

Issues in dietary intake assessment of children and adolescents

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Studies of food habits and dietary intakes face a number of unique respondent and observer considerations at different stages from early childhood to late adolescence. Despite this, intakes have often been reported as if valid, and the interpretation of links between intake and health has been based, often erroneously, on the assumption of validity. However, validation studies of energy intake data have led to the widespread recognition that much of the dietary data on children and adolescents is prone to reporting error, mostly through under-reporting. Reporting error is influenced by body weight status and does not occur systematically across different age groups or different dietary survey techniques. It appears that the available methods for assessing the dietary intakes of children are, at best, able to provide unbiased estimates of energy intake only at the group level, while the food intake data of most adolescents are particularly prone to reporting error at both the group and the individual level. Moreover, evidence for the existence of subject-specific responding in dietary assessments challenges the assumption that repeated measurements of dietary intake will eventually obtain valid data. Only limited progress has been made in understanding the variables associated with misreporting in these age groups, the associated biases in estimating nutrient intakes and the most appropriate way to interpret unrepresentative dietary data. Until these issues are better understood, researchers should exercise considerable caution when evaluating all such data.

Children: Adolescents: Dietary assessment

Introduction

The accurate assessment of food intakes in children and adolescents is an essential prerequisite for monitoring the nutritional status of these age groups, as well as for conducting epidemiological and clinical research on the links between diet and health. The measurement of energy and nutrient intakes in children and adolescents is particularly challenging because of the many unique respondent and observer considerations which surface at different ages from early childhood to late adolescence (Livingstone & Robson, 2000). Consequently, their food intakes are prone to reporting error, but, until recently, the magnitude and direction of the bias have been impossible to gauge. Nevertheless, dietary intakes have often been reported as if valid, and the interpretation of links between intake and health was based, often erroneously, on this assumption.

In the present paper, the main measurement issues that may impact on reporting accuracy when assessing the dietary intakes of children and adolescents are evaluated. In addition, validation studies using doubly labelled water as a biomarker of energy intake (EI), variables associated with misreporting, and issues related to the identification of misreporters and data interpretation are reviewed.

Cognitive aspects of dietary reporting

Parental dietary recall

Until children reach the developmental stage when they are

aware of their food intake and can begin to conceptualize time (at approximately 7–8 years of age), the onus of dietary reporting falls on parents. Parents may reliably report their children's food intake in the home setting (Klesges *et al.* 1987, 1988; Eck *et al.* 1989; Basch *et al.* 1990; Baranowski *et al.* 1991) but often do not know what their children consume outside the home (Baranowski *et al.* 1991). Other care-givers such as child minders may be involved in the reporting process, but it is likely that they will approach the task with varying levels of motivation and interest.

It is generally thought that, before the age of 12 years, children's recall skills, ability to estimate and indicate portion size, and knowledge of foods are limited, which, in turn, constrains their ability to self-report their food intake without parental assistance. Nevertheless, from the age of about 7–8 years there is a fairly rapid increase in the ability of children to participate in unassisted recall, but only for food eaten in the immediate past and for no longer than the previous 24 h. Even then, it is likely that children may just be old enough to cope with remembering weekday food intake, but less so with the more irregular eating pattern associated with weekend days (Haraldsdóttir & Hermansen, 1995). These findings, which have been endorsed by others, suggest that by the age of 8–10 years children can reliably report their food intake, often as reliably as their parents (Emmons & Hayes, 1973; Van Horn *et al.* 1990; Achterberg *et al.* 1991; Lytle *et al.* 1993; Sobo *et al.* 2000). Where the input of parents

is likely to be important is in providing details about the types and quantities of food consumed, because of children's more limited food vocabularies (Sobo *et al.* 2000). Therefore, at a group level, repeated 24 h recalls in this age group may be a feasible alternative to a diet history interview with parents (Haraldsdóttir & Hermansen, 1995). However, whether children younger than 10 years could give valid responses to a food frequency questionnaire (FFQ) covering periods greater than 1 d is much more debatable because of their inability to conceptualize frequency, averaging, etc. (Baranowski *et al.* 1986; Domel *et al.* 1994a).

In conclusion, the assumption that parents are good surrogate reporters of their children's food intake does not always hold in practice and this must be regarded as a limiting factor in studies using recall methodology for assessing the food intakes of young children.

Portion size estimation

The quantification of the amount of food eaten, other than by direct weighing, includes a largely unknown component of error (Cypel *et al.* 1997). Early studies suggested that young children cannot estimate portion size accurately, even when prompted with visual aids (Huenemann & Turner, 1942; Meredith *et al.* 1951). However, older children and adolescents also experience difficulty in reporting portion size, which suggests that the ability of children to estimate portion sizes is not age-dependent.

