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## PAPER

# Physical activity levels in children and adolescents

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**BACKGROUND:** Reference data for physical activity level (PAL) and activity-related energy expenditure (AEE) are needed for a better understanding of the effect of activity on childhood health, growth and development

**OBJECTIVE:** Data from 17 studies measuring TDEE (TDEE) with doubly labelled water DLW were combined to construct a reference line for PAL and AEE as a function of age.

**DESIGN:** A total of 17 studies from the literature were analyzed; 17 on girls and 16 on boys. Children were aged 3–16 y and of Caucasian origin. Weighted least-squares regression was used to obtain reference lines for PAL and AEE as a function of age and gender. The relative numbers of children per study were used as a weighting factor. Basal metabolic rate (BMR) or nonfasted (NF) resting metabolic rate and sex were included in the analysis.

**RESULTS:** Although there was no difference in PAL between boys and girls, a significant difference in AEE was found between the two sexes. PAL:  $0.025 \times \text{age} + 1.40$ . AEE (MJ/day): boys  $0.30 \times \text{age} + 0.025$ ; girls  $0.21 \times \text{age} + 0.33$ . If BMR is measured under NF conditions, the obtained value has to be reduced by 0.21 for PAL and 0.75 MJ/day for AEE. No relation was found between AEE/kg and age.

**CONCLUSIONS:** PAL and AEE were found to increase with age, showing the importance of age-dependent recommendations. Recommendations for AEE need to be differentiated for sex. To compare PAL and AEE between studies, the measurement conditions of BMR have to be taken into account. The increase in PAL and AEE values can be attributed to an increase in weight, because there was no relation between AEE/kg and age.

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**Keywords:** PAL; doubly labeled water; activity-related energy expenditure; age-dependent; sex-dependent; activity-related energy expenditure per kilogram

## Introduction

Industrialized countries are seeing an increase in the prevalence of childhood obesity, which is strongly associated with obesity in adulthood.<sup>1,2</sup> This increase in obesity is probably caused by recent changes in lifestyle. Not only have there been quantitative and qualitative dietary changes, but children now spend a large part of their free leisure time watching television or playing computer games.<sup>3</sup> While in adults the health benefits of physical activity have been well established,<sup>4</sup> it is more difficult to determine the beneficial effect of activity on health in children, since it takes many years before any effect can be observed.

As physical activity determines a large proportion of a person's energy requirements, new recommendations for

dietary intake and physical activity might be necessary to prevent obesity. A better understanding of the effect of physical activity on childhood obesity could be obtained from information on the average activity level of the current childhood population.

The amount of physical activity can be expressed as the physical activity level (PAL) or the activity-related energy expenditure (AEE). The basis for PAL was formulated in 1985 by the FAO/WHO/UNU expert committee on energy requirements.<sup>5</sup> This committee expressed the energy needs as multiples of the BMR (basal metabolic rate). The index TDEE (total daily energy expenditure) over BMR (TDEE/BMR) was referred to as the PAL.<sup>6</sup> TDEE and BMR can subsequently be used to calculate the activity-related energy expenditure:  $\text{AEE} = (0.9 \times \text{TDEE}) - \text{BMR}$ , assuming a diet induced thermogenesis (DIT) of 10%.

In 1995, energy requirements were reconsidered by the International Dietary Exchange Consultancy Group (IDECG).<sup>7</sup> Instead of using energy intake data of healthy thriving children, which used to be the basic assumption

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in the previous reference data, this group used energy expenditure data based on the doubly labeled water (DLW) method, heart rate monitoring and activity diaries. The panel also recommended energy requirements based on PAL.

Normal levels for PAL are the subject of ongoing debate in adults and also in children. The recommendations, which use PAL values to calculate total daily energy expenditure, show little differentiation for ages, which makes it impossible to calculate the expected PAL or AEE value at a certain age.

The DLW method is currently regarded as the gold standard for measuring energy expenditure,<sup>8</sup> as it is reasonably easy to use and a valuable method, based on stable isotopes. Since, the isotopes are expensive, most studies have included small numbers of subjects. The present paper analyzes combined data from 17 studies from the literature with the aim of constructing a reference line for PAL and AEE as a function of age. Separate lines were constructed for boys and girls to investigate the effect of sex.

## Methods

All studies from the literature that included TDEE measurement by DLW among children aged 3–16 y were potentially eligible for inclusion in the present review. The studies were found by a computerized search for relevant articles on MEDLINE (Pubmed) using the following terms: double labeled water, DLW and TDEE with the limit: all children:

0–18 y. In addition, the references of the found articles were screened.

