been linked to the increased prevalence of weight consciousness and thus dietary restraint in this group. Low educational achievement has also been associated with under-reporting (Price *et al.* 1997), and reporting accuracy has been shown to improve with higher levels of literacy (Johnson *et al.* 1998). In addition, smoking and socio-economic characteristics including low social class of origin and current employment status are also related to under-reporting in women but not in men (Price *et al.* 1997).

For some individuals living arrangements may be commensurate with under-reporting. For example, elderly persons living with someone other than a spouse may be financially limited to purchasing and consuming less expensive foods that may be high in fat (Tomoyasu *et al.* 1999). Hence, any under-reporting of these energy-dense foods will substantially affect the matching of EI with EE. Correspondingly, financial constraints may also be a factor in under-reporting in young age groups as well. Middle-aged women falling into the category of low-income status have been also shown to misrepresent their EI (Johnson *et al.* 1998).

Proposed mechanisms for under-reporting

Although the actual mechanisms for the phenomenon of under-reporting are not known, several ideas have been put forward (Price *et al.* 1997). Lack of motivation on the subject's behalf is one such explanation. One may therefore suspect the poor accuracy associated with diet assessment methods could be due to the subjects perceiving food reporting to be a burden (Livingstone *et al.* 1992; Beerman & Dittus, 1993; Martin *et al.* 1996).

However, under-reporting is not confined to selected diet-analysis techniques but occurs indiscriminately across all types, simple or complex. This suggests factors other than just motivation are involved and these are outlined as follows.

Errors in recording food intake may be deliberate or subconscious. Some individuals may see the filling in of nutritional records as an opportunity to diet and subsequently decrease their food consumption over the survey period (Schoeller, 1990; Black *et al.* 1995; Price *et al.* 1997; Bellisle *et al.* 1998). Subjects may therefore omit items from their diet that seem too troublesome or 'naughty' to describe in a diary. Further, in contrast to individuals who generally feel increased hunger, some persons may under-eat due to a less active hunger drive and hence the burden of compiling a diet record overrides the need to eat (Bathalon *et al.* 2000). Although this may occur in studies where weight changes have been observed in participants, the fact that on most occasions EI is substantially lower than expenditure without alterations in body weight, suggests that the under-recording of food consumption is a more likely explanation for discrepancies in intake and expenditure (Davies *et al.* 1994). This may be manifested as denial of consumption, under-reporting eating occasions, misrepresenting the quantity eaten per occasion, or a combination of these (Becker *et al.* 1999).

Under some conditions it seems that under-reporting may be inevitable and is somewhat linked to the nature of the activity itself. Troops performing military manoeuvres may be unexpectedly called away for duty or field exercises and the tight military schedule does not always allow for organised meals (Burstein *et al.* 1996). The subjects may therefore be focused on matters other than the accurate compiling of dietary records. This last factor may also play a role in the under-reporting of EI that occurs when subjects are at high altitudes. It is believed that the lack of energy balance witnessed under these conditions may be due in part to a preferential focus on survival and/or diminished cognition (Reynolds *et al.* 1999). Although these reasons for under-reporting may be valid in these special groups it is doubtful whether they are a viable explanation for the general population.

Memory disturbance may possibly be a frequent cause of under-reporting, especially in the elderly (Pannemans & Westerterp, 1993; Lafay *et al.* 1997). Keeping a dietary record or completing a questionnaire may be exceedingly difficult in this population due to poor vision, hearing, and/or comprehensive skills in conjunction with poor recent memory. This may be a possible explanation for inaccurate nutritional records in older persons, however, it has not been recognized as a common cause for under-reporting in younger individuals.

One of the most prevalent mechanisms for under-reporting in most age groups is 'attitude to food' (Aaron *et al.* 1994; Black *et al.* 1995; Price *et al.* 1997). A person's attitude toward food and its consumption is influenced by many factors including body image, weight consciousness, dietary restraint and social expectations. In most cases all of the aforementioned are inter-linked.

