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Validation of energy intake by 24-hour multiple pass recall: comparison with total energy expenditure in children aged 5–7 years

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Accurate measurement of energy intake (EI) is essential in studies of energy balance in all age groups. Reported values for EI can be validated against total energy expenditure (TEE) measured using doubly labelled water (DLW). Our previous work has indicated that the use of the standardized 24 h multiple pass recall (24 h MPR) method produces slight overestimates of EI in pre-school children which are inaccurate at individual level but acceptable at group level. To extend this work, the current study validated EI by 24 h MPR against TEE by DLW in sixty-three (thirty-two boys) school-aged children (median age 6 years). In both boys and girls, reported EI was higher than TEE, although this difference was only significant in the girls (median difference 420 kJ/d, $P=0{\cdot}05$). On analysis of agreement between TEE and EI, the group bias was an overestimation of EI by 250 kJ/d with wide limits of agreement (−2880, 2380 kJ/d). EI was over-reported relative to TEE by 7 % and 0·9 % in girls and boys, respectively. The bias in the current study was lower than in our previous study of pre-school children, suggesting that estimates of EI become less inaccurate as children age. However, the current study suggests that the 24 h MPR is inaccurate at the individual level.

Diet records: Obesity: Child nutrition: Energy expenditure: Doubly labelled water method

As the prevalence of excess weight in child and adult populations increases, the need for accurate assessment of dietary intake in all age groups becomes more pressing. Due to its cost-effectiveness and the low burden it imposes on respondent and interviewer, the 24 h recall is often the method of choice to obtain population mean intakes for respondents from age 10 years and above (Biró *et al.* 2002). For children below the age of 10 years, it is necessary for an adult carer to act as respondent (Biró *et al.* 2002). The need to standardize the recall method to limit interviewer and/or respondent bias has been highlighted (Slimani *et al.* 2000). The most standardized recall protocol is that of the 24 h multiple pass recall (24 h MPR), originally developed by the United States Department of Agriculture for use in its food surveys (Guenther *et al.* 1998) and since improved (Moshfegh *et al.* 1999).

There is some evidence that the 24 h MPR produces a valid and unbiased estimate of intake in young children (aged 4–7 years) when parents have responded on their behalf (Johnson *et al.* 1999). Parental response regarding their child's intake may therefore avoid some of the age and societal issues that contribute to under-reporting of adult intake. As children become older, it is important that responses from both child and parent are considered (Sobo *et al.* 2000). However, as the issues affecting reporting are likely to differ between children and adults, even when adults are providing the responses for children, the need to validate all methods of assessing EI at more defined ages during childhood has become evident (Livingstone & Robson, 2000).

Validation of EI measurements relies on accurate measurement of the other side of the energy balance equation, namely energy expenditure. The basis for such validation is that in energy balance, total energy expenditure (TEE) and EI are equivalent, with participants assumed to be weight-stable for the duration of study. The reference method for assessing TEE is doubly labelled water (DLW). The use of TEE measured by DLW in the validation of EI estimates has been reviewed elsewhere (Livingstone & Black, 2003). Other methods to validate estimates of EI include the ratio of EI to measured or predicted basal metabolic rate (EI:BMR) and comparison with the Goldberg cut-off. However, the Goldberg cut-off relies on an assumed population physical activity level, which limits sensitivity and specificity (Black, 2000), incurs misidentification, and may not be applicable in young children. In addition, measurement of BMR in young children can be difficult; in the present study, we found that

Abbreviations: BMI SDS, body mass index standard deviation score; DLW, doubly labelled water; EI, energy intake; 24 h MPR, 24-hour multiple pass recall; TEE, total energy expenditure.

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adherence to BMR protocol requirements was limited (Montgomery *et al.* 2004; Reilly *et al.* 2004). Previous validations of energy intake against TEE in children are very scarce (Hill & Davies, 2001).