Overall, in the majority of studies that have used quantification tools such as household measures and graduated food models, scant attention has been paid to the efficacy, or otherwise, of such aids (Moore *et al.* 1967; Emmons & Hayes, 1973; Frank *et al.* 1977; Carter *et al.* 1981; Jenner *et al.* 1989; Lytle *et al.* 1993). Estimating the amount of food consumed is a complex cognitive task (Friedenreich *et al.* 1992) which many children, because of their developmental stage, have probably not mastered (Baranowski & Domel, 1994; Matheson *et al.* 2002). Indeed, many adults, even those with advanced nutritional knowledge, have considerable difficulty in visually estimating quantity (Chambers *et al.* 2000). It requires that children can recognize and describe food quantities in terms of proportions or whole units and that they have an adequately developed concept of time to express food intake in terms of frequency and averages. It also assumes that the child can think abstractly about food while viewing generic food models of different volumes and dimensions, or other tools such as food photographs. It is highly unlikely, therefore, that estimation of portion size is compatible with the perceptual and conceptual capacities of children who have not reached the stage of abstract reasoning (approximately 10–11 years). The problem is further compounded by the fact that food frequencies and portion sizes consumed by children are not constant over time and, in any case, it is most unlikely that they pay attention to frequencies and portion sizes when they are eating. It is therefore not surprising that the tasks involved in food quantification will be beyond the intellectual capacities of many children.

Training in portion size estimation is known to improve the accuracy of dietary self-reporting in adults, but there

are few comparable data in children. In the most rigorous assessment to date, Weber *et al.* (1999) investigated the effect of a 45 min training exercise in portion size estimation on improving the accuracy of estimated food portions in children aged 9–10 years. The training did result in significant improvements in the ability to quantify foods, with the greatest improvements shown for solid foods estimated by dimensions and cups, and for liquids estimated by volume (cups), or by reading package labels. Amorphous foods were estimated least accurately both before and after training. Nevertheless, despite the considerable improvements in estimation capability, the error for several foods remained > 100 % of the true quantity, indicating that more than one training session would be required to further improve reporting accuracy.

In conclusion, there is a clear need for novel methods for estimating portion sizes that are sensitive to the cognitive abilities of children. Until then, it must not be assumed that inclusion of any quantification tool will assist children to estimate portion sizes more accurately. It may merely confuse children at best, or exacerbate the problem at worst.

How children remember

One of the largest concerns about dietary surveys based on recall is their ultimate reliance on memory, which is subject to a variety of errors (Dwyer *et al.* 1987). However, while the importance of good memory is acknowledged, it is unlikely that many researchers fully appreciate the cognitive processes involved during dietary recall. These processes involve understanding what information is being asked for, and searching for and evaluating the retrieved information before providing a response. Errors can arise at any of these stages, either because the respondent is unable to complete the cognitive tasks involved or because they have been prevented from doing so by inappropriate cues on the part of the observer. It has been suggested that what is eaten is rarely encoded into long-term memory, but perhaps is stored in a somewhat 'generic' memory (Bradburn *et al.* 1987; Nelson, 1993). Not surprisingly, recall errors increase as a function of time and up to 30 % of food memory may be lost from the previous day (Fries *et al.* 1995).

The limited research on children's recall of food intake shows that it is prone to considerable error. These errors include both under-reporting (missing foods), over-reporting (phantom foods; Meredith *et al.* 1951; Samuelson, 1970; Emmons & Hayes, 1973; Baranowski *et al.* 1986; Simons-Morton *et al.* 1990; Crawford *et al.* 1994; Domel *et al.* 1994b; Domel, 1997), and incorrect identification of foods (Meredith *et al.* 1951; Samuelson, 1970; Emmons & Hayes, 1973). Other factors that may impact on recall accuracy include: information overload, whereby there is an increased tendency to under-report as the number of foods eaten at a meal or overall eating frequency increases (Meredith *et al.* 1951; Baranowski *et al.* 1986); prevailing distractions (Baranowski *et al.* 1986); and salience of the food items in the diet, such that common foods or main course items are more easily recalled than less common foods or ancillary items (Emmons & Hayes, 1973; Baxter *et al.* 1999).

Unfortunately, most studies have been mainly concerned with short-term recall, often within 2 h of eating. Consequently the observed errors may have less to do with memory decay than they are to inattention. Errors in dietary recall attributable to memory decay are probably those that involve failure to report a percentage of foods eaten as a function of time and/or the developmental stage of the child. Clearly, there are limits to what children can remember, but to date little is known about the cognitive constraints on their ability to retain and retrieve dietary information.