Disturbance of body image and preoccupation with weight which manifests itself in guilt about eating and dietary restraint is commonly reported in girls and women

of all fitness levels (Livingstone *et al.* 1992). Thus, in groups where thinness is important and low EI is viewed as favourable, under-reporting is prevalent. Hill & Davies (1999) and Davies *et al.* (1997) found classical ballet dancers and young gymnasts, respectively, underestimated their self-reported EI. For both these populations the aesthetic nature of the activity places a great emphasis on low body weight and thus is often a determinant of success. Edwards *et al.* (1993) reported heavier female runners were less satisfied with their bodies and displayed greater discrepancies between EI and EE than their lighter counterparts. Similarly, Livingstone *et al.* (1992) suggested guilt about eating and poor body image is highly developed in adolescent girls and is therefore associated with increased under-reporting when compared with boys of the same age.

Pressures on women, and in more recent years men, to conform to an 'ideal' body image is an underlying reason behind many problems associated with dietary intake data (Price *et al.* 1997). Errors in reporting intake accurately may therefore be due to subjects citing intakes that are similar to the expectations for the population. Thus, due to cultural expectations, women in developing nations may under-report their intakes so as to conform to the traditional female role (Schoeller, 1990; Price *et al.* 1997). Athletes may be in denial with respect to actual food consumption and report intakes similar to their non-athletic peers, and likewise, obese individuals conform to society's expectations by reporting intakes similar to lean persons (Schoeller, 1990). In a study by Taren *et al.* (1999) five different psychological inventories were administered to their subjects and social desirability was found to be the most strongly associated measure with under-reporting.

Conclusions

The DLW technique has shown that EI derived from all methods of food recording can be an imprecise measure that is substantially under-reported in most subject groups. The inaccurate reporting of dietary intake has important implications when attempting to analyse food records and thus any results should be interpreted with caution. It is now known that factors including increased adiposity and/or body size, dieting and dietary restraint, gender, socio-economic status, motivation, social expectations and the nature of the testing environment itself, all play a role in under-reporting. Knowledge of these characteristics and mechanisms can help to target populations at risk of under-reporting and therefore enable the process of dietary assessment to be a more useful tool. Awareness is the key to overcoming under-reporting so that strategies, for example the use of questionnaires or psychological inventories that profile the aforementioned factors relating to under-reporting, become standard practice in conjunction with measures of EI.

References

- Aaron JJ, Mela DJ & Evans RE (1994) The influences of attitudes, beliefs, and label information on perceptions of reduced-fat spread. *Appetite* **22**, 25–37.