The ethnicity of the subjects was predominantly Caucasian. Only in two studies,<sup>9,10</sup> containing 82 and 78% of Caucasian children, the distinction between ethnic groups could not be made.

All studies distinguished between data for boys and girls. Intervention studies were excluded, or only their basal values were used. Studies on obese and undernourished children were excluded. Tables 1 and 2 describe the mean percentage (and range) of fat mass or the body mass index (BMI) (if no data on fat mass were available) of the study populations. Studies with subject groups outside these ranges were not evaluated.

Studies indicating that resting metabolic rate was measured after the consumption of breakfast were marked as nonfasted (NF) in Table 1 (for boys) and Table 2 (for girls). Other studies, including studies with predicted metabolic rate, were marked as fasted (F). The regularly applied protocol, where the thermic effect of food was included, was the consumption of a usual breakfast at home before the children came to the laboratory.<sup>9,11</sup>

Two studies<sup>12,13</sup> calculated BMR values, using Schofield's formula,<sup>14</sup> while the other studies measured BMR values using a ventilated hood system. The measuring period of the DLW method was within the optimal range of 7–14 days.<sup>15</sup>

**Table 1** Energy expenditure parameters per study for boys

Author	n	Age (y)	BMR (MJ/day)	TDEE (MJ/day)	AEE (MJ/day)	PAL	BMR/NF	% fat mass ( $\pm$ s.d.)
Atkin and Davies <sup>12</sup>	39	3.1	3.45	5.12	1.15	1.48	F	23 (6)
Bandini <i>et al</i> <sup>34</sup>	13	14.4	7.26	13.00	4.44	1.79	F	16 (5)
Bandini <i>et al</i> <sup>35</sup>	2	16.2	7.42	12.84	4.14	1.73	F	17 (3)
Black <i>et al</i> <sup>36</sup>	29	4.7	3.80	6.10	1.69	1.61	F	16 (2) <sup>a</sup>
	32	9.8	3.12	9.80	3.12	1.72	F	20 (4) <sup>a</sup>
	31	14.5	8.10	14.10	4.59	1.74	F	25 (9) <sup>a</sup>
Bratteby <i>et al</i> <sup>37</sup>	25	15.0	7.31	13.82	5.13	1.89	F	16 (6)
Ekelund <i>et al</i> <sup>13</sup>	15	9.1	5.21	8.87	2.78	1.70	F	20 (6)
Fontvieille <i>et al</i> <sup>3</sup>	15	5.4	4.34	5.92	0.98	1.36	F	22 (4)
Goran <i>et al</i> <sup>38</sup>	5	4.0	4.48	5.64	0.59	1.26	NF	17 (5)
	8	5.0	4.78	6.26	0.85	1.31	NF	19 (4)
	3	6.0	5.06	6.02	0.35	1.19	NF	20 (2)
Goran <i>et al</i> <sup>11</sup>	25	5.3	4.57	5.78	0.63	1.27	NF	19 (4)
Goran <i>et al</i> <sup>39</sup>	11	5.3	4.91	6.59	1.02	1.34	NF	13 (4)
	11	6.4	5.29	7.54	1.50	1.42	NF	16 (5)
	11	9.3	5.91	8.67	1.89	1.47	NF	22 (7)
Hoffman <i>et al</i> <sup>40</sup>	14	10.2	5.21	9.03	2.92	1.73	F	17 (6)
Johnson <i>et al</i> <sup>41</sup>	17	8.2	5.54	8.04	1.70	1.45	NF	25 (7)
Livingstone <i>et al</i> <sup>42</sup>	6	7.5	4.72	7.98	2.46	1.69	F	18 (4)
	5	9.3	4.75	9.77	4.04	2.05	F	19 (4)
	5	12.3	6.30	10.69	3.32	1.70	F	24 (5)
	3	15.4	6.70	11.00	3.18	1.64	F	14 (5)
Luke <i>et al</i> <sup>43</sup>	5	8.4	5.40	8.83	2.55	1.64	F	25 (12)
Nguyen <i>et al</i> <sup>9</sup>	36	5.2	4.50	6.40	1.26	1.42	NF	14 <sup>b</sup>
Sun <i>et al</i> <sup>44</sup>	21	8.3	5.20	7.12	1.21	1.37	F	24 <sup>b</sup>

BMR, basal metabolic rate; TDEE, total daily energy expenditure; AEE, activity-related energy expenditure; PAL, physical activity level; F, BMR; NF, nonfasting metabolic rate. <sup>a</sup>BMI are given because no data on fat mass were available. <sup>b</sup>No standard deviation (s.d.) was available because % fat mass was calculated from weight and fat mass.