We have previously shown that TEE (by DLW) and EI (by 24h MPR) can be successfully measured in pre-school children (mean age 3 years; Reilly *et al.* 2001). Our previous work indicated that although acceptable for group estimates, the 24 h MPR did not produce accurate estimates of EI for individuals of pre-school age (Reilly *et al.* 2001). In the current study, we aimed to assess the validity of EI estimates obtained by the 24h MPR in school-aged children and to compare it with our previous results in pre-school children in the same setting and with the same methods and investigators.

Subjects and methods

Subjects

Children in their initial two years of primary school (aged 4·5–7 years) who were previously recruited to and participating in our larger study of TEE, EI and physical activity (total *n* 209) were eligible for inclusion. All children were recruited from selected postal sectors in the Glasgow area, as previously described (Jackson *et al.* 2003), producing a sample representative of Glasgow in terms of socio-economic status. All parents gave informed written consent to participation and the study had the approval of the Yorkhill Hospital Research Ethics Committee.

Measurement of energy intake

The 24 h MPR has been described in detail elsewhere (Johnson *et al.* 1996; Moshfegh *et al.* 1999) but basically consists of a quick list of all foods and drinks consumed, a detailed description and a review with the interviewer probing for information on time/occasion, forgotten foods and food details. The 24 h MPR can be as successfully administered by telephone interview (Casey *et al.* 1999; Jonnalagadda *et al.* 2000; Tran *et al.* 2000; Brustad *et al.* 2003) as in face-to-face interviews. The main requirement for ensuring that accurate details are obtained by 24 h MPR is a suitably trained interviewer, with knowledge of appropriate questions or probes to ask regarding food identification, preparation and ingredients (Biró *et al.* 2002). Such probes can be effectively standardized by using a validated tool containing questions related to specific foods, such as the Food Instruction Booklet developed in the USA (US Department of Agriculture, Agricultural Research Service, 1998; Casey *et al.* 1999). Recalled portion sizes and the use of household implements such as bowls can provide accurate estimates of consumption during a 24 h recall (Chambers *et al.* 2000). Additional portion size aids such as food replicas, household measures and food photographs can all be used with equal efficacy (Biró *et al.* 2002). In the present study, one trained interviewer (C. M.) administered the 24 h MPR on three separate occasions to include one weekend day and two weekdays, during the 10 d period of TEE measurement. Additional probes were based on the American Food Instruction Booklet (US Department of Agriculture, Agricultural Research Service, 1998), with some language and detail modification to make it specific to the British population. In all cases, the respondent was the mother or main female carer (e.g. grandmother), with intake outside the home verified in writing by an attendant adult (e.g. school staff). Portion sizes were estimated using metric amounts where available, household measures (cups, glasses, bowls, plates) as described using appropriate items from the Food Atlas (Nelson *et al.* 1997) and average UK portion sizes (Ministry of Agriculture, Fisheries and Food, 1993) for individual, composite and proprietary foods. Values for EI were derived from intake records using the nutritional analysis program CompEat (Version 4.0, Nutrition Systems, Grantham, UK) based on the UK Food Composition Database (Royal Society of Chemistry, Cambridge, UK).

Measurement of total energy expenditure

TEE was measured using DLW as described previously (Montgomery *et al.* 2004; Reilly *et al.* 2004). Briefly, following collection of a baseline (pre-dose) urine sample (day 0), participants received a sterilized, weighed dose (1·6 ml/kg body weight) of ^{18}O-labelled water (10 % enriched; Cortec, Paris, France) mixed with 0·24 ml/kg 99·9 % enriched deuterium oxide (Aldrich Chemicals, Dorset, UK). Compared to the pre-school children (Reilly *et al.* 2001), the larger body size and hence lower rate of mass specific isotope turnover of the school-aged children necessitated a longer measurement period in the older children. Urine samples were obtained after the dose was ingested on days 1 and 10 post-dose (compared to 1 and 7 for the pre-school children). Isotopic enrichments of urine samples were measured by isotope ratio mass spectrometry as previously described (Reilly *et al.* 2001). We estimated CO_2 production rate from the differential disappearance of the two isotopes using equation A6 of Schoeller *et al.* (1986). We converted estimated CO_2 production to heat production using the constant 23·8 kJ/l based on the mean food quotient from dietary intake data (Reilly *et al.* 2001). The estimated cost of growth is minimal (approximately or no more than 25 kcal/d; Johnson *et al.* 1996), so no correction for growth was made.