- Ambler C, Eliakim A, Brasel JA, Lee W-NP, Burke G & Cooper DM (1998) Fitness and the effect of exercise training on the dietary intake of healthy adolescents. *International Journal of Obesity* **22**, 354–362.
- Anthony H, Bines J, Phelan P & Paxton S (1998) Relation between dietary intake and nutritional status in cystic fibrosis. *Archives of Disease in Childhood* **78**, 443–447.
- Baecke JAH, Van Staveren WA & Burema J (1983) Food consumption, habitual physical activity, and body fatness in young Dutch adults. *American Journal of Clinical Nutrition* **37**, 278–286.
- Bandini LG, Cyr H, Must A & Dietz WH (1997) Validity of reported energy intake in preadolescent girls. *American Journal of Clinical Nutrition* **65**, Suppl., 1138S–1141S.
- Bandini LG, Schoeller DA, Cyr HN & Dietz WH (1990) Validity of reported energy intake in obese and non-obese adolescents. *American Journal of Clinical Nutrition* **52**, 421–425.
- Bandini LG, Vu D, Must A, Cyr H, Goldberg A & Dietz WH (1999) Comparison of high-calorie, low-nutrient-dense food consumption among obese and non-obese adolescents. *Obesity Research* **7**, 438–443.
- Barden EM, Zemel BS, Kawchak DA, Goran MI, Ohene-Frempong K & Stallings VA (2000) Total and resting energy expenditure in children with sickle cell disease. *Journal of Pediatrics* **136**, 73–79.
- Barrett-Connor E (1991) Nutrition epidemiology: how do we know what they ate? *American Journal of Clinical Nutrition* **54**, 182S–187S.
- Basiotis PP, Welsh SO, Cronin RJ, Kelsey JL & Mertz W (1987) Number of days of food intake records required to estimate individual and group nutrient intakes with defined confidence. *Journal of Nutrition* **117**, 1638–1641.
- Bathalon GP, Tucker KL, Hays NP, Vinken AG, Greenberg AS, McCrory MA & Roberts SB (2000) Psychological measures of eating behavior and the accuracy of 3 common dietary assessment methods in healthy postmenopausal women. *American Journal of Clinical Nutrition* **71**, 739–745.
- Becker W, Foley S, Shelly E & Gibney M (1999) Energy under-reporting in Swedish and Irish dietary surveys: implications for food-based dietary guidelines. *British Journal of Nutrition* Suppl. 2, **81**, S127–S131.
- Beerman KA & Dittus K (1993) Sources of error associated with self-reports of food intake. *Nutrition Research* **13**, 765–770.
- Bellisle F, Blundell JE, Dye L, Fantino M, Fern E, Fletchere RJ, Lamber J, Roberfroid M, Specter S, Westenhöfer J & Westerterp-Plantenga MS (1998) Functional food science and behaviour and psychological functions. *British Journal of Nutrition* Suppl. 1, **80**, S173–S193.
- Bingham S, Wiggins HS, Englyst H, Seppanen R, Helms P, Strand R, Burton R, Jorgensen IM, Poulsen L, Paerregaard A, Bjerrum L & James WP (1982) Methods and validity of dietary assessments in four Scandinavian populations. *Nutrition & Cancer* **4**, 23–33.
- Black AE, Bingham SA, Joansson G & Coward WA (1997) Validation of dietary intakes of protein and energy against 24 hour urinary N and DLW energy expenditure in middle-aged women, retired men and post-obese subjects: comparisons with validation against presumed energy requirements. *European Journal of Clinical Nutrition* **51**, 405–413.
- Black AE, Jebb SA, Bingham SA, Runswick SA & Poppitt SD (1995) The validation of energy and protein intakes by doubly labelled water and 24-hour urinary nitrogen excretion in post-obese subjects. *Journal of Human Nutrition and Dietetics* **8**, 51–64.
- Black AE, Prentice AM, Goldberg GR, Jebb SA, Bingham SA, Livingstone MBE & Coward WA (1993) Measurements of total energy expenditure provide insights into the validity of dietary measurements of energy intake. *Journal of the American Dietetic Association* **93**, 572–579.