**Table 2** Energy expenditure parameters per study for girls

Author	n	Age (y)	BMR (MJ/day)	TDEE (MJ/day)	AEE (MJ/day)	PAL	BMR/NF	% fat mass ( $\pm$ s.d.)
Atkin and Davies <sup>12</sup>	38	3.1	3.19	4.85	1.17	1.52	F	25 (6)
Bandini <i>et al</i> <sup>34</sup>	10	14.1	5.98	10.12	3.13	1.69	F	25 (7)
Bandini <i>et al</i> <sup>35</sup>	2	14.4	6.51	12.28	4.55	1.89	F	33 (2)
Black <i>et al</i> <sup>36</sup>	21	4.9	3.60	5.50	1.35	1.53	F	15 (1) <sup>a</sup>
	24	9.2	4.80	8.00	2.40	1.67	F	18 (2) <sup>a</sup>
	26	14.8	6.70	11.40	3.56	1.70	F	27 (9) <sup>a</sup>
Bratteby <i>et al</i> <sup>37</sup>	25	15.0	5.97	10.70	3.66	1.79	F	28 (6)
Craig <i>et al</i> <sup>10</sup>	49	10.1	5.35	8.37	2.18	1.56	F	21 (6)
Ekelund <i>et al</i> <sup>13</sup>	11	9.1	5.14	8.25	2.29	1.61	F	27 (6)
Fontvieille <i>et al</i> <sup>3</sup>	13	5.5	4.01	5.63	1.06	1.41	F	23 (5)
Goran <i>et al</i> <sup>38</sup>	4	4.0	4.14	4.39	-0.19	1.06	NF	19 (4)
	4	5.0	4.63	5.69	0.49	1.23	NF	26 (4)
	6	6.0	4.75	6.05	0.69	1.27	NF	26 (7)
Goran <i>et al</i> <sup>11</sup>	26	5.1	4.24	5.24	0.48	1.24	NF	26 (7)
Goran <i>et al</i> <sup>39</sup>	11	5.5	4.57	5.71	0.57	1.25	NF	19 (5)
	11	6.6	4.79	7.59	2.05	1.59	NF	20 (6)
	11	9.5	5.44	6.72	0.61	1.24	NF	27 (6)
Hoffman <i>et al</i> <sup>40</sup>	15	10.0	4.66	8.08	2.61	1.73	F	24 (6)
Johnson <i>et al</i> <sup>41</sup>	14	8.5	5.19	6.50	0.65	1.25	NF	26 (7)
Livingstone <i>et al</i> <sup>42</sup>	5	7.4	4.36	7.14	2.07	1.64	F	21 (2)
	4	9.2	4.43	8.14	2.89	1.84	F	27 (3)
	5	12.4	5.85	9.89	3.05	1.69	F	28 (3)
	3	15.6	5.14	9.57	3.48	1.86	F	27 (9)
Luke <i>et al</i> <sup>43</sup>	4	6.8	4.47	6.74	1.59	1.51	F	35 (9)
Nguyen <i>et al</i> <sup>9</sup>	35	5.5	4.30	5.90	1.01	1.37	NF	18 <sup>b</sup>
Sun <i>et al</i> <sup>44</sup>	18	8.4	5.35	8.14	1.97	1.52	F	39 <sup>b</sup>

BMR, basal metabolic rate; TDEE, total daily energy expenditure; AEE, activity related energy expenditure; PAL, physical activity level; F BMR; NF Non fasting metabolic rate. <sup>a</sup>BMI are given because no data on fat mass were available. <sup>b</sup>No standard deviation (sd) was available because % fat mass was calculated from weight and fat mass.

PAL was calculated as TDEE/BMR, while AEE was calculated as  $(0.9 \times \text{TDEE}) - \text{BMR}$ , assuming a DIT of 10%.

## Statistics

To compensate for the differences in the number of children per study, a weighted least-squares linear regression was performed between age and PAL, age and AEE, and between age and AEE/kg for both sexes, using the relative number of children per study as the weighting factor. To test the difference between boys and girls, an interaction term (age  $\times$  sex) was included in the analysis. Since some studies measured NF metabolic rate instead of BMR, a parameter named feeding (BMR=0, NF metabolic rate=1) was included in the analysis.