Anthropometry measurements

Participants were measured in light indoor clothing without shoes. Height was measured using a Leicester stadiometer (Child Growth Foundation, London, UK) to 0·001 m and weight was measured using a Seca scale (Seca Ltd, Birmingham, UK) to 0·1 kg. Values for BMI were expressed as standard deviation scores (BMI SDS) relative to UK 1990 growth reference data (Cole *et al.* 1995) using software from the Child Growth Foundation.

Statistical analyses and power

The statistical distribution of all variables for boys and girls separately was tested using Shapiro–Wilk normality tests; variables were found to be of non-normal distribution. Differences between boys and girls were assessed using Mann–Whitney Utests. Differences between TEE (kJ/d) and EI (kJ/d) were tested using Wilcoxon tests for each gender. Agreement between TEE (kJ/d) and EI (kJ/d) was assessed using the Bland–Altman method of agreement analysis (Bland & Altman, 1986). In this method, the bias is calculated as the mean difference between the reference method (TEE by DLW) and the reported value (EI by 24h MPR), and limits of agreement are calculated as the bias ± 2SD of the difference.

Power was difficult to assess, as agreement rather than an absolute difference was the main outcome sought in the present setting. Agreement and bias at group and individual level had previously been detected in samples of between twenty-four and eighty-one children between the ages of 1·5 and 7 years (Davies & Coward 1994; Kaskoun *et al.* 1994; Johnson *et al.* 1996, 1999). The largest published validation study on forty-one children within a more narrowly defined age range originated from our group (Reilly *et al.* 2001). No previous validation study has been large enough to allow for separate gender analyses. We therefore sought to recruit a minimum total of thirty boys and thirty girls into the study.

Results

Characteristics of participants

Of the 209 children in our larger study on physical activity, TEE and EI, seventy-three successfully completed TEE measurements and seventy-six EI measurements. A total of sixty-three children (thirty-two boys, thirty-one girls) successfully completed both TEE and EI protocols. Physical characteristics are shown in Table 1. There were no significant differences between boys and girls regarding anthropometry or EI (kJ/d) but boys had a significantly higher TEE (median 6870 kJ/d *v.* median 6000 kJ/d, $P=0{\cdot}0001$; Table 1).

Comparison of TEE and EI

The difference between median TEE (kJ/d) and median EI (kJ/d) was not significant for boys (median difference: TEE higher by 90 kJ/d, $P=0{\cdot}758$), but was significant for girls (median difference: TEE higher by 420 kJ/d, $P=0{\cdot}05$), with EI (MJ/d) significantly higher than TEE (MJ/d). The linear relationship between TEE (kJ/d) and EI (kJ/d) for both genders is illustrated in Fig. 1.

Agreement between TEE (kJ/d) and EI (kJ/d) was assessed for the genders combined (Fig. 2(a)) and separately (Fig. 2(b, c)). The negative mean difference or bias indicates that TEE was generally lower than reported EI (see Table 1 for values of TEE and EI). The bias was larger in the girls than the boys and the upper and lower limits of agreement (bias ±2SD) were wider for the girls (Table 2), although this gender difference was not significant ($P=0{\cdot}27$). The individual error was significantly correlated with EI ($r - 0{\cdot}7$, $P<0{\cdot}01$), indicating that as reported EI increased, its overestimation relative to TEE increased (Fig. 3). The percentage error (the individual bias expressed as a percentage of the reported EI) was not significantly correlated with EI ($r - 0{\cdot}10$, $P=0{\cdot}4$), indicating that the magnitude of error was not related to EI.