Baranowski & Domel (1994) have proposed a model of how children remember and process information in which the cognitive processes involved in the recall of dietary information can be categorized as attention, perception, organization, retention, retrieval and response formulation. Further work with this model has demonstrated that children employ a number of retrieval strategies during self-report of their dietary intake: visual imagery (appearance of the food); usual practice (familiarity with eating the food); behaviour chaining (association with preferred food or favourite activity during a meal or day); and preference (favourite food). Non-directive prompts and cues have been shown to be vital to gain maximum recall (Baxter *et al.* 1997; Warren *et al.* 2003). While the insights gained from cognitive psychology about how food-related information is stored, retrieved and recalled by children are encouraging, further research is clearly needed to address many unresolved issues such as the impact of time lapse and less experimentally controlled conditions on retention and retrieval responses.

Variability in nutrient intake

In epidemiological investigations of diet–health relationships in children and adolescents, accurate estimates of the intake of specific nutrients is vital to correctly rank or classify subjects in the distribution of intakes. The number of days of records or recalls required to rank individuals depends on within-subject:between-subject variance (variance ratio) in nutrient intake: the larger the ratio, the more days of recording are required to rank individuals correctly. The few studies that have examined this issue in children and adolescents have clearly demonstrated that the variance ratios for children's nutrient intakes are much greater than are those for adults (Farris *et al.* 1985a,b; Nelson *et al.* 1989; Miller *et al.* 1991).

In younger children (<4 years old), the variance ratios are relatively low; therefore, 7 d of records are probably adequate for ranking subjects for energy and most nutrients. This has been substantiated by Birch *et al.* (1991), who examined the intra-individual variability in EI over 6 d in children aged 2–5 years. In contrast to the mean CV of 33.6% for each child's EI at individual meals, the mean CV for each child's total daily EI was only 10.4%. Thus within-subject daily EI is relatively constant because children adjust their EI at successive meals.

In contrast, the variance ratios for older children and adolescents (5–17 years) are, in general, approximately twice that observed in adults. Consistently higher values are observed in females, implying that males will be

ranked more accurately for most nutrients for a given study period. As might be expected, the variability in intake is lowest for the nutrients that are eaten regularly in the diet and highest for those nutrients that are eaten in large amounts only occasionally. Vitamin intakes, e.g. carotene, retinol and vitamin E, are the most variable, often requiring >20 d of records to capture habitual intake, particularly in girls. Higher variance ratios for nutrient intakes in these groups have a number of important implications for the design and interpretation of dietary surveys.

First, the finding that prolonged recording may be required to characterize the intakes of many nutrients has major implications for the choice of survey instrument and the design of surveys. Clearly, ranking of children and adolescents based on only 7 d of records or recalls will be grossly inaccurate. On one hand, this issue calls into question the feasibility of using intrusive and burdensome instruments such as weighed or estimated dietary records (whose validity has, in any case, been questioned in older children and adolescents) or recalls, even if splitting the required recording period into discrete time periods is entertained. On the other hand, the application of FFQ or diet histories must be carefully evaluated, given the numerous problems in their application, such as retrieval of dietary information from memory, conceptualization skills and portion size estimation.

Second, these high variance ratios have been based, at least until recently, on the assumption that the dietary data represent valid measures of habitual food intake. However, the recognition that self-reported dietary intakes, particularly in adolescents, are likely to be biased, mainly in the direction of under-reporting (Bandini *et al.* 1990, 1997; Livingstone *et al.* 1992; Bratteby *et al.* 1998), has implications for the way in which such surveys are interpreted. Since under- and over-reported intakes will extend the range of reported intakes, the ranking of these subjects into the extremes of the distribution may be invalid and result in biased conclusions. There is evidence that the range of 'habitual' energy expenditure is narrower than the range of reported EI. The total between-subject variation in 574 measurements of energy expenditure (EE) by the doubly labelled water method (including 163 children and adolescents) from seventy-four studies was 15.4% (Black *et al.* 1996). However, in studies with repeated measurements of EE by the doubly labelled water method, the true between-subject variation may be approximately 12% (Black & Cole, 2000). If this value represents the range of 'habitual' energy expenditure, then it must also represent the range of 'habitual' EI. However, dietary surveys on children and adolescents typically report a total between-subject variation in EI of approximately 20%, or even higher. This finding suggests that over- and under-reporting substantially extend the range of reported intakes beyond 'habitual' intakes. The effect of this could be to give a false impression of the ability to rank subjects, simply because the extreme values of a population distribution may reflect over- and under-reporting rather than true high or low intakes. The extent to which the observed high variability in the nutrient intake

Table 1. Comparisons of reported energy intake (EI) with energy expenditure (EE) measured by the doubly labelled water method in children and adolescents aged 1–18 years