## Results

The energy expenditure parameters used in each study are listed in Table 1 for boys and in Table 2 for girls. In all, 16 studies were included for boys and 17 for girls.

The weighted least-squares linear regression yielded the following regression equation for PAL:

$\text{PAL} = 0.025 \times \text{age} + 1.40$  ( $r = 0.85$ ,  $P < 0.001$ , standard error = 0.10).

If the NF metabolic rate is measured, the obtained value should be reduced by 0.21, because feeding was a significant ( $P < 0.0001$ ) variable in the regression model. The inclusion of age and age  $\times$  sex in the analysis was not significant (F change = 1.62,  $P = 0.21$ ).

For AEE, there was a significant difference between boys and girls (F change 12.5,  $P < 0.0001$ ). Therefore equations are given for boys and girls separately:

boys:  $\text{AEE} = 0.30 \times \text{age} + 0.025$ , girls:  $\text{AEE} = 0.21 \times \text{age} + 0.33$  ( $r = 0.94$ ,  $P < 0.001$ , standard error = 0.44).

Also in this model, feeding was a significant contributor. So if the NF metabolic rate is measured, AEE has to be reduced with 0.75 (MJ/day). AEE/kg was not significantly related to age for boys or for girls.

## Discussion

For all kinds of research questions, energy expenditure of children is measured. Several studies use the DLW method, which is regarded as the 'gold standard'. The results of these studies are used in the present paper to estimate the relation between physical activity and age represented by the construction of a reference line.

Reference data for PAL and AEE are needed for a better understanding of the activity level of children, which is

especially relevant in childhood obesity. Several studies have demonstrated a negative relation between body fat and physical activity<sup>16–19</sup> or activity time.<sup>20</sup> Some studies showed a sex difference in the relation of physical activity and body fat.<sup>21–23</sup> All these studies show the importance of physical activity in the treatment of obesity, which can be evaluated if normal values of a healthy population are available.

Although children may appear to be more active than adults, the present review actually found low values in young children increasing to adult values with age. This might be explained from the observation made by Noland et al,<sup>24</sup> who showed that the energy cost of playing is less than that of a slow walk. Besides, children's activities are not only low in intensity but also not sustained over extended periods of time.<sup>25</sup> Although children need more energy per kilogram body weight to perform a particular activity than adults,<sup>26</sup> their lower body weight leads to a smaller overall energy expenditure compared to older subjects.

In addition to the effect of body weight, there is a pronounced difference between children and adults in the time they are active. Adults were shown to have a mean sleeping time of 8 h.<sup>27,28</sup> In a recent study we found a mean sleeping time of 11 h in children with a mean age of 8.6 y (personal observation). As children grow older, they sleep less and spend more time on physical activities, resulting in higher PAL and AEE values.

The present review found no difference in PAL values between boys and girls, but did show a difference between the sexes in AEE. Boys had higher AEE values than girls, which might be explained by the difference in body composition between the two. Body composition does not influence PAL, because this parameter adjusts energy expenditure for BMR, which depends heavily on body composition.

PAL and AEE describe the amount of energy spent on activity. However, energy costs of physical activity do not need to be identical to body movement.<sup>29</sup> Schoeller and Jefford<sup>30</sup> suggested normalizing the energy expenditure of physical activity by division by body weight. No relation was found between AEE/kg and age, which means that the increase in PAL and AEE can be contributed to the increase in weight.

Longitudinal studies describing the participation into different activity levels,<sup>31–33</sup> measured by interviews and questionnaires, reported a decline in physical activity with age especially after the age of 12–15 y. The time spent on activities decreases, but because there is an increase in weight the total amount of energy spent on physical activity might increase.

PAL was defined by the WHO in 1985 as TDEE/BMR. However, sometimes NF metabolic rate, which includes the thermic effect of food, was measured. In the present analysis we corrected for this, and showed that for the comparison of PAL and AEE data, one has to keep the measurement conditions of BMR in mind.

Because of the high cost of the DLW method, the studies tended to include relatively small numbers of children. Our

analysis would have yielded more precise results if ages and energy expenditure data had been available for individual subjects. The ratio of the means may differ from the mean of the individual ratios. As it was, we had to use aggregated data, which could have attenuated the relation. Moreover, we cannot exclude the possibility that another factor, related to age and influencing TDEE, could be (at least partly) responsible for the observed relations.

