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Validation of a pre-coded food diary used among 13-year-olds: comparison of energy intake with energy expenditure

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Abstract

Objective: To validate energy intake (EI) estimated from pre-coded food diaries against energy expenditure (EE) measured with a validated position-and-movement monitor (ActiReg®) in groups of 13-year-old Norwegian schoolchildren.

Design: Two studies were conducted. In study 1 the monitoring period was 4 days; participants recorded their food intake for four consecutive weekdays using food diaries and wore the ActiReg® during the same period. In study 2 the monitoring period was 7 days; participants recorded their food intake for four consecutive days but wore the ActiReg® for a whole week.

Settings: Participants were recruited from grade 8 in a school in and one outside Oslo (Norway).

Subjects: Forty-one and 31 participants from study 1 and 2, respectively, completed the study.

Results: The group average EI was 34% lower than the measured EE in study 1 and 24% lower in study 2. The width of the 95% confidence limits of agreement in a Bland–Altman plot for EI and EE varied from −0.2 MJ to 8.2 MJ in study 1 and from −2.3 MJ to 6.9 MJ in study 2. The Pearson correlation coefficients between reported energy intake and expenditure were 0.47 ($P = 0.002$) in study 1 and 0.74 ($P < 0.001$) in study 2.

Conclusion: The data showed that there was substantial variability in the accuracy of the food diary at the individual level. Furthermore, the diary underestimated the average energy intake. The ability of the food diary to rank individuals according to energy intake was found to be good in one of the studies and moderate in the other.

Keywords
Energy intake
Energy expenditure
Food diary
Validation

Accurate assessment of food intake in children and adolescents is of concern because dietary habits formed early in life may have a considerable impact on long-term health status[1,2]. Traditionally, dietary assessment methods were constructed for use in adult populations. They should not be used uncritically among children and adolescents.

Measurement of dietary intake among adolescents is challenging because they often have unstructured eating patterns with a significant degree of out-of-home eating, because of general knowledge deficits about food and food preparation techniques and because of a general lack of interest in the subject[3,4]. In 2000, a nationwide survey among 13-year-old Norwegians was conducted to provide detailed information on their current dietary habits[5]. Experience from a similar study conducted in 1993 in the same age group showed that a semi-quantitative food-frequency questionnaire was too difficult for the students to complete alone[6]. A pre-coded food diary was therefore chosen as the assessment method for the 2000 survey.

Several studies among adults using energy expenditure (EE) estimated by the doubly labelled water (DLW) method to assess the accuracy of self-reported energy intake (EI) have shown a tendency for record methods to underestimate food intake[7]. During the last decade a few validation studies among adolescents have also been published, where self-reported EI from record methods (both weighed and estimated) has been validated against EE estimated by the DLW method[8–11]. These studies indicate that misreporting of EI (especially underreporting) is also highly probable in this age group.

Although the DLW method is clearly the most accurate one for measuring average EE during a time period and for use as a biomarker of habitual EI[12,13], its use is prohibited in large groups by the high cost of the labelled water and the requirement of highly specialised and expensive equipment for the analysis[13]. In the present study we have used the ActiReg®, a validated position-and-movement monitor, to measure EE[14,15]. Our aim was to validate EI estimated from pre-coded food diaries against EE

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measured with the ActiReg® in groups of 13-year-old Norwegian schoolchildren.

Subjects and methods

Subjects

Two separate validation studies were conducted: the first in September–November 2000 in a school in the Oslo area (study 1) and the second in October–November 2001 in a school outside Oslo (study 2). Both samples were convenience samples. A total of 56 and 51 students (13 years old) in the 8th grade were invited to participate in study 1 and study 2, respectively. In total, 46 students from study 1 and 35 students from study 2 agreed to participate, and 41 and 31 from study 1 and 2, respectively, completed the study. The causes of non-completion were technical problems with the ActiReg® or missing days of ActiReg® assessments.