Subjects	n	Sex	Age (years)	Diet method	EI:EE		Reference
					Mean	SD	
Young children							
England	81	MF	1.5–4.5	4 d WR	0.97	–	Davies <i>et al.</i> (1994)
Scotland	41	MF	3–4	3 × MP24hR	1.12	–	Reilly <i>et al.</i> (2001)
N. Ireland	20	MF	3–5	DH	1.12	0.19	Livingstone <i>et al.</i> (1992)
USA	45	MF	4–7	FFQ	1.59	–	Kaskoun <i>et al.</i> (1994)
USA	24	MF	4–7	3 × MP24hR	0.97	–	Johnson <i>et al.</i> (1996)
England	8	M	4–6	7 d WR	0.82	0.21	Smithers <i>et al.</i> (1998)
England	6	F	4–6	7 d WR	0.79	0.22	Smithers <i>et al.</i> (1998)
USA	146	MF	4–11	3 × MP24hR	1.10	0.31	Fisher <i>et al.</i> (2000)
N. Ireland – low risk of obesity	50	MF	6	7 d WR	0.98	0.17	McGloin <i>et al.</i> (2002)
N. Ireland – high risk of obesity	50	MF	6	7 d WR	0.95	0.19	McGloin <i>et al.</i> (2002)
N. Ireland – obese	14	MF	6	7 d WR	0.86	0.16	McGloin <i>et al.</i> (2002)
Pre-puberty							
N. Ireland	11	M	7–9	DH	1.13	0.23	Livingstone <i>et al.</i> (1992)
N. Ireland	12	F	7–9	DH	1.07	0.18	Livingstone <i>et al.</i> (1992)
N. Ireland	11	M	7–9	7 d WR	1.18	0.22	Livingstone <i>et al.</i> (1992)
N. Ireland	12	F	7–9	7 d WR	0.96	0.16	Livingstone <i>et al.</i> (1992)
England	13	M	7–10	7 d WR	0.93	0.13	Smithers <i>et al.</i> (1998)
England	13	F	7–10	7 d WR	0.80	0.14	Smithers <i>et al.</i> (1998)
USA	50	MF	8–16	FFQ	1.02	–	Perks <i>et al.</i> (2000)
USA – African-American	45	MF	8	2 × MP24hR	1.14	–	Ku <i>et al.</i> (1998)
USA – Caucasian	21	MF	8	2 × MP24hR	1.24	–	Ku <i>et al.</i> (1998)
USA	14	F	8	7 d ER	0.97	–	Bandini <i>et al.</i> (1997)
USA	40	F	9	7 d ER	0.65	–	Bandini <i>et al.</i> (1997)
USA	33	F	10	7 d ER	0.84	–	Bandini <i>et al.</i> (1997)
USA	19	F	11	7 d ER	0.81	–	Bandini <i>et al.</i> (1997)
Scotland	20	MF	10.7 ± 3	3 d ER	0.84	–	Reilly <i>et al.</i> (1998)
USA – African-American	27	F	9–12	8 d ER	0.74	–	Champagne <i>et al.</i> (1998)
USA – African-American	29	M	9–12	8 d ER	0.72	–	Champagne <i>et al.</i> (1998)
USA – Caucasian	31	F	9–12	8 d ER	0.76	–	Champagne <i>et al.</i> (1998)
USA – Caucasian	31	M	9–12	8 d ER	0.83	–	Champagne <i>et al.</i> (1998)
USA – African-American	5	F	11	8 d ER	0.67	–	Champagne <i>et al.</i> (1996)
USA – African-American	6	M	11	8 d ER	0.60	–	Champagne <i>et al.</i> (1996)
USA – Caucasian	6	F	11	8 d ER	0.88	–	Champagne <i>et al.</i> (1996)
USA – Caucasian	6	M	11	8 d ER	0.85	–	Champagne <i>et al.</i> (1996)
N. Ireland	6	M	12	DH	1.07	0.19	Livingstone <i>et al.</i> (1992)
N. Ireland	6	F	12	DH	1.20	0.14	Livingstone <i>et al.</i> (1992)
N. Ireland	6	M	12	7 d WR	0.92	0.10	Livingstone <i>et al.</i> (1992)
N. Ireland	6	F	12	7 d WR	0.85	0.12	Livingstone <i>et al.</i> (1992)
Adolescents							
USA – African-American	41	F	13	3 d ER	0.72	–	Wong <i>et al.</i> (1999)
USA – Caucasian	40	F	13	3 d ER	0.64	–	Wong <i>et al.</i> (1999)
England	12	M	11–14	7 d WR	0.71	0.24	Smithers <i>et al.</i> (1998)
England	9	F	11–14	7 d WR	0.76	0.13	Smithers <i>et al.</i> (1998)
USA – lean	28	MF	12–18	14 d ER	0.81	0.19	Bandini <i>et al.</i> (1990)
USA – obese	27	MF	12–18	14 d ER	0.59	0.24	Bandini <i>et al.</i> (1990)
USA	14	F	12–16	7 d ER	0.78	0.17	Bandini <i>et al.</i> (1997)
N. Ireland	11	M	15–18	DH	1.03	0.21	Livingstone <i>et al.</i> (1992)
N. Ireland	11	F	15–18	DH	0.96	0.21	Livingstone <i>et al.</i> (1992)
N. Ireland	11	M	15–18	7 d WR	0.77	0.23	Livingstone <i>et al.</i> (1992)
N. Ireland	11	F	15–18	7 d WR	0.72	0.20	Livingstone <i>et al.</i> (1992)
Sweden	25	M	15	7 d WR	0.82	0.18	Bratteby <i>et al.</i> (1998)
Sweden	25	F	15	7 d WR	0.78	0.16	Bratteby <i>et al.</i> (1998)
England	5	M	15–17	7 d WR	0.97	0.09	Smithers <i>et al.</i> (1998)
England	10	F	15–17	7 d WR	0.63	0.18	Smithers <i>et al.</i> (1998)
USA – controls	10	M	15–17	3 d ER	1.04	–	Ambler <i>et al.</i> (1998)
USA – exercising subjects	10	M	15–17	3 d ER	0.89	–	Ambler <i>et al.</i> (1998)
USA – controls	6	F	15–17	3 d ER	1.01	–	Ambler <i>et al.</i> (1998)
USA – exercising subjects	6	F	15–17	3 d ER	0.79	–	Ambler <i>et al.</i> (1998)