Discussion

The current study is the largest undertaken in children of any age to use DLW to validate the 24 h MPR (see Livingstone & Black, 2003 for review of studies). It is also one of the few studies to estimate EI using the 24 h MPR performed on three separate occasions; fewer recalls are unlikely to yield accurate estimates (Mennen *et al.* 2002). Calls for the validation of EI methodology in larger samples of children with wider age ranges (Livingstone & Robson, 2000) led us to extend our assessment of the use of the 24 h MPR in pre-school children (Reilly *et al.* 2001) to school-aged children (reported here).

A previous comparison of three separate 24 h MPR to TEE measured by DLW in twenty-four children aged 4–7 years indicated a small bias (with TEE higher on average by 226 kJ/d) and wide limits of agreement (−4611 to 3376 kJ/d; Johnson *et al.* 1996). Although the magnitude of the bias (251 kJ/d) and limits of agreement (−2879 to 2380 kJ/d) in the current study are similar to those found by Johnson *et al.* (1996), they are of the opposite direction, with a bias towards a higher EI reported here.

As in the current study, the bias in the oldest children (aged 3·50–4·49 years) studied by Davies and Coward (1994) indicated an EI (measured by weighed intake) that was higher than TEE (by 40 kJ/d). In a similar age group to that of the current study (4·2–6·9 years), Kaskoun *et al.* (1994) found that EI reported using a food-frequency questionnaire was significantly higher than TEE by DLW. Although a bias towards overestimation of EI could indicate errors in the measurement of TEE and EI, it is interesting that it is only apparent at this young age, when children have less autonomy over their intake and are reliant on parental reports of EI. Older children and adults not only tend to under-report EI (Hill & Davies, 2001), but the decline in accuracy of reported EI with age is evident from as young as 10 years (Bandini *et al.* 2003).

We have previously shown that 24 h MPR incurred large errors at the individual level but provided acceptable estimates of EI at group level in pre-school children (Reilly *et al.* 2001). Inaccuracy was reduced in the school-aged children in the present study compared to the pre-school children studied by us previously (Reilly *et al.* 2001). In the pre-school children, the bias for both genders was 660 kJ/d (2SD 3020 kJ/d, limits of agreement −2360 to

Table 1. Characteristics of participants

	Boys (n 32)		Girls (n 31)		
	Median	Range	Median	Range	*P* value*
Age (years)	6·0	4·8–6·7	5·7	4·5–6·9	0·06
Weight (kg)	20·6	14·9–34·9	19·6	15·4–27·1	0·06
Height (m)	1·152	1·049–1·275	1·123	1·028–1·250	0·10
BMI (kg/m^2)	16·25	13·5–21·5	15·40	14·0–20·5	0·18
BMI SDS	0·50	−1·80–4·10	0·00	−1·20–2·30	0·15
TEE (kJ/d)	6870	5740–9830	6000	3530–7430	<0·01
EI (kJ/d)	6910	5060–10 440	6280	4870–9030	0·09

BMI SDS, body mass index standard deviation score; EI, energy intake; TEE, total energy expenditure.
* *P* value obtained on Mann–Whitney test for differences between boys and girls.

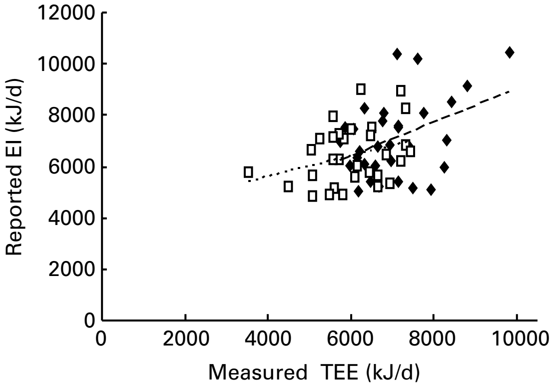

Fig. 1. Relationship between total energy expenditure (TEE; kJ/d) measured by doubly labelled water and energy intake (EI; kJ/d) reported by 24-hour multiple pass recall. Individual values are plotted for boys (*n* 32, ◆) and girls (*n* 31, □) separately. The linear relationships are plotted for boys (– – –) and girls (. . .).