The Regional Ethics Committee for Medical Research approved the studies. Informed consent was obtained from one of the parents and the student.

Design

The students were informed about the study at their school during a physical education lesson, and were handed an information letter. A nutritionist visited the class and the students who wanted to participate were carefully instructed how to fill in the pre-coded food diary and how to use the ActiReg®. Moreover, they filled in a short questionnaire about physical activity, time watching television, parental education, satisfaction/dissatisfaction with body weight and meal patterns. In study 1 the monitoring period was 4 days; the participants recorded their entire food intake for four consecutive weekdays and wore the ActiReg® during the same period. In study 2 the monitoring period was 7 days; the participants recorded their entire food intake for four consecutive days but wore the ActiReg® for a whole week (seven days). The recording of the diet started at day 3 in the monitoring period and included three weekdays and one weekend day.

Food diary

The participants received one pre-coded food diary for each day they had to record their food intake and were instructed how to fill in the diary. The diary lists 277 drinks, food items and dishes grouped into the following sections: beverages, bread, spread on bread, yoghurt, breakfast cereals, milk for breakfast cereals, meat dishes, fish dishes, other dishes, mixed salads, potatoes/rice/pasta, vegetables, sauces, dessert, cakes, fruit and berries, snacks, sweets and chocolate, supplements[5]. Each food group is supplemented with open-ended alternatives. The design of the booklet is similar to a cross-table with food listed on the left and time span across the top. Food amounts are presented in predefined household units (e.g. beverage is recorded in glasses) or as portions estimated from photographs. Along with the diary each participant was given a photographic booklet containing 13 series of colour photographs, each with four different portion photographs ranging from small to large[16]. The participants indicated an eating event by filling in how many units they had eaten of each food item in the correct time span. The day was divided into five time spans; four time spans each covered 4 h, e.g. from 06.00 to 10.00, from 10.00 to 14.00, etc., and one covered 8 h, from 22.00 to 06.00. The participants were instructed to either fill in the food diary immediately after each meal was finished, or record the food eaten on attached notepaper and then fill in the diary in the evening.

All instruction about recording of the diet was done in the same way as in the nationwide survey from 2000.

The data were scanned using the Teleform program, version 6.0 (Datascan, Oslo, Norway). Daily intake of energy was computed using the food database and software system (KBS, version 3.1, 2002) developed at the Department of Nutrition, University of Oslo. The food database is mainly based on the official food composition table[17], and is continuously supplemented with data on new food items and nutrients.

Weight, height, body mass index and basal metabolic rate

Weight and height were measured by the project staff. Weight was measured with subjects in light clothing, i.e. T-shirt, pants and socks, and height was measured to the nearest 0.5 cm. Body mass index (BMI) was calculated as weight divided by the square of height (kg/m^2). Estimates of basal metabolic rate (BMR) were calculated from equations based on weight, age and sex[18].

Parental education

Parental education level was defined based on the highest school education achieved by either the mother or the father. 'Low' education level was assigned to those who attended school for up to 9 years; 'middle' to those who attended school for 10–12 years; and 'high' to those who achieved an advanced level of education (13 or more years).

ActiReg®

The ActiReg® system (PreMed AS, Oslo, Norway) uses a combined second-to-second recording of body position and motion to calculate EE. The apparatus has two pairs of position-and-motion sensors connected by cables to a battery-operated storage unit fixed to a waist belt. Each pair of sensors is attached by medical tape to the chest and the front of the right thigh, respectively. The storage capacity of the ActiReg® is sufficient for more than 30 days of continuous registration of normal activity. The collected data are transferred to a personal computer and processed by a dedicated program ActiCalc®. More details about the monitor are published elsewhere[14,15].