M, male; F, female; WR, weighed record; MP24hR, multiple-pass 24 h recall; DH, diet history; FFQ, food frequency questionnaire; ER, record in household measures/estimated weights.

of children and adolescents can be attributed to bias in dietary reporting remains to be established.

Tracking of nutrient intake

Tracking has been defined as the maintenance of relative position in rank over time (Kelder *et al.* 1994). Given that physiological processes that lead to diet-related diseases in adulthood have their antecedents in childhood diet, a high degree of stability over time in nutrient intake implies that the primary prevention of diet-related chronic diseases should be initiated through interventions that are directed at children from the outset.

The data to support the contention that food and nutrient intake patterns in adulthood are established during childhood are not convincing. Moderate to good tracking of some, but not all, nutrients has been observed in younger children (Stein *et al.* 1991; Singer *et al.* 1995). However, this finding is perhaps not surprising, since food intakes were likely to have been supervised, controlled and reported mostly by parents and/or care-givers. It is also conceivable that the apparent stability in nutrient intakes may simply be due to the close proximity of the measurements.

Unfortunately, there are relatively few rigorously conducted longitudinal studies of sufficient duration that would permit an informed evaluation of the phenomenon of tracking. Boulton *et al.* (1995) assessed the tracking of dietary energy, fat and Ca intakes in an Australian cohort from the age of 1 to 15 years. The Ca intakes of the boys remained relatively consistent over time, and children who were 'big eaters' at a young age remained so. However, those children who had reported lower EI at younger ages became more evenly spread out across the distribution of intakes over time. On the other hand, when Ca intakes were monitored in Dutch males and females (The Amsterdam Growth and Health Longitudinal Study) over a 15-year period (from age 13 to 27 years), the tracking was not sufficiently strong to identify subjects who were likely to have inadequate Ca intakes in adulthood (Welten *et al.* 1997). Tracking coefficients obtained in the same cohort for energy and the macronutrients were also slight to fair, indicative of poor maintenance in rank over time (Twisk *et al.* 1997). Over a 20-year period (from age 13 to 33 years), the tracking data for the same Dutch cohort have reinforced the earlier observations, leading the authors to conclude that food and nutrient intakes during adolescence are poor predictors of adult food and nutrient consumption patterns (Post *et al.* 2001). Even during adolescence, data from the Northern Ireland Young Hearts Project have demonstrated that between the ages of 12 and 15 years, nutrient intake is unstable over time (Robson *et al.* 2000).

Is it reasonable to expect that nutrient intakes during childhood/adolescence would strongly predict nutrient intake patterns in adulthood? In the first place, the assessment of tracking is fraught with methodological constraints. Bias in self-reports of food intake is pervasive and very difficult to quantify (Livingstone & Black, 2003). Furthermore, repeat testing is likely to compound the response bias. Changes in nutrient databases may intro-

duce additional errors in the estimation of nutrient intakes. Finally, food intake patterns at any given age reflect a complex interaction of biological, psychological and sociological factors, and it is inconceivable that these patterns (and associated nutrient intakes) would remain stable from childhood to adulthood.

In conclusion, there is very little evidence that nutrient intake patterns track over long periods of time, and the studies that have been undertaken provide few clues as to the most appropriate stages during childhood and adolescence for targeting nutrition education interventions.

Validation of dietary intakes

Validation studies

A valid (or accurate) dietary report is one that measures the true intake during the period of study (Livingstone & Black, 2003), but, until the advent of biomarkers, independent and objective validation of dietary intakes was not possible. Despite this, most studies of dietary intakes in children and adolescents were reported as if valid, and the interpretation of links between intake and health was based, often erroneously, on the assumption of validity. However, since 1990, validation studies using estimates of EE by the doubly labelled water method as a biomarker of EI have conclusively demonstrated that much of the data is prone to bias, mostly through under-reporting.