- Blair SN, Horton E, Leon AS, Lee I-M, Drinkwater BL, Dishman RK, Mackey M & Kienholz ML (1996) Physical activity, nutrition, and chronic disease. *Medicine and Science in Sports and Exercise* **28**, 335–349.
- Boyer SJ & Blume FD (1984) Weight loss and changes in body composition at high altitude. *Journal of Applied Physiology* **57**, 1580–1585.
- Braitman LE, Adlin EV & Stanton JL Jr (1985) Obesity and caloric intake: the National Health and Nutrition Examination Survey of 1971–1975 (NHANES 1). *Journal of Chronic Diseases* **38**, 727–732.
- Branth S, Hambraeus L, Westerterp K, Andersson A, Edsgren R, Mustelin M & Nilsson R (1996) Energy turnover in a sailing crew during offshore racing around the world. *Medicine and Science in Sports and Exercise* **28**, 1272–1276.
- Bratteby L-E, Sandhagen B, Fan H, Enghardt H & Samuelson G (1998) Total energy expenditure and physical activity as assessed by the doubly labeled water method in Swedish adolescents in whom energy intake was underestimated by 7-d diet records. *American Journal of Clinical Nutrition* **67**, 905–911.
- Briefel RR, Sempos CT, McDowell MA, Chien S & Alaimo K (1997) Dietary methods research in the third National Health and Nutrition Examination Survey: under-reporting of energy intake. *American Journal of Clinical Nutrition* Suppl., **65**, 1203S–1209S.
- Buhl KM, Gallagher D, Hoy K, Matthews DE & Heymsfield S (1995) Unexplained disturbance in body weight regulation: diagnostic outcome assessed by doubly labeled water and body composition analyses in obese patients reporting low energy intakes. *Journal of the American Dietetic Association* **95**, 1393–1400.
- Burstein R, Coward AW, Askew WE, Carmel K, Irving C, Shpilber O, Moran D, Pikarsky A, Ginot G, Sawyer M, Golan R & Epstein Y (1996) Energy expenditure variations in soldiers performing military activities under cold and hot climate conditions. *Military Medicine* **161**, 750–754.
- Buttriss J (1999) Nutrition in older people – the findings of a national survey. *Journal of Human Nutrition and Dietetics* **12**, 461–466.
- Champagne C, Baker NB, DeLany JP, Harsha DW & Bray GA (1998) Assessment of energy intake under-reporting by doubly labeled water and observations on reported nutrient intakes in children. *Journal of the American Dietetic Association* **98**, 426–430, 433.
- Champagne CM, Delany JP, Harsha DW & Bray GA (1996) Under-reporting of energy intake in biracial children is verified by doubly labeled water. *Journal of the American Dietetic Association* **96**, 707–709.
- Clark D, Tomas F, Withers RT, Brinkman M, Chandler C, Phillips J, Ballard FJ, Berry MN & Nestel P (1992) Differences in energy metabolism between normal weight ‘large-eating’ and ‘small-eating’ women. *British Journal of Nutrition* **68**, 31–44.
- Clark D, Tomas F, Withers RT, Chandler C, Brinkman M, Phillips J, Berry M, Ballard FJ & Nestel P (1994) Energy metabolism in free-living, ‘large-eating’ and ‘small-eating’ women: studies using $^2\text{H}_2^{18}\text{O}$. *British Journal of Nutrition* **72**, 21–31.
- Clark D, Tomas F, Withers RT, Neville SD, Nolan SR, Brinkman M, Chandler C, Clark C, Ballard FJ, Berry M & Nestel P (1993) No major differences in energy metabolism between matched and unmatched groups of ‘large-eating’ and ‘small-eating’ men. *British Journal of Nutrition* **70**, 393–406.
- Collins CE, Oloughlin EV & Henry R (1998) Discrepancies between males and females with cystic fibrosis in dietary intake