Prior to and at the end of the recording period we checked the functionality of the instruments. During processing of the collected data, a visual onscreen examination of the data was performed to ensure that each pair of position-and-motion sensors had been positioned correctly. The ActiReg® device was not carried during the night when sleeping and during water activity. However, since the instruments record data continuously they were not turned off during sleeping hours but put aside with the sensors oriented horizontally. This mimics the recording of lying still, which is equivalent to the body position and activity of a sleeping person. Subjects put the instruments back on when they got out of bed in the morning. If the device was removed during the daytime for periods of less than 2 h, e.g. due to water activity, the same procedure was used. Periods of more than 2 h led to exclusion of this day from the calculations.

The ActiReg® system has been validated against both the DLW method and indirect calorimetry[14]. Both validation experiments demonstrated that there was no significant mean difference between EE estimated with the ActiReg® and EE measured with indirect calorimetry or the DLW method[14]. The Bland–Altman plot for EE measured with indirect calorimetry and EE measured with the ActiReg® ($EE_{AR} - EE_{IC}$ plotted against the mean of EE_{AR} and EE_{IC}) showed a mean difference of $-8\,kJ\,h^{-1}$, with the limits of agreement (plus or minus two standard deviations ($\pm$2SD)) being -168 and $152\,kJ\,h^{-1}$, respectively[14]. The Bland–Altman plot for EE measured using the DLW method and EE measured with the ActiReg® ($EE_{AR} - EE_{DLW}$ plotted against mean of EE_{AR} and EE_{DLW}) showed a mean difference of -0.41 MJ, and the $\pm$2SD limits of agreement were -2.30 and 3.10 MJ, respectively[14]. Moreover, the correlation coefficients between EE estimated with the ActiReg® and EE measured with indirect calorimetry and DLW were 0.86 and 0.70, respectively (unpublished data).

Statistical analysis

Sample size calculation for the two studies was based on an SD of energy intake of 2 MJ and a correlation coefficient between the two measures of 0.5. Using a paired *t*-test, an 80% power and a 5% significance level, we needed 32 individuals to be sure of detecting a mean difference between ActiReg EE and food diary EI of 1 MJ.

The data were normally distributed and parametric statistical analysis has been used. The data are presented as means and SD. Differences between methods and gender were analysed using paired and unpaired *t*-tests, respectively. Difference in parental education between study 1 and 2 was tested with the chi-square statistic. The visual agreement between methods was analysed by the method proposed by Bland and Altman[19], using a plot of the difference between the two methods against the average of the measurements. This type of plot shows the magnitude of disagreement, spots outliers and any trend. The Pearson correlation coefficient was also calculated. The accuracy of the reported energy intake was calculated by expressing the ratio EI/EE, for which a value of 1 would mean complete agreement between EI and EE. Acceptable reporters were defined as having the ratio EI/EE in the range 0.80–1.20, underreporters as $EI/EE < 0.80$ and overreporters as $EI/EE > 1.20$. These definitions are partly based on the 95% confidence limits of agreement between EI and EE measured by the DLW method as proposed by Black[20].

Table 1 Characteristics of the participants in study 1, study 2 and the nationwide survey

	Study 1				Study 2				Nationwide survey*†			
	Boys ($n=22$)		Girls ($n=19$)		Boys ($n=14$)		Girls ($n=17$)		Boys ($n=490$)		Girls ($n=515$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	12.9	0.4	12.7	0.5	12.9	0.3	13.0	0	12.9	0.3	12.9	0.3
Weight (kg)	50.0	9.3	47.3	8.1	51.6	9.8	53.6	8.2	49.3	10.3	49.5	8.5
Height (cm)	161	9.1	160	7.7	160	7.0	164	5.4	161	9.3	161	6.6
BMI‡ ($kg\,m^{-2}$)	19.1	2.0	18.5	2.1	19.9	2.7	20.0	3.0	19.0	2.8	19.1	2.8
BMR‡ ($MJ\,day^{-1}$)	6.4	0.7	5.6	0.4‖	6.5	0.7	5.9	0.3‖	6.4	0.8	5.7	0.4
Parental education level§¶												
High, *n* (%)	34 (87)				12 (43)				386 (48)			
Middle, *n* (%)	5 (13)				11 (39)				385 (48)			
Low, *n* (%)					5 (18)				37 (5)			