In conclusion, PAL and AEE values increased with age. The increase can be attributed to an increase in body weight.

## References

- 1 Mossberg HO. Forty year follow-up of overweight children. *Lancet* 1989; 2: 491–494.
- 2 Gortmaker SL, Dietz WH, Sobol AM, Wehler CA. Increasing paediatric obesity in the United States. *Am J Dis Child* 1987; 141: 491–494.
- 3 Fontvieille AM, Herper IT, Spraul M, Ravussin E. Daily energy expenditure by five-year-old children, measured by doubly labeled water. *J Pediatr* 1993; 123: 200–207.
- 4 US Department Of Health And Human Services. *Physical activity and health: a report of the surgeon general*. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion: Atlanta, GA: US; 1996.
- 5 World Health Organization. *Energy and protein requirements, report of a joint FAO/WHO/UNU expert consultation*. WHO: Geneva; 1985.
- 6 James WPT, Ferro-Luzzi A, Waterlow JC. Definition of chronic energy deficiency in adults. Report of a working party of the International Dietary Energy Consultancy Group. *Eur J Clin Nutr* 1988; 42: 969–981.
- 7 Torun B, Davies PSW, Livingstone MBE, Paolissis M, Spurr GB. Energy requirements and dietary recommendations for children and adolescents 1 to 18 years old. *Eur J Clin Nutr* 1996; 50: S37–S81.
- 8 Westerterp KR, Bouten CVC. Physical activity assessment: comparison between movement registration and double labeled water method. *Z Ernahrungswiss* 1997; 36: 263–267.
- 9 Nguyen VT, Larson DE, Johnson RK, Goran MI. Fat intake and obesity in children of lean and obese parents. *Am J Clin Nutr* 1996; 63: 507–513.
- 10 Craig SB, Bandini LG, Lichtenstein AH, Schaefer EJ, Dietz WH. The impact of physical activity on lipids, lipoproteins, and blood pressure in preadolescent girls. *Pediatrics* 1996; 98: 389–395.
- 11 Goran MI, Kaskoun M, Johnson R, Martinez C, Kelly B, Hood V. Energy expenditure and body fat distribution in Mohawk children. *Pediatrics* 1995; 95: 89–95.
- 12 Atkin L-M, Davies PSW. Diet composition and body composition in preschool children. *Am J Clin Nutr* 2000; 72: 15–21.
- 13 Ekelund U, Sjostrom M, Yngve A, Poortvliet E, Nilsson A, Froberg K, Wedderkopp N, Westerterp K. Physical activity assessed by activity monitor and doubly labeled water in children. *Med Sci Sports Exerc* 2001; 33: 275–281.
- 14 Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* 1985; 39: 5–41.
- 15 Westerterp KR, Wouters L, Van Marken-Lichtenbelt W. The Maastricht protocol for the measurement of body composition and energy expenditure with labeled water. *Obes Res* 1995; 3: 49–57.
- 16 Bar-Or O. Physical activity and physical training in childhood obesity. *J Sports Med Phys Fit* 1993; 33: 323–329.
- 17 Obarzanek E, Schreiber GB, Crawford PB, Goldman SR, Barrier PM, Frederick MM, Lakatos E. Energy intake and physical activity in relation to indexes of body fat: the National Heart, Lung and

