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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: $0.025 \times$ age+1.40. AEE (MJ/day): boys $0.30 \times$ age+0.025; girls $0.21 \times$ 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.[1,2] 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.[3] While in adults the health benefits of physical activity have been well established,[4] 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.[5] 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.[6] 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).[7] 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,[8] 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,[9,10] 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.[9,11]

Two studies[12,13] calculated BMR values, using Schofield's formula,[14] 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.[15]

Table 1 Energy expenditure parameters per study for boys

Author	n	Age (y)	BMR (MJ/day)	TDEE (MJ/day)	AEE (MJ/day)	PAL	BMRF/NF	% fat mass (±s.d.)
Atkin and Davies[12]	39	3.1	3.45	5.12	1.15	1.48	F	23 (6)
Bandini et al[34]	13	14.4	7.26	13.00	4.44	1.79	F	16 (5)
Bandini et al[35]	2	16.2	7.42	12.84	4.14	1.73	F	17 (3)
Black et al[36]	29	4.7	3.80	6.10	1.69	1.61	F	16 (2)[a]
	32	9.8	3.12	9.80	3.12	1.72	F	20 (4)[a]
	31	14.5	8.10	14.10	4.59	1.74	F	25 (9)[a]
Bratteby et al[37]	25	15.0	7.31	13.82	5.13	1.89	F	16 (6)
Ekelund et al[13]	15	9.1	5.21	8.87	2.78	1.70	F	20 (6)
Fontvieille et al[3]	15	5.4	4.34	5.92	0.98	1.36	F	22 (4)
Goran et al[38]	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 et al[11]	25	5.3	4.57	5.78	0.63	1.27	NF	19 (4)
Goran et al[39]	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 et al[40]	14	10.2	5.21	9.03	2.92	1.73	F	17 (6)
Johnson et al[41]	17	8.2	5.54	8.04	1.70	1.45	NF	25 (7)
Livingstone et al[42]	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 et al[43]	5	8.4	5.40	8.83	2.55	1.64	F	25 (12)
Nguyen et al[9]	36	5.2	4.50	6.40	1.26	1.42	NF	14[b]
Sun et al[44]	21	8.3	5.20	7.12	1.21	1.37	F	24[b]

BMR, basal metabolic rate; TDEE, total daily energy expenditure; AEE, activity-related energy expenditure; PAL, physical activity level; F, BMR; NF, nonfasting metabolic rate. [a]BMI are given because no data on fat mass were available. [b]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	BMRF/NF	% fat mass (±s.d.)
Atkin and Davies[12]	38	3.1	3.19	4.85	1.17	1.52	F	25 (6)
Bandini *et al*[34]	10	14.1	5.98	10.12	3.13	1.69	F	25 (7)
Bandini *et al*[35]	2	14.4	6.51	12.28	4.55	1.89	F	33 (2)
Black *et al*[36]	21	4.9	3.60	5.50	1.35	1.53	F	15 (1)[a]
	24	9.2	4.80	8.00	2.40	1.67	F	18 (2)[a]
	26	14.8	6.70	11.40	3.56	1.70	F	27 (9)[a]
Bratteby *et al*[37]	25	15.0	5.97	10.70	3.66	1.79	F	28 (6)
Craig *et al*[10]	49	10.1	5.35	8.37	2.18	1.56	F	21 (6)
Ekelund *et al*[13]	11	9.1	5.14	8.25	2.29	1.61	F	27 (6)
Fontvieille *et al*[3]	13	5.5	4.01	5.63	1.06	1.41	F	23 (5)
Goran *et al*[38]	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 *et al*[11]	26	5.1	4.24	5.24	0.48	1.24	NF	26 (7)
Goran *et al*[39]	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 *et al*[40]	15	10.0	4.66	8.08	2.61	1.73	F	24 (6)
Johnson *et al*[41]	14	8.5	5.19	6.50	0.65	1.25	NF	26 (7)
Livingstone *et al*[42]	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 *et al*[43]	4	6.8	4.47	6.74	1.59	1.51	F	35 (9)
Nguyen *et al*[9]	35	5.5	4.30	5.90	1.01	1.37	NF	18[b]
Sun *et al*[44]	18	8.4	5.35	8.14	1.97	1.52	F	39[b]

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. [a]BMI are given because no data on fat mass were available. [b]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 × 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 × 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[16–19] or activity time.[20] Some studies showed a sex difference in the relation of physical activity and body fat.[21–23] 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,[24] 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.[25] Although children need more energy per kilogram body weight to perform a particular activity than adults,[26] 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.[27,28] 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.[29] Schoeller and Jefford[30] 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,[31–33] 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.

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