- and pancreatic enzyme use. *Journal of Pediatric Gastroenterology and Nutrition* **26**, 258–262.
- Committee on Dietary Allowances, Food and Nutrition Board (1980) *Recommended Dietary Allowances*. Washington, DC: National Academy of Sciences.
- Coward WA, Prentice AM, Murgatroyd PR, Davies HL, Cole TJ, Sawyer MB, Goldberg GR, Halliday D & Macnamara JP (1985) Measurement of CO₂ and water production rates in man using ²H₂¹⁸O labelled H₂O: comparison between calorimeter and isotope values. In *Human Energy Metabolism: Physical Activity and Energy Expenditure Measurements in Epidemiological Research Based upon Direct and Indirect Calorimetry*. *Euro-Nut Report* no. 5, pp. 126–128 [AJH van Es, editor]. Den Haag: CIP-gevevens Koninklijke Bibliotheek.
- Crawley H & Summerbell C (1997) Feeding frequency and BMI among teenagers aged 16–17 years. *International Journal of Obesity* **21**, 159–161.
- Davies PSW, Coward WA, Gregory J, White A & Mills A (1994) Total energy expenditure and energy intake in the pre-school child: a comparison. *British Journal of Nutrition* **72**, 13–20.
- Davies PSW, Feng J-Y, Crisp JA, Day JME, Laidlaw A, Chen J & Liu X-P (1997) Total energy expenditure and physical activity in young Chinese gymnasts. *Pediatric Exercise Science* **9**, 243–252.
- DeLany JP, Schoeller DA, Hoyt RW, Askew EW & Sharp MA (1989) Field use of D₂¹⁸O to measure energy expenditure of soldiers at different energy intakes. *Journal of Applied Physiology* **67**, 1922–1929.
- Edwards JE, Lindemam AK, Mikesky AE & Stager JM (1993) Energy balance in highly trained female endurance runners. *Medicine and Science in Sports and Exercise* **25**, 1398–1404.
- Fogelholm GM, Kukkonenharjula TK, Sievanen HT, Oja P & Vuori IM (1996) Body composition assessment in lean and normal-weight young women. *British Journal of Nutrition* **75**, 793–802.
- Food and Agriculture Organization/World Health Organization/United Nations University (1985) *Energy and Protein Requirements*. *Technical Report Series* no. 724, WHO: Geneva.
- Forbes-Ewan CH, Morrissey BLL, Gregg GC & Waters DR (1989) Use of doubly labeled water technique in soldiers training for jungle warfare. *Journal of Applied Physiology* **67**, 14–18.
- Fulco CS, Hoyt RW, Baker-Fulco CJ, Gonzalez J & Cymerman A (1992) Use of bioelectrical impedance to assess body composition changes at high altitude. *Journal of Applied Physiology* **72**, 2181–2187.
- Gibson RS (1990) *Principals of Nutritional Assessment*. New York, NY: Oxford University Press.
- Goran MI & Poehlman ET (1992) Total energy expenditure and energy requirements in healthy elderly persons. *Metabolism* **41**, 744–753.
- Gois AHC, Westertep-Plantenga MS & Westertep KR (2000) Underreporting and underrecording of habitual food intake in obese men: selective under-reporting of fat intake. *American Journal of Clinical Nutrition* **71**, 130–134.
- Griffiths M, Payne PR, Stunkard JA, Rivers JP & Cox M (1990) Metabolic rate and physical development in children at risk of obesity. *Lancet* **336**, 76–78.
- Guilland JC & Klepping J (1985) Nutritional alterations at high altitude in man. *European Journal of Applied Physiology and Occupational Physiology* **54**, 517–523.
- Haggarty P, McGaw BA, Maughan RJ & Fenn C (1988) Energy expenditure of elite female athletes measured by the doubly-labeled water method. *Proceedings of the Nutrition Society* **47**, 35A.
- Hampton MC, Hueneman RL, Shapiro LR & Mitchell BW (1967) Calorie and nutritional intakes of teenagers. *Journal of the American Dietetic Association* **50**, 385–394.
- Heitmann BL (1993) The influence of fatness, weight change, slimming history and other lifestyle variables on diet reporting in Danish men and women aged 35–65. *International Journal of Obesity* **17**, 329–336.
- Hildreth HG, Johnson RK, Goran MI & Contompasis SH (1997) Body composition in adults with cerebral palsy by dual-energy x-ray absorptiometry, bioelectrical impedance analysis, and skinfold anthropometry compared with the O-18 isotope dilution technique. *American Journal of Clinical Nutrition* **66**, 1436–1442.
- Hill RJ & Davies PSW (1999) The validity of a four day weighed food record for measuring energy intake in female classical ballet dancers. *European Journal of Clinical Nutrition* **53**, 752–753.
- Howat PM, Mohan R, Champagne C, Monlezun C, Wozniak P & Bray GA (1994) Validity and reliability of reported dietary intake data. *Journal of the American Dietetic Association* **94**, 169–173.
- Hoyt RW, Jones TE, Baker-Fulco CJ, Schoeller DA, Schoene RB, Schwartz RS, Askew EW & Cymerman A (1994) Doubly labeled water measurement of human energy expenditure during exercise at high altitude. *American Journal of Physiology* **266**, R966–R971.
- Hoyt RW, Jones TE, Stein TP, McAninch GW, Lieberman HR, Askew EW & Cymerman A (1991) Doubly labeled water measurement of human energy expenditure during strenuous exercise. *Journal of Applied Physiology* **71**, 16–22.
- Jain M, Howe GR, Johnson KC & Miller AB (1980) Evaluation of a diet history questionnaire for epidemiologic studies. *American Journal of Epidemiology* **111**, 212–219.
- Johnson ML, Burke BS & Mayer J (1956) Relative importance of inactivity and overeating in the energy balance of obese high school girls. *American Journal of Clinical Nutrition* **4**, 37–44.
- Johnson RK, Driscoll P & Goran MI (1996) Comparison of multiple-pass 24-hour recall estimates of energy intake with total energy expenditure determined by the doubly labeled water method in young children. *Journal of the American Dietetic Association* **96**, 1140–1144.
- Johnson RK, Goran MI & Poehlman ET (1994) Correlates of over- and under-reporting of energy intake in healthy older men and women. *American Journal of Clinical Nutrition* **59**, 1286–1290.
- Johnson RK, Souttanakis RP & Matthews DE (1998) Literacy and body fatness are associated with under-reporting of energy intake in US low-income women using the multiple-pass 24-hour recall: a doubly labeled water study. *Journal of the American Dietetic Association* **98**, 1136–1140.
- Jones PJH, Jacobs IRA, Morris A & Ducharme MB (1993) Adequacy of food rations in soldiers during an arctic exercise measured by doubly labeled water. *Journal of Applied Physiology* **75**, 1790–1797.
- Jones PJH, Martin LJ, Su WF & Boyd NF (1997) Canadian recommended nutrient intakes underestimate true energy requirements in middle-aged women. *Canadian Journal of Public Health. Revue Canadienne de Sante Publique* **88**, 314–319.
- Kaskoun MC, Johnson RK & Goran MI (1994) Comparison of energy intake by semiquantitative food-frequency questionnaire with total energy expenditure by the doubly labeled water method in young children. *American Journal of Clinical Nutrition* **60**, 43–47.
- King N, Muttter SH, Roberts DE, Askew EW, Young AJ, Jones TE, Mays MZ, Sutherland MR, DeLany JP, Cheema BE & Tully R (1992) *Nutrition and Hydration Status of Soldiers Consuming the 18-Man Arctic Trey Pack Ration Module With Either the*