SD – standard deviation.
* Missing values for height: 77 girls and 79 boys; missing values for weight: 70 girls and 75 boys.
† Differences between study 1 and the nationwide survey, and between study 2 and the nationwide survey.
‡ BMI – body mass index defined as weight (in kg) divided by the square of height (in m); BMR – basal metabolic rate estimated from equations[18].
§ Parental education level was defined based on the highest school education achieved by either the mother or the father. 'Low' education level – those who attended school for up to 9 years; 'middle' – those who attended school for 10–12 years; 'high' – those who achieved an advanced level of education (13 or more years). Missing data for parental education: $n=2$ in study 1, $n=3$ in study 2, $n=201$ in the nationwide study.
¶ Difference in parental education between study 1 and 2, $P < 0.001$.
‖ Difference between genders, $P < 0.01$.

Results were considered to be statistically significant at $P < 0.05$. All statistical analyses were performed using SPSS 11.0 (SPSS Inc., Chicago, IL, USA).

Results

Characteristics of the participants are shown in Table 1. No differences in BMI and BMR were observed between the participants in study 1 and study 2 ($P = 0.06$ and $P = 0.38$, respectively). Overall, the difference between EI and EE was larger in study 1 than in study 2 (Table 2) ($P = 0.001$). In study 1 the difference between EI and EE was significantly larger among boys than girls; the opposite was observed in study 2 with the girls having the larger difference (Table 2). Table 2 also shows that the physical activity level (PAL = EE/BMR) was higher in both boys and girls in study 1 compared with study 2. There was a wide range in reporting accuracy. In study 1 only seven subjects (17%) had EI/EE in the range 0.80–1.20; in study 2 the corresponding number was 10 (32%). The percentage of underreporters in study 1 and 2 was 83% and 61%, respectively. The group average EI was 34% lower than the measured EE in study 1 and 24% lower in study 2.

Bland–Altman plots, showing the difference between EI from the pre-coded food diaries and EE from the ActiReg® method plotted against the mean of the two methods, are presented in Fig. 1a (study 1) and Fig. 1b (study 2). The plots illustrate that both underreporting and overreporting of energy intake occurred. The 95% confidence limits of agreement varied from −0.2 MJ to 8.2 MJ (±2SD) in study 1 and from −2.3 MJ to 6.9 MJ (±2SD) in study 2, which indicates wide discrepancies between the two methods for individual subjects in both studies. However, the plots did not indicate that differences tended to increase as absolute energy intake increased, except for the two individuals with the highest energy expenditure in study 2.

The Pearson correlation coefficients between reported EI and EE were 0.47 ($P = 0.002$) in study 1 and 0.74 ($P < 0.001$) in study 2. Figure 2 shows the association between EI and EE estimated from study 1 and 2.

There was a significant negative relationship between BMI and the difference between EE and EI (EE − EI) among girls in study 1 ($r = -0.69$, $P = 0.003$). The correlations among girls from study 2 and among all boys were non-significant: $r = -0.13$, $P = 0.62$ and $r = -0.16$, $P = 0.35$, respectively. No association was found between the difference between EE and EI for participants who were or were not dissatisfied with their body weight.

Discussion

In the present study a newly developed pre-coded food diary for use among adolescents was evaluated using estimated energy expenditure. The advantage of this method compared with traditional methods like weighed records, 24-hour recall and dietary history is that it is less time-consuming for the participants and the researchers to conduct. Moreover, results from four focus group interviews including a total of 24 13-year-olds showed that the students found it easy to fill in the food diary (data not shown). In addition the daily time needed to complete the diary was 10–15 min, which was acceptable for the adolescents.