- Blood Institute Growth and Health Study. *Am J Clin Nutr* 1994; **60**: 15–22.
- 18 Wilkinson PW, Parkin JM, Pearlson G, Strong H, Sykes P. Energy intake and physical activity in obese children. *BMJ* 1977; **6063**: 756.
  - 19 Dietz WH, Gortmaker SL. Do we fatten our children at the television set? Obesity and television viewing in children and adolescents. *Pediatrics* 1985; **75**: 807–812.
  - 20 Goran MI, Hunter G, Johnson R. Physical activity related energy expenditure and fat mass in young children. *Int J Obes Rel Metab Disord* 1997; **21**: 171–178.
  - 21 Ball EJ, O'Connor J, Abbott R, Steinbeck KS, Davies PSW, Wishart C, Gaskinand KJ, Baur LA. Total energy expenditure, body fatness, and physical activity in children aged 6–9 years. *Am J Clin Nutr* 2001; **74**: 524–528.
  - 22 Ku LC, Shapiro LR, Crawford PB, Huenemann RL. Body composition and physical activity in 8-year-old children. *Am J Clin Nutr* 1981; **34**: 2770–2775.
  - 23 Schoeller DA. Measurement of energy expenditure in free-living humans using double labeled water. *J Nutr* 1988; **118**: 1278–1289.
  - 24 Noland M, Danner F, Dewalt K, McFadden M, Kotchen JM. The measurement of physical activity in young children. *Res Q Exerc Sport* 1990; **61**: 146–153.
  - 25 Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc* 1995; **27**: 1033–1041.
  - 26 Waters RLL, Perry BR, Byrd JR. Energy–speed relationship of walking: standard tables. *Orthop Res Soc* 1988; **6**: 215–222.
  - 27 Bouten CV, Verboeket-van de Venne WP, Westerterp KR, Verduin M, Janssen JD. Daily physical activity assessment: comparison between movement registration and doubly labeled water. *J Appl Physiol* 1996; **81**: 1019–1026.
  - 28 Meijer EP, Goris AHC, Wouters L, Westerterp KR. Physical activity as a determinant of the physical activity level in the elderly. *Int J Obes Relat Metab Disord* 2001; **25**: 935–939.
  - 29 Ekelund U, Aman J, Yngve A, Renman C, Westerterp K, Sjostrom M. Physical activity but not energy expenditure is reduced in obese adolescents: a case–control study. *Am J Clin Nutr* 2002; **76**: 935–941.
  - 30 Schoeller DA, Jefford G. Determinants of the energy costs of light activities: inferences for interpreting doubly labeled water data. *Int J Obes Relat Metab Disord* 2002; **26**: 97–101.
  - 31 Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc* 2000; **32**: 1601–1609.
  - 32 van Mechelen W, Twisk JW, Post GB, Snel J, Kemper HC. Physical activity of young people: the Amsterdam Longitudinal Growth and Health Study. *Med Sci Sports Exerc* 2000; **32**: 1610–1616.
  - 33 Telama R, Yang X. Decline of physical activity from youth to young adulthood in Finland. *Med Sci Sports Exerc* 2000; **32**: 1617–1622.
  - 34 Bandini LG, Schoeller DA, Dietz WH. Energy expenditure in obese and nonobese adolescents. *Paediatr Res* 1990; **27**: 198–203.
  - 35 Bandini LG, Schoeller DA, Edwards J, Young VR, Oh SH, Dietz WH. Energy expenditure during carbohydrate overfeeding in obese and nonobese adolescents. *Am J Physiol* 1989; **256**: E357–E367.
  - 36 Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. *Eur J Clin Nutr* 1996; **50**: 72–92.
  - 37 Bratteby L-E, Sandhagen B, Fan H, Enghardt H, Samuelson G. Total energy expenditure and physical activity as assessed by the doubly labeled water method in Swedish adolescents in whom energy intake was underestimated by 7-d diet records. *Am J Clin Nutr* 1998; **67**: 905–911.
  - 38 Goran MI, Carpenter WH, Poehlman ET. Total energy expenditure in 4- to 6-yr-old children. *Am J Physiol* 1993; **264**: E706–E711.
  - 39 Goran MI, Gower BA, Nagy TR, Johnson RK. Developmental changes in energy expenditure and physical activity in children: evidence for a decline in physical activity in girls before puberty. *Pediatrics* 1998; **101**: 887–891.
  - 40 Hoffman DJ, Sawaya AL, Coward WA, Wright A, Martins PA, Nascimento C, Tucker KL, Roberts SB. Energy expenditure of stunted and nonstunted boys and girls living in the shantytowns of Sao Paulo, Brazil. *Am J Clin Nutr* 2000; **72**: 1025–1031.
  - 41 Johnson RK, Russ J, Goran MI. Physical activity related energy expenditure in children by doubly labeled water as compared with the Caltrac accelerometer. *Int J Obes Relat Metab Disord* 1998; **22**: 1046–1052.
  - 42 Livingstone MB, Coward WA, Prentice AM et al. Daily energy expenditure in free-living children: comparison of heart-rate monitoring with the doubly labeled water (2H2(18)O) method. *Am J Clin Nutr* 1992; **56**: 343–352.
  - 43 Luke A, Roizen NJ, Sutton M, Schoeller DA. Energy expenditure in children with Down syndrome: correcting metabolic rate for movement. *J Pediatr* 1994; **125**: 829–838.
  - 44 Sun MI, Gower BA, Nagy TR, Trowbridge CA, Dezenberg C, Goran MI. Total, resting and activity-related energy expenditures are similar in Caucasian and African-American children. *Am J Physiol* 1998; **274**: E232–E237.