- Meal, Ready-to-Eat or the Long-Life Ratio Packet During a Cold Weather Field Training Exercise*, technical report T4-92, Natick, MA: US Army Research Institute.
- Kretsch MJ, Fong AKH & Green MW (1999) Behavioral and body size correlates of energy intake under-reporting by obese and normal-weight women. *Journal of the American Dietetic Association* **99**, 300–306.
- Kroke A, Klipstein-Grobusch K, Voss S, Möseneder J, Thielecke F, Noack R & Boeing H (1999) Validation of a self-administered food-frequency questionnaire administered in the European Prospective Investigation into Cancer and Nutrition (EPIC) Study: comparison of energy, protein, and macronutrient intakes estimated with the doubly labeled water, urinary nitrogen, and repeated 24-h dietary recall methods. *American Journal of Clinical Nutrition* **70**, 439–447.
- Kromhout D (1983) Energy and macronutrient intake in lean and obese middle-aged men (the Zutphen study). *American Journal of Clinical Nutrition* **37**, 295–299.
- Kuczmariski RJ (1996) Bioelectrical impedance analysis measurements as part of a national nutrition survey. *American Journal of Clinical Nutrition* **64**, Suppl., 453S–458S.
- Lafay L, Basdevant A, Charles M-A, Vray M, Balkau B, Borys J-M, Eschwège E & Romon M (1997) Determinants and nature of dietary under-reporting in a free-living population: the Feurbaix Laventie Ville Sante (FLVS) study. *International Journal of Obesity* **21**, 567–573.
- Lichtman SW, Pisarska K, Berman ER, Pestone M, Dowling H, Offenbacher E, Weisel H, Heshka S, Matthews DE & Heymsfield SB (1992) Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. *New England Journal of Medicine* **327**, 1893–1898.
- Livingstone MBE, Prentice AM, Coward WA, Strain JJ, Black AE, Davies PSW, Stewart CM, McKenna PG & Whitehead RG (1992) Validation of estimates of energy intake by weighed dietary record and diet history in children and adolescents. *American Journal of Clinical Nutrition* **56**, 29–35.
- Livingstone MBE, Prentice AM, Strain JJ, Coward WA, Black AE, Barker ME, McKenna PG & Whitehead RG (1990) Accuracy of weighed dietary records in studies of diet and health. *British Medical Journal* **300**, 708–712.
- McArdle WD, Katch FI & Katch VL (1985) *Exercise Physiology: Energy, Nutrition, & Human Performance*, Philadelphia, PA: Lea & Febiger.
- McNeill G, McBridge A, Smith JS & James WPT (1989) Energy expenditure in large and small eaters. *Nutrition Research* **9**, 363–372.
- Martin LJ, Su W, Jones PJ, Lockwood GA, Tritchler DL & Boyd NF (1996) Comparison of energy intakes determined by food records and doubly labeled water in women participating in a dietary-intervention trial. *American Journal of Clinical Nutrition* **63**, 483–490.
- Mertz W, Tsui JC, Judd JT, Reiser S, Hallfrisch J, Morris ER, Steele PD & Lashley E (1991) What are people really eating? The relation between energy intake derived from estimated diet records and intake determined to maintain body weight. *American Journal of Clinical Nutrition* **54**, 291–295.
- Morgan JB, York DA, Wasilewska A & Portman J (1982) A study of the thermic responses to a meal and to a sympathomimetic drug (ephedrine) in relation to energy balance in man. *British Journal of Nutrition* **47**, 21–32.
- Morgan RW, Jain M, Miller AB, Choi NW, Matthews V, Munan L, Burch JD, Feather J, Howe GR & Kelly A (1978) A comparison of dietary methods in epidemiologic studies. *American Journal of Epidemiology* **107**, 488–498.
- Mulligan K & Butterfield GE (1990) Discrepancies between energy intake and expenditure in physically active women. *British Journal of Nutrition* **64**, 23–36.