The data from the two validation studies showed that there was substantial underreporting with the food diaries compared with EE measured with the ActiReg® device. On average, EI was underreported by 34% and 24% in study 1 and 2, respectively. Several food record validation studies among adolescents using DLW as the reference method have observed a varied degree of underreporting ranging from 11% to 24%[3]. The underreporting observed in the present study is somewhat higher than this. The underreporting of EI is consistent over the two studies among girls (32% and 36%), while there was a higher degree of underreporting in study 1 than in study 2 among boys, 39% versus 14%. The mean EI in both genders in study 1, and in the girls in study 2, is lower than the EI observed in a nationwide sample of Norwegian 13-year-olds ($n = 517$ girls and $n = 492$ boys) where the diary also was used[5].

Table 2 Energy expenditure (EE), energy intake (EI), the relationship between EI and EE, physical activity level (PAL = EE/basal metabolic rate) and underreporters in study 1 and study 2

	Study 1†						Study 2‡					
	Boys ($n = 22$)		Girls ($n = 19$)		All ($n = 41$)		Boys ($n = 14$)		Girls ($n = 17$)		All ($n = 31$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EE (MJ day^{-1})	12.9	2.1	10.8***	1.4	11.9	2.0	11.3	1.5	9.5***	0.8	10.3	1.5
EI (MJ day^{-1}	8.0	2.0	7.6	2.4	7.8	2.2	10.1	3.5	6.4*	1.6	8.0	3.2
EI − EE (MJ day^{-1})	−4.8	1.8	−3.2**	2.3	−4.1	2.2	−1.3	2.6	−3.1*	1.7	−2.3	2.3
EI/EE	0.62	0.13	0.71	0.21	0.66	0.18	0.87	0.23	0.67**	0.17	0.76	0.22
PAL	2.02	0.26	1.92	0.22	1.97	0.24	1.75	0.15	1.62**	0.10	1.68	0.13
Underreporters, *n* (%)§	20 (91)		14 (74)		34 (83)		6 (43)		13 (76)		19 (61)	

SD – standard deviation.
† Four days' diet and 4 days' energy expenditure recording.
‡ Four days' diet and 7 days' energy expenditure recording.
§ Underreporters are defined as those with EI/EE < 0.80.
Difference between genders: *, $P = 0.02$; **, $P = 0.01$; ***, $P = 0.001$.