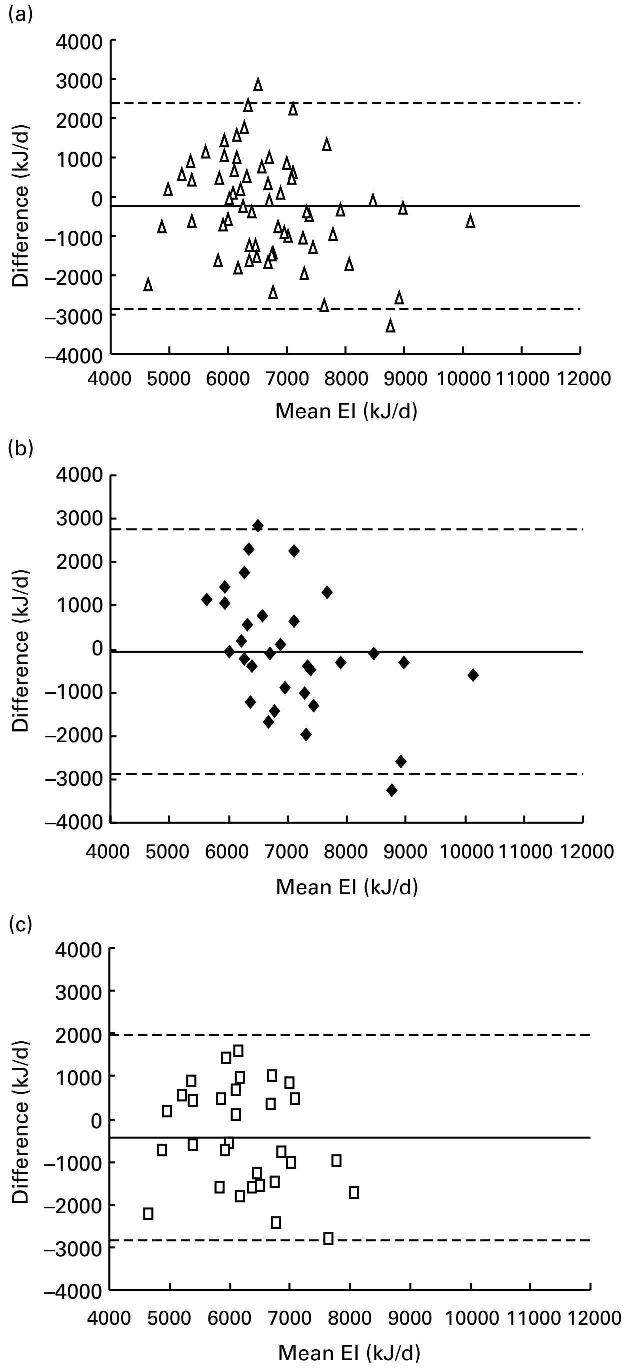

Fig. 2. Analysis of agreement between total energy expenditure (kJ/d) measured by doubly labelled water and energy intake (EI; kJ/d) reported by 24-hour multiple pass recall. The mean of both values is plotted on the *x*-axis and the difference between the values is plotted on the *y*-axis. Individual values are plotted for the genders combined (*n* 63 (a)), and for boys (*n* 32 (b)) and girls (*n* 31 (c)) separately. The bias (solid line) and the upper and lower limits of agreement (broken lines) are superimposed.

3680 kJ/d), equating to an 11 % overestimate of EI (Reilly *et al.* 2001). In the school-aged children reported here, the bias for both genders was 250 kJ/d (2SD 2630 kJ/d, limits of agreement −2880 to 2380 kJ/d), a 4 % overestimation in EI relative to TEE. This decrease in bias with age is in agreement with the previous finding of Davies & Coward (1994) that the difference between EI and TEE was lower in children aged 3·50–4·49 years compared to younger children.