- O'Neil CE, Nicklas TA, Myers L, Johnson CC & Berenson GS (1997) Cardiovascular risk factors and behavior lifestyles of young women: implications from findings of the Bogalusa Heart Study. *American Journal of the Medical Sciences* **314**, 385–395.
- Pannemans LE & Westerterp KR (1993) Estimation of energy intake to feed subjects at energy balance as verified with doubly labelled water: a study in the elderly. *European Journal of Clinical Nutrition* **47**, 490–496.
- Power ML, Heaney RP, Kalkwarf HJ, Pitken RM, Repke JT, Tsang RC & Schulkin J (1999) The role of calcium in health and disease. *American Journal of Obstetrics & Gynecology* **181**, 1560–1569.
- Prentice AM (1984) Adaptations to long-term low energy intake. In *Energy Intake and Activity*, pp. 3–31 [E Pollit, editor]. New York, NY: Liss.
- Prentice AM, Black AE, Coward WA, Davies HL, Goldberg GR, Murgatroyd PR, Ashford J, Sawyer M & Whitehead RG (1986) High levels of energy expenditure in obese women. *British Medical Journal* **292**, 983–987.
- Price GM, Paul AA, Cole TJ & Wadsworth MEJ (1997) Characteristics of the low-energy reporters in a longitudinal national dietary survey. *British Journal of Nutrition* **77**, 833–851.
- Ravussin E, Lillioja S, Knowler WC, Christin L, Freymond D, Abbott WG, Boyce V, Howard BV & Bogardus C (1988) Reduced rate of energy expenditure as a risk factor for body-weight gain. *New England Journal of Medicine* **318**, 467–472.
- Reilly JJ (1998) Assessment of body composition in infants and children. *Nutrition* **14**, 821–825.
- Reilly JJ, Lord A, Bunker VW, Prentice AM, Coward WA, Thomas AJ & Briggs RS (1993) Energy balance in healthy elderly women. *British Journal of Nutrition* **69**, 21–27.
- Reilly JJ, Ralston JM, Paton JY, Edwards CA, Weaver LT, Wilkinson J & Evans TJ (1999) Energy balance during acute respiratory exacerbations in children with cystic fibrosis. *European Respiratory Journal* **13**, 804–809.
- Reynolds RD, Lickteig JA, Deuster PA, Howard MP, Conway JM, Pietersma A, deStoppelaar J & Deurenberg P (1999) Energy metabolism increases and regional body fat decreases while regional muscle mass is spared in humans climbing Mt. Everest. *Journal of Nutrition* **129**, 1307–1314.
- Riumallo JA, Schoeller D, Barrera G, Gattas V & Uauy R (1989) Energy expenditure in underweight free-living adults: impact of energy supplementation as determined by doubly labeled water and indirect calorimetry. *American Journal of Clinical Nutrition* **49**, 239–246.
- Rose MS, Houston CS, Fulco CS, Coates G, Sutton JR & Cymerman A (1988) Operation Everest II: nutrition and body composition. *Journal of Applied Physiology* **65**, 2545–2551.
- Rothenberg E, Bosaeus I, Lernfelt B, Landahl S & Steen B (1998) Energy intake and expenditure: validation of a diet history by heart rate monitoring, activity diary and doubly labeled water. *European Journal of Clinical Nutrition* **52**, 832–838.
- Sawaya AL, Tucker K, Tsay R, Willet W, Saltzman E, Dallal GE & Roberts SB (1996) Evaluation of four methods for determining energy intake in young and older women: comparison with doubly labeled water measurements of total energy expenditure. *American Journal of Clinical Nutrition* **63**, 491–499.
- Schoeller DA (1990) How accurate is self-reported dietary energy intake? *Nutrition Reviews* **48**, 373–379.
- Schoeller DA & van Santen E (1982) Measurement of energy expenditure in humans by doubly labelled water. *Journal of Applied Physiology* **53**, 955–959.
- Schulz LO, Alger S, Harper I, Wilmore JH & Ravussin E (1992) Energy expenditure of elite female runners measured by