Use of doubly labelled water as a biomarker of EI is based on the assumption of energy balance: under conditions of weight stability, EI and EE are equivalent. During growth and development children are normally in positive energy balance, but after infancy, energy accretion is only about 1–2% of EI (Kuzawa, 1998). Table 1 summarizes EI:EE in validation studies of food intake in children and adolescents. Unfortunately, most of these studies were carried out on small numbers of highly selected subjects across various age groups and the majority of the studies employed either weighed or estimated diet records. Nevertheless, the totality of the data indicates that while misreporting of EI in these groups is highly probable, reporting accuracy varies as a function of age, weight status and the dietary survey method used.

Effect of age on validity

The overall trend for the magnitude of under-reporting to increase with increasing age has several possible explanations. In younger children, reporting is the responsibility of a parent or care-giver and there is likely to be less access to unsupervised in- and out-of-home eating. For 7- to 12-year-olds where reporting accuracy is highly variable, the novelty and curiosity of assisting in or self-reporting of food intakes may help to sustain enthusiasm for, and compliance in, dietary monitoring. However, by adolescence, the additional demands on recording imposed by increased energy requirements, unstructured eating patterns, a significant degree of out-of-home eating, concerns with self-image and rebellion against authority may all contribute, to a greater or lesser extent, to poor compliance in dietary reporting.

Effect of body weight on validity

Consistent with previous studies in adults (Livingstone & Black, 2003), one of the most robust findings in dietary studies of children and adolescents is the positive association between low-energy reporting and increased body fatness, particularly in adolescents (Bandini *et al.* 1990). In younger children, the relationship between reporting accuracy and weight status is not so clear-cut. In some studies (Champagne *et al.* 1998; Fisher *et al.* 2000; McGloin *et al.* 2002), but not in others (Johnson *et al.* 1996; Bandini *et al.* 1997; Reilly *et al.* 2001), body fatness was a predictor of under-reporting. Of note, Fisher *et al.* (2000) also observed that, relative to under-reporters and acceptable reporters, those who over-reported EI were lighter and had less body fat.

Overall, the magnitude of under-reporting in obese subjects is also age-related, since up to 40% of EI in obese adolescents may go unrecorded (Bandini *et al.* 1990) compared with 25% in 10-year-olds (Champagne *et al.* 1998) and 14% in 6-year-olds (McGloin *et al.* 2002). Even in normal-weight adolescents a positive association between underestimation of food intake and a tendency towards increased body fatness and overweight has been observed (Livingstone *et al.* 1992; Bratteby *et al.* 1998). Biased reporting may be due to one or more of the following factors: a wilful failure to record because it is time-consuming and inconvenient; a conscious/subconscious need for social approval; subconscious memory lapses across all or selected dietary items such as snacks; and unconscious dieting resulting in accurate but nevertheless unrepresentative food intake data. In addition, given the exaggerated preoccupation with body weight and image that is pervasive in adolescents, particularly girls, it is conceivable that obese teenagers may feel even more stigmatized about their fatness than obese adults (Wardle & Beales, 1986; Hill *et al.* 1994).

In younger children where parents are acting as surrogate respondents of children's food intake, reporting accuracy may be compromised by parental obesity status and/or by the extent to which parents perceive that such information is a reflection of their child's weight. Parental adiposity status has not been found to undermine the integrity of dietary intake data of lean children (Johnson *et al.* 1996; Bandini *et al.* 1997; McGloin *et al.* 2002), but a bias towards underestimation of food intakes of obese 6- to 7-year-old children who have at least one obese parent has been observed (McGloin *et al.* 2002).

Although low-energy reporting is not inevitable in these groups, obesity, dieting and weight consciousness have nevertheless been identified as having the most robust associations with misreporting. Researchers need to be alert, therefore, to the real probability of misreporting in these groups, either by the subjects themselves and/or by obese or weight-conscious parents who report their children's food intake.

Effects of the dietary survey technique

It is well recognized that the imposition of a particular survey technique may induce method-specific behavioural

alterations in actual and reported food intake. The nature and extent of these constraints are difficult to quantify and, thus, the true validity of different dietary survey methods is unknown.