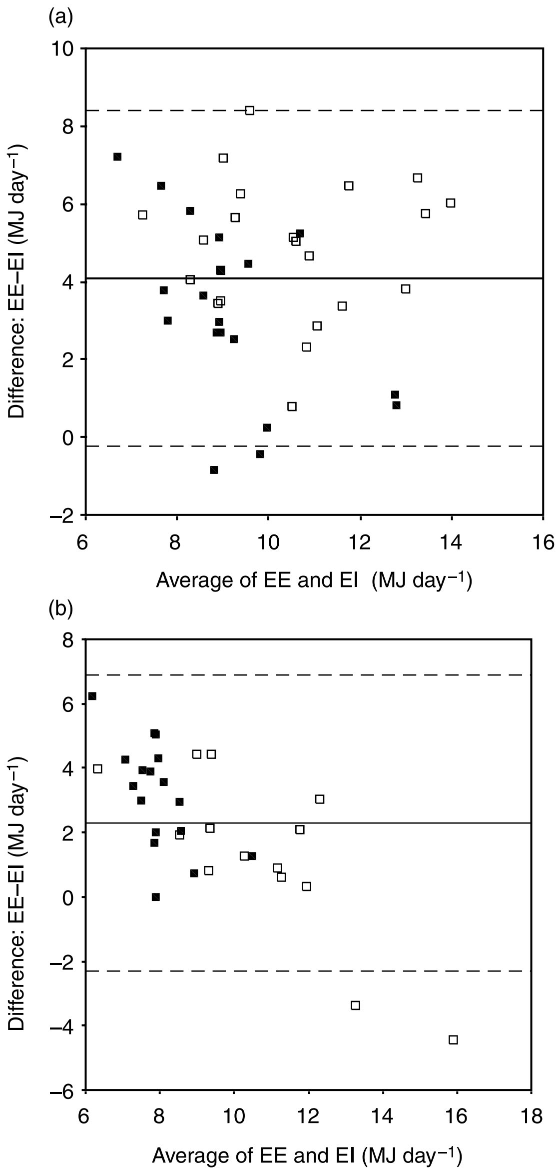

Fig. 1 Bland–Altman plots: the difference between estimated energy expenditure (EE) and estimated energy intake (EI) plotted against the mean of EE and EI for (a) the subjects in study 1 ($n = 41$) and (b) the subjects in study 2 ($n = 31$). ——, Mean difference; – – –, limits of agreement (plus or minus two standard deviations); ■, girls; □, boys

In the national survey mean EI among girls was 8.0 (SD 2.6) MJ and among boys 9.5 (SD 3.5) MJ.

The correlation coefficient is widely viewed as inappropriate for assessing the level of agreement between two measurements. Therefore, the mean difference is calculated to obtain information on bias in the group estimate, and limits of agreement indicate the scatter of individual results. Applying the Bland–Altman plot to the energy data, we showed a mean difference with a large bias and a wide scatter of differences between self-reported EI and estimated EE in both studies. The wide scattering of the differences showed clearly that some subjects under- or overreported their energy intake

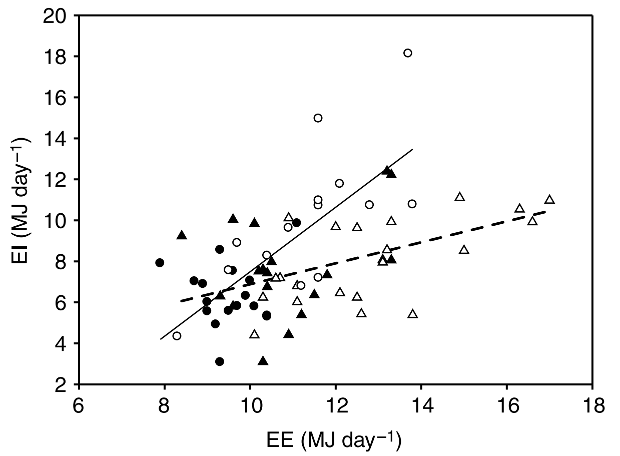

Fig. 2 Energy intake (EI, MJ day^{-1}) estimated from the diary plotted against energy expenditure (EE, MJ day^{-1}) measured with the ActiReg® from study 1 (▲, girls; △, boys) ($n = 41$) and study 2 (●, girls; ○, boys) ($n = 31$). – – –, Linear regression line for study 1; ——, linear regression line for study 2

more than others. Underreporting was a much larger problem than overreporting – 83% in study 1 and 61% in study 2 were identified as underreporters.

The observed underreporting of energy intake in the present study could be due to under-eating or under-recording or a combination of these. In study 1 the participants were promised a letter with information about their dietary intake after the study had finished. This may have influenced the participants to under-eat or under-report during the recording period. In study 2 no feedback was promised and the underreporting was more pronounced among girls than boys; this could be due to girls being more conscious about social desirability. There are few studies about social desirability bias in self-reported dietary intake data among adolescents, but studies among adults and one study among 8–10-year-old girls have found a negative association between social desirability and reporting accuracy[21–23].

The age of our population may also explain a part of the observed underreporting. As mentioned above, adolescence may be a special challenge when measuring food intake because low motivation and issues surrounding body image may hinder willingness to report[3]. Moreover, more food may be eaten outside the home, where it is easy to forget to report. In two studies by Bandini and co-workers comparing EI from a 7-day dietary record based on household measures and EE measured by the DLW method among girls aged 8–12 years and 10–15 years, they observed increasing underreporting with age[9,24].