- respiratory chamber and doubly labeled water. *Journal of Applied Physiology* **72**, 23–28.
- Schulz S, Westerterp KR & Brück K (1989) Comparison of energy expenditure by the doubly labeled water technique with energy intake, heart rate, and activity recording in man. *American Journal of Clinical Nutrition* **49**, 1146–1154.
- Seale JL & Rumpler WV (1997) Comparison of energy expenditure measurements by diet records, energy intake balance, doubly labeled water and room calorimetry. *European Journal of Clinical Nutrition* **51**, 856–863.
- Silman AJ (1980) Assessment of the intake of dietary fibre from cereal foods: an epidemiological approach. *Journal of Epidemiology & Community Health* **34**, 204–207.
- Singh J, Coward WA, Prentice AM, Ashford J, Sawyer M, Diaz E & Whitehead RG (1988) Doubly-labelled water measurements of energy expenditure in Gambian women during the agricultural season. *Proceedings of the Nutrition Society* **47**, 41A.
- Singh J, Prentice AM, Diaz E, Coward WA, Ashford J, Sawyer M & Whitehead RG (1989) Energy expenditure of Gambian women during peak agricultural activity measured by the doubly-labelled water method. *British Journal of Nutrition* **62**, 315–329.
- Sjödín AM, Andersson AB, Högberg JM & Westerterp KR (1994) Energy balance in cross-country skiers: a study using doubly labeled water. *Medicine and Science in Sports and Exercise* **26**, 720–724.
- Stager JM, Lindeman AK & Edwards JE (1992) Energy intake and energy expenditure during a high altitude expedition on Mt. McKinley, Alaska. *International Journal of Sports Medicine* **13**, 89.
- Stager JM, Lindeman A & Edwards J (1995) The use of doubly labelled water in quantifying energy expenditure during prolonged activity. *Sports Medicine* **19**, 166–172.
- Stallings VA, Zemel BS, Davies JC, Cronk CE & Charney EB (1996) Energy expenditure of children and adolescents with severe disabilities: a cerebral palsy model. *American Journal of Clinical Nutrition* **64**, 627–634.
- Stroud MA, Coward WA & Sawyer MB (1993) Measurements of energy expenditure using isotope-labelled water ($^2\text{H}_2^{18}\text{O}$) during an Arctic expedition. *European Journal of Applied Physiology* **67**, 375–379.
- Taren DL, Tobar M, Hill A, Howell W, Shisslak C, Bell I & Ritenbaugh C (1999) The association of energy intake bias with psychological scores of women. *European Journal of Clinical Nutrition* **53**, 570–578.
- Tomoyasu NJ, Toth MJ & Poehlman ET (1999) Misreporting of total energy intake in older men and women. *Journal of the American Geriatrics Society* **47**, 710–715.
- Trappe TA, Gastaldelli A, Jozsi AC, Troup JP & Wolfe RR (1997) Energy expenditure of swimmers during high volume training. *Medicine and Science in Sports and Exercise* **29**, 950–954.
- van Etten LMLA, Westerterp KR, Verstappen FTJ, Boon BJB & Saris WHM (1997) Effect of an 18-wk weight-training program on energy expenditure and physical activity. *Journal of Applied Physiology* **82**, 298–304.
- Velthuis-te Wierik EJM, Westerterp KR & van den Berg H (1995) Impact of a moderately energy-restricted diet on energy metabolism and body composition in non-obese men. *International Journal of Obesity* **19**, 318–324.
- Westerterp KR, Kayser B, Brouns F, Herry JP & Saris WHM (1992a) Energy expenditure climbing Mt. Everest. *Journal of Applied Physiology* **73**, 1815–1819.
- Westerterp KR, Kayser B, Wouters L, Le Trong J-L & Richalet J-P (1994) Energy balance at high altitude of 6542 m. *Journal of Applied Physiology* **77**, 862–866.
- Westerterp KR, Meijer GAL, Janssen EME, Saris WH & Ten Hoor F (1992b) Long-term effect of physical activity on energy balance and body composition. *British Journal of Nutrition* **68**, 21–30.
- Westerterp KR, Saris WHM, van Es M & ten Hoor F (1986) Use of the doubly labeled water technique in humans during heavy sustained exercise. *Journal of Applied Physiology* **61**, 2162–2167.
- Westerterp KR, Verboeket-van de Venne WPHG, Bouten CVC, de Graaf C, van Het Hof KH & Weststrate JA (1996) Energy expenditure and physical activity in subjects consuming full- or reduced-fat products as part of their normal diet. *British Journal of Nutrition* **76**, 785–795.