There are several plausible explanations for the apparent decrease in bias with age. It may be postulated that there is improvement in reporting EI by parents as children become older, either because parents become more adept at accurate reporting or because the portion size estimates used are more appropriate for older rather than younger children. In both the present and our previous study, the amount of time taken to perform each 24 h MPR was similar, with an overall total interview time of 30 min over 3 d. Each MPR was performed by the same investigator (C. M.) in both studies, limiting any differences between the studies in the prompting of parents to recall items consumed. Portion sizes were estimated using the same methods in both studies. Portion sizes were reported by parents using metric amounts where available (e.g. size of tin or bottle purchased), or household measures which were verified by each respondent by comparing their own household implements (e.g. cups, glasses, plates, spoons) to illustrated examples from the Food Atlas (Nelson *et al.* 1997). Where portion sizes could not be accurately provided, average portion sizes for the UK were used (Ministry of Agriculture, Fisheries and Food, 1993) for individual (e.g. slice of bread), composite (e.g. lasagne) and proprietary foods (e.g. biscuits, confectionery, savoury snacks and yoghurts). As the method for portion size estimation was consistent between studies, it is possible that such estimates are more accurate for older children, but in each case, such estimates were in broad agreement (75–120 %) with guide weights for portion sizes of young children (Gregory *et al.* 1995).

One potential limitation of the current study is that we did not perform additional analyses to assess the relationship between reporting accuracy and body composition (Fisher *et al.* 2000). However, we found no relationship between the individual bias and BMI SDS (data not shown). Given our total sample size of sixty-three children, any analyses that separated respondents into under-, accurate- or over-reporters and then factored in body weight or composition would have had limited power.

In the present study, EI was over-reported using the 24 h MPR in young children. This is in contrast to work on adolescents and adults (Johnson *et al.* 1999; Hill & Davies, 2001), but is generally consistent with previous work in children (Davies & Coward,

Table 2. Bias and limits of agreement between total energy expenditure (TEE; kJ/d) and energy intake (EI; kJ/d) for both genders combined and separately*

		Limit of agreement (kJ/d)	
	Bias (kJ/d)	Upper	Lower
Both genders	−250	2380	−2880
Boys	−60	2750	−2870
Girls	−440	1970	−2860

*Bias calculated as mean (TEE − EI); limits of agreement calculated as the bias +2SD (upper limit) and bias − 2SD (lower limit).

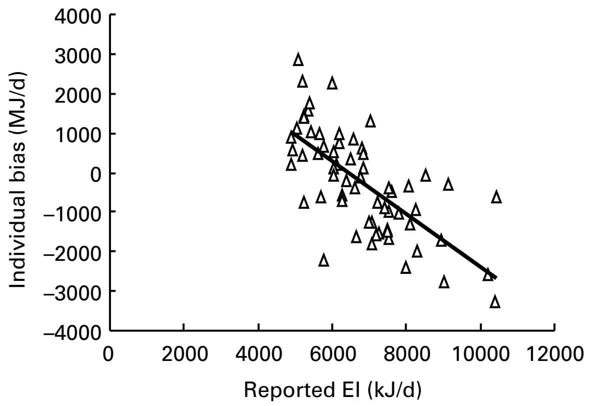

Fig. 3. Relationship between the bias at the individual level (calculated as total energy expenditure − energy intake (EI) (kJ/d)) and reported EI (kJ/d). The correlation ($r - 0·7$, full line) was statistically significant ($P<0·01$).

1994; Kaskoun *et al.* 1994; Reilly *et al.* 2001). The present study and previous studies (Johnson *et al.* 1999) indicate that the 24 h MPR can be used for group estimates of EI, but further work is required to enhance the accuracy of reported EI for individual children.

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