Most of the validation studies carried out on children and adolescents have employed diet records, either weighed or estimated. These have been shown to provide unbiased records of EI in lean subjects up to 9 years old (Livingstone *et al.* 1992; Davies *et al.* 1994; Bandini *et al.* 1997; McGloin *et al.* 2002). However, the studies of older children, adolescents and young adults unanimously show that EI by this method is under-reported by approximately 20%, with the greatest bias being observed in the older subjects (Livingstone *et al.* 1992; Bandini *et al.* 1997; Bratteby *et al.* 1998). Thus, while mean EI by weighed dietary record was underestimated by 14% ($P < 0.01$) in 12-year-olds, in 15- to 18-year-olds the magnitude of underestimation had increased to 24% ($P < 0.01$; Livingstone *et al.* 1992). Using 14 d estimated dietary records, Bandini *et al.* (1990) also showed a remarkably similar degree of under-reporting, with the negative bias being particularly pronounced in obese subjects. It appears, therefore, that the magnitude of under-reporting by diet records is independent of the specific method used to quantify food intakes.

Only one study to date has validated the diet history technique concurrently with weighed dietary records in children and adolescents (Livingstone *et al.* 1992). The former method apparently overcomes the age-related reporting bias of weighed dietary records. However, while the diet history obtained good mean intakes, the data lacked precision at the individual level, with 35% of the results by diet history lying outside the 95% CI that assume a valid measure of habitual intake.

There have been relatively few studies assessing the validity of 24 h recalls and FFQ, which makes it difficult to generalize about the results. With the exception of the study by Johnson *et al.* (1996), which demonstrated that the multiple-pass 24 h recall accurately reflected mean EI, the other studies employing this protocol demonstrated a positive bias in mean EI (Ku *et al.* 1998; Fisher *et al.* 2000; Reilly *et al.* 2001). In all of these studies, accuracy at the individual level was poor. It has been speculated that inappropriate tools used to estimate portion size might partly account for the bias in some studies (Reilly *et al.* 2001). Results using FFQ have been highly variable. On one hand, valid mean intakes but significant individual variability in reporting accuracy have been noted in a group of prepubertal children and adolescents (Perks *et al.* 2000). In contrast, the Willett FFQ resulted in a significant overestimation of EI (53%) in 4- to 7-year-olds, probably due to the inappropriate portion sizes built into the design (Kaskoun *et al.* 1994).

In summary, there have been too few validation studies in paediatric groups to justify advocating one particular method over another.

Subject-specific response in dietary reporting

Dietary surveys usually report a range of EI that, at the extremes of the distribution, cannot represent habitual

intake. It has been customary to assume that these extreme values were obtained by chance due to day-to-day variation in food intake, but that with repeat measurements the extreme values would balance out to provide a valid measure of mean intake. However, it is conceivable that a subject who has under-reported dietary intake on one occasion will also under-report on a second occasion, in which case the bias cannot be eliminated by repeated measurements. It has also been suggested that estimates of intake can be improved by administering two different dietary assessment instruments, an approach that recognizes that there are large errors in all techniques, but assumes that the sources of error are independent in different methods.

The latter assumption has not been borne out in children and adolescents. When EI was assessed simultaneously by weighed dietary record and diet history, and validated by the doubly labelled water method (Livingstone *et al.* 1992), there was clear evidence of a subject-specific response, such that subjects who under-reported by the weighed dietary record also did so by the diet history. The strongest influence on EI:EE was the dietary assessment method ($P < 0.0001$), with the weighed dietary record showing the greater bias to under-reporting. The second most important influence was the age of the subject ($P < 0.001$). Compared with 7-, 9- and 12-year-olds, 15- and 18-year-olds showed a marked bias to under-reporting and a stronger tendency for these individuals to give a similar response to both methods. The effect of gender was small and not significant, with males just as likely to under-report as females.

Subject-specific bias has important implications for the analysis of dietary surveys. Under- and over-reported intakes will simply extend the range of reported intakes and will distort the ranking of subjects, resulting in biased conclusions (Black & Cole, 2001).

The detection of misreporting

It is now widely accepted that misreporting is a major problem in dietary surveys, not just in adults, but also in children. What children say they eat is clearly not what they eat. Consequently, their dietary data can no longer be accepted at face value, and all data should be subjected to critical examination for evidence of bias. Unfortunately, the cost and technical complexity of the doubly labelled water technique preclude its routine use for detecting bias in EI data. However, reported EI can also be evaluated against presumed energy requirements, expressed as physical activity levels (PAL; Goldberg *et al.* 1991; Black, 2000a). This procedure, known as the Goldberg cut-off technique, was devised to evaluate the overall bias towards under-reporting at the group level. Although its use has been extended to identify under-reporters at the individual level, the cut-off is limited by low sensitivity, as it identifies only about 50% of under-reporters and, furthermore, it can make no distinction between varying degrees of misreporting (Black, 2000b). In addition, a common misinterpretation of the Goldberg cut-off technique is that the cut-offs, which were originally designed for

screening the EI data of adults, can also be applied to the evaluation of the EI data of children and adolescents.