The ability of the food diary to rank individuals according to energy intake was evaluated using the Pearson correlation coefficient. We observed a moderate (0.47 in study 1) to high (0.74 in study 2) correlation coefficient between individual values for EE and self-reported EI. Perks *et al.*[25] found a correlation of 0.61 between EI and EE in a group of 8–16-year-old children/adolescents. In a Swedish study the observed correlation was 0.59[26]. It is

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important to remember that the correlations obtained from these studies are not directly comparable because the assessment techniques used therein to measure EI and EE were different from those in our study.

Differential underreporting depending on subject characteristics like body weight could have serious implications on risk estimates of diet–disease relations. In the present study an inverse association was found between BMI and underreporting among girls from study 1, the girls with the largest underreporting having the lowest BMI. This effect of BMI on the reporting accuracy of girls is the reverse of earlier observations, where a greater underreporting of EI on diet records was found among obese than among non-obese children and adolescents[8,27]. We do not have an explanation for this 'opposite' pattern observed among the girls in study 1, but the pattern was not replicated among the girls in study 2. The girls in study 1 were slimmer than the girls in study 2 and they reported being less concerned about their body weight than the girls in study 2; both these factors should indicate less underreporting.

The two studies included in the present paper differed in length of monitoring. The number of days was increased from four to seven in study 2 compared with study 1 because the participants in study 1 were suspected to be more active in the monitoring period than they normally were, maybe without increasing their dietary intake to the same extent during this period. A longer monitoring period would make it less convenient to be more active than normal all days. We are aware that when using energy expenditure for evaluation of energy intake, energy balance is assumed in the dietary recording period. In study 2 the periods of energy expenditure assessment and diet recording were not completely overlapping, which may have introduced some error in relation to energy balance. However, since no significant difference was observed between the energy expenditure for the whole week and for days 3–6 where the food intake was recorded, we decided to use the activity data from all seven days.

The PAL values demonstrated that both girls and boys in study 1 were more physically active than the participants in study 2. The difference in EE observed between the two studies may be due to differences in parental education level between study 1 and study 2 (Table 1). Participants in study 1 had parents with a significantly higher education level than participants in study 2, and several studies have shown that adolescents having parents with higher education or coming from families with higher socio-economic status are more physically active during leisure time than adolescents from families with lower socio-economic status[28,29]. The mean EE in both studies is within the range documented for children in the same age group in two Swedish studies using the DLW method and heart-rate monitoring[10,30].

EE was measured with the new instrument, ActiReg®. Validation experiments against indirect calorimetry and doubly labelled water have demonstrated that the ActiReg® provides an estimate of EE at the group level which is comparable to the results from heart-rate and accelerometer recordings, although, like these methods, ActiReg® shows considerable variation at the individual level, but the ranking is fairly good[14]. However, so far the ActiReg® has been validated only in young adults and not in adolescents. Moreover, it has lately been shown that the World Health Organization equations for estimation of resting energy expenditure (REE), which were used in the ActiReg® system for calculation of EE, systematically overestimate REE among adolescents[31]. This may have introduced an error resulting in an overestimation of the EE estimates from the ActiReg® system. The advantage of the ActiReg® is that it enables more subjects to participate in a validation study than would be the case if DLW were used, both because the technique is less expensive than the DLW technique and because the subjects do not have to collect urine samples or measure metabolic rate.

The samples in the present report were convenience samples, relatively small, and not a random sample of 13-year-olds. This may have resulted in a non-random sample that may be more health-conscious than participants in the nationwide survey. We did not find any differences between height, weight, BMI and BMR in the validation samples compared with the sample in the nationwide survey among 13-year-olds. However, the parents in study 1 had higher educational level compared with the parents in the nationwide survey, and in study 2 a higher proportion of the parents had lower educational level than in the nationwide study.

In summary, the data showed that there was substantial variability in the accuracy of the food diary at the individual level. Furthermore, the diary underestimated the average energy intake among 13-year-old students. The ability of the food diary to rank individuals according to energy intake was found to be good in one of the studies and moderate in the other.

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