The effect of substituting the Goldberg *et al.* (1991) cut-off for adults (based on an assumed PAL of 1.55 for a sedentary life-style) for the appropriate age- and gender-specific cut-offs for children (also based on an assumed light activity PAL) have been illustrated by Kersting *et al.* (1998) using a data set of 695 3 d weighed dietary records by German children and adolescents aged 1–18 years. Based on a blanket cut-off derived from a PAL of 1.55, approximately 10% of the records were excluded as implausible. The extent of misreporting varied by age, being lowest in the 1- to 5-year-olds (approximately 2%) and highest in the adolescent males (11%) and females (31%). Since the appropriate age- and sex-specific cut-offs for children and adolescents (Torun *et al.* 1996) are lower than the cut-off based on a sedentary PAL of 1.55 for adults (except in older adolescent males aged 14–18 years), the overall effect of applying the former cut-offs was to reduce the exclusion rate to 6.5% in the total group, and to 20% in the adolescent females. Thus, the use of cut-offs that were never designed to evaluate the EI of children and adolescents can distort a data set by 'overestimating' the extent of dietary misreporting in these age groups. While the principles of the Goldberg *et al.* (1991) cut-off technique still hold good when assessing the EI of children and adolescents, appropriate age- and sex-specific cut-offs should always be applied in these population groups.

One of the major limitations in using a single EI:BMR cut-off based on a sedentary PAL value is that it will uncover only the probable degree of overall bias in a study, provided that a PAL value appropriate to that population is used for comparison. However, under-reporting occurs at all levels of levels of energy expenditure (Black, 1997) and, to improve sensitivity, methods need to be applied which will account for different levels of physical activity. Questionnaires have their errors and raise the issue of choosing appropriate PAL values for differing levels of physical activity. If more objective methods of assessing EE such as heart-rate monitoring are used, then EE can be estimated in absolute terms and EI can be then be compared directly with EE, in which case the Goldberg cut-off technique becomes redundant. However, the validity of techniques such as heart-rate monitoring for estimating EE also needs to be ensured before they come into common use for validating EI data (Livingstone *et al.* 2003).

Although most attention to date has focused on the issue of under-reporting, the possibility of systematic over-reporting cannot be excluded. At present, however, identification of its presence and magnitude in the EI data of children and adolescents is virtually impossible. The existing doubly labelled water data in these groups (Black *et al.* 1996) provide only limited information on which to define an appropriate PAL suitable for calculating a cut-off for identifying over-reporters. Caution should also be applied if using the age- and sex-specific PAL values for heavy habitual physical activity (Torun *et al.* 1996) because these were defined arbitrarily, not derived experimentally.

Consequences of misreporting

Validation of dietary intakes against EE will identify bias in the reporting of EI only, but provides no clues as to whether this reflects under-reporting of the diet as a whole or if there is bias in estimating nutrient intakes through altered food choices and/or selective misreporting of foods. In relation to the dietary intakes of adults, the under-reporting of food intake tends to be a selective rather than a general phenomenon (Livingstone & Black, 2003). Thus, bias in reporting of total EI is associated with variable bias in reporting macro- and micronutrient intakes, foods and meal patterns. Unfortunately, to date, few of the validation studies of children's food intakes have examined the data for selective misreporting. Kersting *et al.* (1998) noted that adolescent under-reporters recorded fewer daily snacks and a lower sugar intake (percentage of EI) than those deemed to be non-under-reporters. It was speculated that this finding might be due to specific omissions of sweet and/or snack foods. In contrast, Fisher *et al.* (2000) found no differences in macronutrient reporting among 4- to 11-year-old children who were identified as under-reporters, accurate reporters or over-reporters. These data provide few insights into either the nature or the implications of misreporting in paediatric groups. For example, under-reported food intakes could produce serious exaggeration of deficient intakes, while selective misreporting of foods would seriously hamper derivation of food-based dietary guidelines. Thus, until the nature and magnitude of misreporting can be characterized, all dietary data on children and adolescents need to be interpreted with considerable caution. In the mean time, the most appropriate action to take when evaluating nutrient intake data is to assume that the reported intakes are minimum true intakes, while accepting that for some nutrients an over-estimation will be made.

Conclusion

Studies of the food habits and dietary intakes of children and adolescents face a number unique problems which are more or less specific to these age groups and which are highly likely to bias the outcome measurements. The cross-validation of EI data using doubly labelled water estimates of EE has led to the widespread recognition that much of the dietary data on children and adolescents is prone to reporting error, mostly in the form of under-reporting. Moreover, this reporting bias does not occur systematically across age groups or different dietary survey techniques. It appears that the available methods for assessing the dietary intakes of children and adolescents are, at best, able to provide unbiased estimates of EI only at the group level in the younger age groups. The food intake data of most adolescents are particularly prone to reporting error at both the group and the individual level. To date, only limited progress has been made in understanding the variables associated with misreporting in these age groups, the associated biases in estimating nutrient intakes and the most appropriate way to interpret unrepresentative dietary data. Until these issues are better understood, researchers should exercise considerable caution when evaluating all such data.

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